EMPIRICAL DISTRIBUTIONS OF RADIONUCLIDES, FROM RWMIS DATA

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ABSTRACT

The RWMIS data base gives data on each shipment of waste received at the Transuranic Storage Area, including the total volume of the shipment and the activity (Ci) of each nuclide in the shipment. This report assumes that the RWMIS numbers are correct, and considers the waste containers now retrievably stored at the Transuranic Storage Area. The total decay-corrected activities are summarized for several classes, such as for transuranic (TRU) waste and non-TRU waste, for α -emitters and β/γ -emitters, by waste originator and by current storage location. The total activity for each nuclide is also given.

The empirical distributions are then given for a number of classes and individual nuclides, reflecting the variability between waste shipments. They are expressed in terms of mCi/cu-ft; for fissionable nuclides, the same information is also expressed in terms of mg/cu-ft; finally, the distribution is also given for the committed effective dose equivalent from inhalation, expressed in Mrem/cu-ft. The empirical distributions can be used for simulating the contents of a random waste container with a postulated volume. Examples are given illustrating the uses and limitations of the results.

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EMPIRICAL DISTRIBUTIONS OF RADIONUCLIDE ACTIVITIES, FROM RWMIS DATA

DESCRIPTION OF THE DATA SETS

RWMIS contains three subsets: the BAD, the Historical, and the Current. The "BAD" Data (an acronym for Best Available Data) contains data for shipments before 1971. All the waste containers in this data base are now buried, and therefore are not considered in this report. The "Historical Data" corresponds to shipments from Oct. 22, 1970 through Dec. 1, 1983; some of these containers are now retrievably stored. The "Current Data" corresponds to shipments from Dec. 1, 1983 on, all of which are retrievably stored.

For the present task, Deborah Litteer, custodian of RWMIS, downloaded the Current Data, and that portion of the Historical Data corresponding to above-ground containers, from the NOMAD system used by RWMIS to dBASE files. The effective date of the download was Dec. 23, 1992. The number of records agreed in the original and downloaded files, and the total activities of selected nuclides also agreed to several significant digits. This downloading apparently produced some (negligible) inaccuracy: typically, activities are entered in RWMIS to only 3 or 4 significant digits, but the dBASE files normally appeared to have many significant digits. Considering the fact that the original activities are only rough estimates, the inaccuracy introduced by the download is negligible.

The accuracy of the RWMIS data is not addressed here. This analysis is not an endorsement of the RWMIS data's accuracy. Based on past experience with RWMIS, we knew that when the container type code is BLX, the reported container volume should be divided by 10; we would have done this if that code had occurred. We also have identified one case for which it appears that two shipments were given one identifier; because we could not tell which containers

went with which shipment, we wrote our software to combine the shipments in any such case, adding the activities of each nuclide and summing the container volumes. We are not aware of other anomalies in the RWMIS data. As a guiding principle, however, one must realize that there are approximately 20,000 shipments, and that the originally entered nuclide activities for these shipments were probably not all obtained from direct measurements of the shipments.

ANALYSIS METHOD

Software was written in the dBASE language to decay the radionuclides to 2/17/93, and to provide a summary of the activities of the individual nuclides. This summary is shown in Table 1. Only four significant digits are shown for each activity. Because of the generation of daughters, some nuclides appear in the present inventory which were not reported in the original inventories. This is one more sign that the original inventories should not be taken as more than an approximation. Another consequence of the generation of daughters is that some activities have increased over time; for example, Am-241, a daughter of Pu-241, has increased from what was originally reported. No daughter nuclide was generated if its activity would be less than 2 Ci. Therefore, some of the small listed activities are incorrect, because they do not include the activity (< 2 Ci) of newly generated atoms. Details of the decay calculations are given in Appendix A.

The data base was scanned and tallied, to show the shipments' number and total volume, for the various nuclides, present storage locations, and waste generators. This tally is shown in Table 2. For example, from Table 2 there was one shipment containing any Ac-227. This shipment had total volume of 7.35 cu-ft (which equals 55 gal), and the total decayed activity of the Ac-227 is 0.04079 Ci. By contrast, there were 18863 shipments containing Am-241. The numbers of shipments for the individual nuclides add up to more than the total number of shipments, because most shipments contain more than one nuclide, and similarly the shipment volumes for the nuclides add up to more than the total volume. The activities for the individual nuclides, on the other hand, add up to the total activity. Because every shipment came from one waste generator and

Table 1. Retrievably stored TSA nuclides in RWMIS.^a

Nuclide	Half-life (d)	Original Activity (Ci)	2/17/93 Activity (Ci)	TRU?	α ?	Fis?	Daughter
Ac-227	7.947E+03	0.07290	0.04079	n	β/γ	n	negl
Am-241	1.580E+05	87910.	89780.	T	α	F	negl
Am-242m	5.146E+04	0.0003074	0.0003001	T	α	n	stable
Am-243	2.690E+06	0.3802	0.3799	T	α	n	negl
Ba-137m	1.771E-03	97.33	2246.	n	β/γ	n	stable
Bi-212	4.205E-02	0.	26.55	n	β/γ	n	Tl-208, Po-212
Bi-214	1.375E-02	0.04800	0.00000000000	n	β/γ	n	negl
Bk-249	3.200E+02	0.2140	0.0005709	n	β/γ	n	negl
C-14	2.091E+06	0.00004230	0.00004225	n	β/γ	n	stable
Ce-144	2.850E+02	3899.	27.06	n	β/γ	n	Pr-144
Cf-249	1.281E+05	0.009890	0.009729	T	α	n	negl
Cf-252	9.636E+02	0.06486	0.004077	n	α	n	negl
Cm-242	1.630E+02	3.321	0.000001436	n	α	n	negl
Cm-243	1.040E+04	0.01721	0.01531	T	α	n	negl
Cm-244	6.606E+03	1132.	539.0	n	α	F	negl
Cm-246	1.744E+06	0.001533	0.001530	T	α	n	negl
Cm-248	1.241E+08	0.00000004170	0.00000004170	T	α	n	negl
Co-58	7.090E+01	113.3	0.0000001101	n	β/γ	n	stable
Co-60	1.930E+03	232.6	94.30	n	β/γ	n	stable
Cr-51	2.770E+01	8.460	0.00000000000	n	β/γ	n	stable
Cs-134	7.540E+02	929.6	110.7	n	β/γ	n	stable
Cs-137	1.100E+04	2366.	2003.	n	β/γ	n	Ba-137m
Eu-150	5.250E-01	0.00004500	0.00000000000	n	β/γ	n	negl
Eu-152	4.928E+03	0.1712	0.06756	n	β/γ	n	negl
Eu-154	3.135E+03	1.555	0.7104	n	β/γ	n	stable
Eu-155	1.719E+03	0.7775	0.1863	n	β/γ	n	stable
Fe-55	9.970E+02	3.859	1.132	n	β/γ	n	stable
Fe-59	4.450E+01	5.340	0.00000000000	n	β/γ	n	stable
H-3	4.490E+03	1.950	0.7978	n	β/γ	n	stable
Kr-85	3.906E+03	9.362	6.857	n	β/γ	n	stable
MAP ^b	note b	5.755	1.280	n	β/γ	n	note b
MFP ^c	note c	629.8	483.3	n	β/γ	n	note c
Mn-54	3.120E+02	115.5	0.2287	n	β/γ	n	stable
Nb-95	3.500E+01	0.7200	0.00000000000	n	β/γ	n	stable
Ni-63	3.650E+04	3.694	3.572	n	β/γ	n	stable
Np-237	7.811E+08	0.3552	0.3552	T	α	F	negl
Pa-233	2.700E+01	0.001973	0.00000000000	n	β/γ	n	negl
Pb-210	8.140E+03	0.02100	0.01756	n	β/γ	n	negl
Pb-212	4.433E-01	0.	26.55	n	β/γ	n	Bi-212
Pb-214	1.861E-02	0.04800	0.00000000000	n	β/γ	n	negl
Pm-147	9.563E+02	548.1	27.26	n	β/γ	n	negl
Po-212	4.6065E-1	0.	17.01	n	α	n	negl
Po-214	1.895E-09	0.04800	0.00000000000	n	α	n	negl
Po-216	1.736E-06	0.	26.55	n	α	n	Pb-212
Po-218	2.160E-03	0.04800	0.00000000000	n	α	n	negl
Pr-144	1.200E+00	15.64	27.18	n	β/γ	n	stable

Table 1. (Cont.)

Pu-236	1.040E+03	0.05764	0.01479	n	α	n	negl
Pu-238	3.201E+04	67590.	60800.	T	α	F	U-234
Pu-239	8.796E+06	40160.	40150.	T	α	F	negl
Pu-240	2.394E+06	9837.	9825.	T	α	n	negl
Pu-241	5.256E+03	281600.	161100.	n	β/γ	F	Am-241
Pu-242	1.369E+08	0.9451	0.9451	T	α	n	negl
Ra-224	3.660E+00	0.	26.55	n	α	n	Rn-220
Ra-226	5.840E+05	0.04802	0.04790	n	α	n	negl
Ra-228	2.102E+03	0.2750	0.03062	n	β/γ	n	negl
Rh-106	3.461E-04	1.300	0.00000000000	n	β/γ	n	stable
Rn-220	6.435E-04	0.	26.55	n	α	n	Po-216
Rn-222	3.820E+00	0.04800	0.00000000000	n	α	n	negl
Ru-106	3.723E+02	106.2	0.1865	n	β/γ	n	negl
Sb-125	1.007E+03	6.087	1.647	n	β/γ	n	negl
Sr-90	1.062E+04	2116.	1778.	n	β/γ	n	Y-90
Ta-182	1.140E+02	0.7350	0.00001548	n	β/γ	n	stable
Tc-99	7.774E+07	0.001760	0.001760	n	β/γ	n	stable
Th-228	6.982E+02	0.	26.55	n	α	n	Ra-224
Th-230	2.752E+07	0.01998	0.01998	n	α	n	negl
Th-232	5.110E+12	0.3301	0.3301	n	α	n	negl
Th-234	2.410E+01	0.00009280	0.00000000000	n	β/γ	n	negl
Tl-208	2.120E-03	0.	9.540	n	β/γ	n	negl
U-228	6.319E-03	0.0001070	0.00000000000	n	α	n	negl
U-232	2.555E+04	30.02	26.04	n	α	n	Th-228
U-233	5.840E+07	898.6	898.5	n	α	F	negl
U-234	8.979E+07	3.359	5.778	n	α	n	negl
U-235	2.570E+11	0.06669	0.06669	n	α	F	negl
U-236	8.541E+09	0.001199	0.001199	n	α	n	negl
U-238	1.632E+12	0.1171	0.1171	n	α	n	negl
Unid β/γ^d note d		14.89	12.44	n	β/γ	n	note d
Y-90	2.670E+00	101.8	2019.	n	β/γ	n	stable
Zn-65	2.440E+02	0.001100	0.00000001868	n	β/γ	n	stable
Zr-95	6.400E+01	67.23	0.00000000234	n	β/γ	n	negl

a. The activities are rounded off to four significant digits, the maximum accuracy of any shipment's reported activity. They are printed in decimal rather than scientific notation to make the large activities more obvious to the eye. TRU nuclides are shown by a T, non-TRU nuclides by n. α -emitters and β/γ -emitters are shown by α and β/γ , respectively. Fissionable nuclides are shown by F, non-fissionable nuclides by n. The daughters are shown as "negl" if less than 2 Ci of the daughter would be generated. The daughters are shown as "stable" if they are not radioactive.

b. "Mixed Activation Products," treated as Co-60.

c. "Mixed Fission Products," treated as a mixture of half Cs-137 and half Sr-90.

d. "Unidentified β/γ -emitters," treated as Cs-137.

Table 2. Tally of shipments, volume, and decayed activity.^a

	<u>Shipments</u>	<u>Volume (cu-ft)</u>	<u>2/17/93 Activity (Ci)</u>
Total	19521	2287042.84	372200.
TRU	19086	2268701.20	200600.
Non-TRU	19107	2281803.53	171600.
α -emitters	19168	2283910.69	202200.
β/γ -emitters	18814	2244506.53	170000.
Fissionable	19166	2283901.34	353300.
<u>By Nuclide</u>			
<u>Nuclide</u>			
Ac-227	1	7.35	0.04079
Am-241	18488	2193758.64	89780.
Am-242m	2	10.00	0.0003001
Am-243	22	6196.17	0.3799
Ba-137m	459	51287.99	2246.
Bi-212	54	13940.21	26.55
Bi-214	0	0.00	0.00000000000
Bk-249	4	2280.00	0.0005709
C-14	2	1440.00	0.00004225
Ce-144	45	399.41	27.06
Cf-249	4	1567.35	0.009729
Cf-252	9	4102.06	0.004077
Cm-242	2	960.00	0.000001436
Cm-243	2	10.00	0.01531
Cm-244	15	4872.23	539.0
Cm-246	3	1474.67	0.001530
Cm-248	1	720.00	0.00000004170
Co-58	7	35.00	0.0000001101
Co-60	19	848.41	94.30
Cr-51	0	0.00	0.00000000000
Cs-134	34	327.00	110.7
Cs-137	167	6134.85	2003.
Eu-150	0	0.00	0.00000000000
Eu-152	9	4574.35	0.06756
Eu-154	15	4038.00	0.7104
Eu-155	10	205.00	0.1863
Fe-55	4	1450.00	1.132
Fe-59	0	0.00	0.00000000000
H-3	5	5362.67	0.7978
Kr-85	2	10.00	6.857
MAP ^b		36 265.00	1.280
MFP ^c		304 46712.14	483.3
Mn-54	26	153.00	0.2287
Nb-95	0	0.00	0.00000000000
Ni-63	3	730.00	3.572
Np-237	38	13026.83	0.3552
Pa-233	0	0.00	0.00000000000

Table 2. (Cont.)

Pb-210	1	7.35	0.01756
Pb-212	54	13940.21	26.55
Pb-214	0	0.00	0.00000000000
Pm-147	3	17.35	27.26
Po-212	54	13940.21	17.01
Po-214	0	0.00	0.00000000000
Po-216	54	13940.21	26.55
Po-218	0	0.00	0.00000000000
Pr-144	45	399.41	27.18
Pu-236	299	7540.70	0.01479
Pu-238	18400	2217049.04	60800.
Pu-239	19059	2268443.85	40150.
Pu-240	18881	2213546.71	9825.
Pu-241	18386	2180718.05	161100.
Pu-242	18329	2181792.61	0.9451
Ra-224	54	13940.21	26.55
Ra-226	2	14.35	0.04790
Ra-228	1	7.35	0.03062
Rh-106	0	0.00	0.00000000000
Rn-220	54	13940.21	26.55
Rn-222	0	0.00	0.00000000000
Ru-106	13	250.00	0.1865
Sb-125	11	208.00	1.647
Sr-90	32	315.00	1778.
Ta-182	1	5.00	0.00001548
Tc-99	3	847.35	0.001760
Th-228	54	13940.21	26.55
Th-230	1	720.00	0.01998
Th-232	105	25332.08	0.3301
Th-234	0	0.00	0.00000000000
Tl-208	54	13940.21	9.540
U-228	0	0.00	0.00000000000
U-232	54	13940.21	26.04
U-233	152	56010.22	898.5
U-234	18410	2225539.37	5.778
U-235	1107	311137.15	0.06669
U-236	31	10070.01	0.001199
U-238	331	32485.69	0.1171
Unid β/γ^d	6	45.41	12.44
Y-90	334	47015.14	2019.
ZN-65	2	1440.00	0.00000001868
ZR-95	8	57.41	0.00000000234

By Location			
Location ^e			
TSA			
Total	19179	2284317.04	363700.
TRU	18744	2265975.40	200500.
Non-TRU	18771	2279125.73	163200.

Table 2. (Cont.)

ILTSF			
Total	342	2725.80	8489.
TRU	342	2725.80	100.3
Non-TRU	336	2677.80	8388.

By Waste Generator			
Generator			
ALE	407	54076.28	6002.
ANL	227	1531.35	6812.
ARA	4	356.41	11.94
BCL	13	7572.88	120.6
BEN	1	7.35	18.48
BET	78	15301.31	1586.
CFA	2	7.67	0.04360
CPP	29	1720.60	1330.
D+D	1	7.35	2.488
LOF	1	7.35	1.189
MRC	446	137598.34	61000.
NRF	37	246.16	428.5
RFO	17960	1913380.83	280500.
TAN	5	31.41	16.00
TRA	42	357.60	836.7
WMC	268	154839.93	13480.

- The activities are rounded off to four significant digits, as in Table 1.
- "Mixed Activation Products," as in Table 1.
- "Mixed Fission Products," as in Table 1.
- "Unidentified β/γ -emitters," as in Table 1.
- The locations given as text in the data base are the Transuranic Storage Area (TSA), and the Intermediate Level Transuranic Storage Facility (ILTSF). ILTSF is the designated location for all remote-handled waste. In this table, the designation TSA therefore means all of the Transuranic Storage Area except ILTSF. Locations outside of the Transuranic Storage Area, such as Pad A and the Burial Ground Pit Air Support Building, are not considered here.

is stored at one location, the numbers of shipments for the locations add up to the total number, and their volumes and activities add up to the total volume and activity, and the same is true for the breakdown by waste generator.

Table 3 shows a tally of the various containers in the data base. There are diverse potential uses for this information, so the raw counts are simply presented, and not reduced to summaries.

Table 3. Tally of containers of different types and volumes.

Arranged by Volume, then by Type					
Type ^a	Volume ^b	Number	Type ^a	Volume ^b	Number
BLM	1.0 F	1	O	112.0 F	1
BXC	1.0 F	1	BIN	115.0 F	18
O	1.0 F	29	BIN	120.0 F	528
BXC	2.0 F	1	BXM	120.0 F	25
BXW	2.0 F	2	BXW	120.0 F	7
BLM	3.0 F	1	BXW	121.0 F	137
BXW	3.0 F	1	BXW	128.0 F	9
I	5.0 F	30	BXW	130.0 F	7
BLM	7.0 F	189	BXW	144.0 F	5
RD5	7.0 F	4	BXW	145.0 F	2
RDL	7.0 F	16	BXW	155.0 F	2
BLM	8.0 F	1750	BXW	169.0 F	6
BXW	8.0 F	1	BXW	176.0 F	6
RDL	8.0 F	10	BXW	188.0 F	3
BLM	9.0 F	3	BXW	212.0 F	3
BXW	18.0 F	1	BXW	228.0 F	22
O	22.0 F	9	BXW	272.0 F	3
BXW	25.0 F	1	BXW	378.0 F	4
BLM	28.0 F	1	BXW	400.0 F	11
BXW	46.0 F	1	BXW	404.0 F	3
BIN	48.0 F	2	BXW	424.0 F	2
BLM	50.0 F	1	BXW	611.0 F	5
BLM	55.0 F	36	BXW	617.0 F	20
BXW	56.0 F	182	BXW	636.0 F	2
BXW	61.0 F	4	O	1.0 K	3
BIN	62.0 F	1	BLM	2.0 K	2
BXW	69.0 F	2	O	2.0 K	1
BXW	72.0 F	5	BLM	5.0 K	3
BXW	84.0 F	9	O	5.0 K	1
BXW	93.0 F	13	BLM	30.0 K	1070
BIN	96.0 F	25	BLM	35.0 K	70
BXM	96.0 F	85	BLM	55.0 K	139259
BXW	106.0 F	88	RD5	55.0 K	3
BIN	108.0 F	1	BLM	83.0 K	3953
BXW	108.0 F	8	BLM	86.0 K	55
BXW	111.0 F	24	BLM	100.0 K	77
BXM	112.0 F	2331	BXM	355.0 K	2
BXW	112.0 F	10228			

Table 3. (Cont.)

Arranged by Type, then by Volume					
Type ^a	Volume ^b	Number	Type ^a	Volume ^b	Number
BIN	48.0 F	2	BXW	84.0 F	9
BIN	62.0 F	1	BXW	93.0 F	13
BIN	96.0 F	25	BXW	106.0 F	88
BIN	108.0 F	1	BXW	108.0 F	8
BIN	115.0 F	18	BXW	111.0 F	24
BIN	120.0 F	528	BXW	112.0 F	10228
BLM	1.0 F	1	BXW	120.0 F	7
BLM	3.0 F	1	BXW	121.0 F	137
BLM	7.0 F	189	BXW	128.0 F	9
BLM	8.0 F	1750	BXW	130.0 F	7
BLM	9.0 F	3	BXW	144.0 F	5
BLM	28.0 F	1	BXW	145.0 F	2
BLM	50.0 F	1	BXW	155.0 F	2
BLM	55.0 F	36	BXW	169.0 F	6
BLM	2.0 K	2	BXW	176.0 F	6
BLM	5.0 K	3	BXW	188.0 F	3
BLM	30.0 K	1070	BXW	212.0 F	3
BLM	35.0 K	70	BXW	228.0 F	22
BLM	55.0 K	139259	BXW	272.0 F	3
BLM	83.0 K	3953	BXW	378.0 F	4
BLM	86.0 K	55	BXW	400.0 F	11
BLM	100.0 K	77	BXW	404.0 F	3
BXC	1.0 F	1	BXW	424.0 F	2
BXC	2.0 F	1	BXW	611.0 F	5
BXM	96.0 F	85	BXW	617.0 F	20
BXM	112.0 F	2331	BXW	636.0 F	2
BXM	120.0 F	25	I	5.0 F	30
BXM	355.0 K	2	O	1.0 F	29
BXW	2.0 F	2	O	22.0 F	9
BXW	3.0 F	1	O	112.0 F	1
BXW	8.0 F	1	O	1.0 K	3
BXW	18.0 F	1	O	2.0 K	1
BXW	25.0 F	1	O	5.0 K	1
BXW	46.0 F	1	RD5	7.0 F	4
BXW	56.0 F	182	RD5	55.0 K	3
BXW	61.0 F	4	RDL	7.0 F	16
BXW	69.0 F	2	RDL	8.0 F	10
BXW	72.0 F	5			

a. The codes for container type are BIN for bin, BLM for metal barrel, BXC for cardboard box, BXM for metal box, BXW for wooden box, I for insert, O for other, RDL for 55 gal metal barrel with liner, and RD5 for 55 gal metal barrel without liner.

b. F means cubic foot, K means gallon.

The above summarizes the data to be analyzed. Conceptually, the analysis method is as follows. Assume that each shipment is homogeneous, and divide the shipment activity by the shipment volume to obtain the "normalized activity" (mCi/cu-ft) for each shipment. From this, obtain the empirical distribution of normalized activity (mCi/cu-ft), reflecting the fact that different shipments have different activities and different volumes. One could work with the gallon or the cubic foot as the basic normalizing unit, but we choose the cubic foot. The two are related by $1 \text{ gal} = 231/1728 \text{ cu-ft} = 0.1337 \text{ cu-ft}$.

This approach yields the correct overall mean activity per cubic foot. It underestimates the variance somewhat, because it uses the assumption that each shipment is perfectly homogeneous. See Appendix B for some examples of the degree of underestimation of the variance. In those examples the variance is underestimated by 1/10 to 1/3; this corresponds to underestimating the standard deviation by from 5% to 20%. No way has been found, however, to improve on the method used here, based on the RWMIS data as it is.

To carry out this analysis, software was written in the dBASE language to write, for each shipment, the total container volume and the current (decayed) activity of each nuclide that is present in the shipment. This text file was read by a Fortran program to extract the relevant information for the major nuclides, and for classes of nuclides such as transuranic (TRU) nuclides or α -emitters. Finally the statistical package SAS was used to analyze this information and to approximate the empirical distribution.

To simulate a container using this method, draw a random normalized activity (mCi/cu-ft) from the empirical distribution, then multiply that normalized activity by the number of cubic feet in the container. The result is the simulated activity (mCi) for the container. In the same manner, one can simulate the mass (mg) of a fissionable nuclide or class of nuclides, or the committed effective dose equivalent (Mrem) from inhalation.

RESULTS

TABULATED EMPIRICAL DISTRIBUTIONS

The empirical distributions are given for a number of nuclides and classes of nuclides and containers. Several classes of nuclides are mentioned below: transuranic (TRU), non-TRU, α -emitters, β/γ -emitters, and fissionable nuclides. Table 1 shows which nuclides fall into which classes. For nearly all classes, the empirical distribution is expressed in terms of mCi/cu-ft, and reflects the variation between shipments. For fissionable nuclides, the empirical distribution is expressed in mg/cu-ft. Finally, the committed effective dose equivalent from inhalation is considered, and its empirical distribution is expressed in Mrem/cu-ft. The empirical distribution is given for:

- All the nuclides combined.
- The transuranic (TRU) nuclides as a class. The total activity of the TRU nuclides in a shipment is found, the resulting normalized activity in mCi/cu-ft is found for each shipment, and the empirical distribution of this normalized activity is presented. The standard definition of a TRU nuclide is used: atomic number > 92, and half-life > 20 years.
- The non-TRU nuclides as a class.
- The α -emitting nuclides as a class.
- The β/γ -emitting nuclides as a class.
- Any nuclide with present total activity greater than 2 Ci. The cutoff of 2 Ci was chosen because the generation of daughter products was fairly easy to program in dBASE for nuclides that would result in activity of 2 Ci or more, but would have been cumbersome if certain other nuclides had been included. Because the generation of daughters was not programmed for daughters with less than 2 Ci, it is not meaningful to consider the

empirical distributions of those nuclides.

- Each major waste generator as a class. For example, the empirical distribution of normalized activity (mCi/cu-ft) from Rocky Flats is given. Seven waste generators are treated in this way. For each such generator, three empirical distributions are given, for the total normalized activity, the TRU normalized activity, and the non-TRU normalized activity.
- Two storage locations, as classes: the Intermediate-Level Transuranic Storage Facility (ILTSF) and everywhere else at the Transuranic Storage Area (TSA). The reason for this dichotomy is that all remote-handled waste is required to be stored at the ILTSF, while the waste everywhere else must be contact-handled waste. For each of these two locations, three empirical distributions are given, for total normalized activity, TRU normalized activity, and non-TRU normalized activity.
- Fissionable nuclides, as a class. These empirical distributions are expressed as mg/cu-ft, because criticality calculations usually use grams rather than curies. The relation between grams and curies is: $\text{grams} = 2.798\text{E-}6 \times (\text{activity in Ci}) \times (\text{half-life in years}) \times (\text{atomic mass})$. Empirical distributions are given for: the total fissionable mass, as a class; the mass of the fissionable TRU nuclides, as a class; the mass of the fissionable non-TRU nuclides, as a class; and the mass of individual fissionable nuclides with total decayed activity > 2 Ci.
- The total inhalation committed effective dose equivalent, expressed as Mrem/cu-ft. The dose conversion factors, for converting curies to rems, are listed in Appendix A.

These empirical distributions are presented in Tables 4 through 11. The use of these tables is explained in the following sections.

HOW TO READ THE TABLES

The empirical distributions are discrete rather than continuous, because they are based on the normalized activities of a finite number of shipments. If only a few shipments contain the class of nuclides under consideration, the simplest way to present the empirical distribution is to list the normalized activities and their probabilities. This is done for a few cases in Table 10, and is explained in more detail below. On the other hand, for a class of nuclides that occurs in many (but not all) shipments the empirical distribution can be approximated by two parts: a point probability at zero, and a continuous distribution covering the range of normalized activities greater than zero. The continuous portion can be summarized by the quantiles: the 10% point, the 20% point, etc. Because the distribution is typically skewed, with a few very large values in the right tail, we show more detail in the uppermost quantiles, listing the 98%, 99.5%, and 99.9% points, as well as the absolute maximum.

Nearly all the results in Tables 4 through 11 are presented by giving three numbers, which must be combined:

- (1) A , a normalized activity, in units mCi/cu-ft in Tables 4 through 7, in mg/cu-ft in Tables 8 and 9, and in Mrem/cu-ft in Table 11
- (2) $P(A)$, the cumulative probability that the random normalized activity is less than A , conditional on the activity being greater than zero
- (3) p_{pos} , the probability that a random cubic foot of waste will contain non-zero activity of the type of interest.

The probability that a random cubic foot of waste will have activity less than or equal to A is given by

$$(1 - p_{\text{pos}}) + p_{\text{pos}} \times P(A) \quad (1)$$

The first of the two added terms is the probability that the random cubic foot has no activity from the class of interest, and the second term is the probability that the activity is positive but at most A .

Table 4. Distributions of major classes of nuclides, mCi/cu-ft.

All	TRU	Non-TRU	α -Emitters	β/γ -Emitters	Conditional Cumulative Probability
Normalized Activity (mCi/cu-ft)					
0.	0.	0.	0.	0.	0.0
0.449	0.135	0.278	0.136	0.291	0.10
2.25	0.556	0.727	0.567	0.872	0.20
11.8	3.68	5.32	3.72	5.47	0.30
24.7	7.71	13.2	7.78	13.6	0.40
34.6	11.5	20.0	11.5	20.4	0.50
61.2	19.7	30.1	20.0	30.7	0.60
91.0	41.3	44.8	41.7	45.6	0.70
188.	74.9	81.3	74.8	83.0	0.80
430.	223.	178.	223.	179.	0.90
1020.	691.	456.	689.	459.	0.98
2920.	1830.	906.	1810.	914.	0.995
7510.	4370.	3680.	4370.	3720.	0.999
390000.	30300.	389000.	71400.	389000.	1.000
P(Activity > 0)					
1.00000	0.99198	0.99771	0.99863	0.98140	

Table 5. Distributions of individual nuclides, mCi/cu-ft.

Am-241	Ba-137m	Bi-212	Ce-144	Cm-244 ^a	Cond. Cum. Probability
Normalized Activity (mCi/cu-ft)					
0.	0.	0.	0.	0.	0.0
0.0143	0.255	0.269	0.00140	0.000000	0.10
0.0363	1.23	0.317	0.00176	0.000001	0.20
0.216	1.25	0.443	0.00210	0.000151	0.30
0.500	1.28	0.485	0.00242	0.000151	0.40
0.847	1.31	0.541	0.00647	0.000944	0.50
1.16	1.37	0.738	0.0374	0.0378	0.60
2.97	1.38	0.789	0.422	2.35	0.70
27.1	1.40	0.941	0.925	9.47	0.80
120.	1.47	9.22	35.5	12.2	0.90
465.	109.	16.1	790.	12.2	0.98
814.	760.	23.9	3560.	27.4	0.995
1300.	6460.	23.9	3560.	71400.	0.999
3370.	93100.	23.9	3560.	71400.	1.000
P(Activity > 0)					
0.9592	0.0224	0.00609	0.000175	0.00213	
Co-60 ^a	Cs-134	Cs-137	Kr-85 ^a	MFP	Cond. Cum. Probability
Normalized Activity (mCi/cu-ft)					
0.	0.	0.	0.	0.	0.0
0.000176	1.30	0.000020	522.	2.43	0.10
0.000176	1.73	0.000233	522.	2.44	0.20
0.000176	2.57	0.00109	522.	2.53	0.30
0.000176	2.59	0.00181	522.	2.61	0.40
0.000176	3.01	0.00181	850.	2.67	0.50
0.000176	4.15	0.00181	850.	2.73	0.60
0.000176	19.2	0.244	850.	2.75	0.70
0.000176	103.	1.49	850.	2.78	0.80
17.7	650.	98.3	850.	2.82	0.90
2680.	3050.	1630.	850.	113.	0.98
2940.	10300.	13000.	850.	329.	0.995
2940.	10300.	74000.	850.	934.	0.999
2940.	10300.	93100.	850.	2700.	1.000
P(Activity > 0)					
0.000371	0.000143	0.00268	0.00000437	0.0204	

Table 5. (Cont.)

<u>Ni-63</u> ^a	<u>Pb-212</u>	<u>Pm-147</u> ^a	<u>Po-212</u>	<u>Po-216</u>	Cond. Cum. Probability
<u>Normalized Activity (mCi/cu-ft)</u>					
0.	0.	0.	0.	0.	0.0
0.000129	0.269	507.	0.172	0.269	0.10
0.000129	0.317	507.	0.203	0.317	0.20
0.000129	0.443	507.	0.284	0.443	0.30
0.000129	0.485	507.	0.311	0.485	0.40
0.000129	0.541	1530.	0.347	0.541	0.50
0.000129	0.738	1530.	0.473	0.738	0.60
0.000129	0.789	1530.	0.506	0.789	0.70
0.000129	0.941	3180.	0.603	0.941	0.80
0.000129	9.22	3180.	5.91	9.22	0.90
0.000129	16.1	3180.	10.3	16.1	0.98
589.	23.9	3180.	15.3	23.9	0.995
589.	23.9	3180.	15.3	23.9	0.999
589.	23.9	3180.	15.3	23.9	1.000
<u>P(Activity > 0)</u>					
0.000319	0.00610	0.00000759	0.00610	0.00610	
<u>Pr-144</u>	<u>Pu-238</u>	<u>Pu-239</u>	<u>Pu-240</u>	<u>Pu-241</u>	Cond. Cum. Probability
<u>Normalized Activity (mCi/cu-ft)</u>					
0.	0.	0.	0.	0.	0.0
0.00141	0.00242	0.0684	0.0210	0.290	0.10
0.00177	0.0106	0.186	0.0521	0.841	0.20
0.00211	0.0862	1.03	0.366	6.70	0.30
0.00243	0.158	3.66	0.981	15.2	0.40
0.00650	0.211	6.04	1.50	21.3	0.50
0.0376	0.323	7.82	1.92	31.2	0.60
0.424	0.559	12.3	3.04	47.3	0.70
0.929	1.01	20.9	5.23	85.6	0.80
35.7	3.22	43.9	10.9	181.	0.90
793.	132.	121.	29.1	460.	0.98
3570.	1670.	195.	47.1	905.	0.995
3570.	4360.	729.	195.	3580.	0.999
3570.	30300.	1600.	1780.	25100.	1.000
<u>P(Activity > 0)</u>					
0.000175	0.9694	0.99187	0.9679	0.9535	

Table 5. (Cont.)

Ra-224	Rn-220	Sr-90	Th-228	Tl-208	Cond. Cum. Probability
Normalized Activity (mCi/cu-ft)					
0.	0.	0.	0.	0.	0.0
0.269	0.269	278.	0.269	0.0966	0.10
0.317	0.317	515.	0.317	0.114	0.20
0.443	0.443	644.	0.443	0.159	0.30
0.485	0.485	773.	0.485	0.174	0.40
0.541	0.541	773.	0.541	0.195	0.50
0.738	0.738	901.	0.738	0.265	0.60
0.789	0.789	1620.	0.789	0.284	0.70
0.941	0.941	5730.	0.941	0.338	0.80
9.22	9.22	11800.	9.22	3.31	0.90
16.1	16.1	73600.	16.1	5.80	0.98
23.9	23.9	92800.	23.9	8.59	0.995
23.9	23.9	92800.	23.9	8.59	0.999
23.9	23.9	92800.	23.9	8.59	1.000
P(Activity > 0)					
0.00610	0.00610	0.000138	0.00610	0.00610	
U-232	U-233	U-234	Unid. β/γ ^a	Y-90	Cond. Cum. Probability
Normalized Activity (mCi/cu-ft)					
0.	0.	0.	0.	0.	0.0
0.262	0.000162	0.000000	47.6	1.21	0.10
0.309	0.000485	0.000000	63.4	1.21	0.20
0.432	0.000612	0.000004	63.4	1.26	0.30
0.473	0.000705	0.000007	209.	1.29	0.40
0.527	0.00140	0.000010	209.	1.33	0.50
0.720	0.0368	0.000013	313.	1.36	0.60
0.769	0.846	0.000019	319.	1.37	0.70
0.917	20.7	0.000034	319.	1.39	0.80
9.09	47.8	0.000125	731.	1.46	0.90
15.8	198.	0.00727	731.	71.6	0.98
23.5	215.	0.145	731.	644.	0.995
23.5	319.	0.440	731.	7510.	0.999
23.5	330.	1.81	731.	92800.	1.000
P(Activity > 0)					
0.00610	0.0245	0.9731	0.0000199	0.0206	

a. This nuclide occurred in fewer than 20 shipments. The exact distribution is given in Table 10.

Table 6. Distributions of activity from major generators, mCi/cu-ft.

ALE (Argonne Lab East)			ANL (Argonne Lab West)			Cond. Cum. Probability
All	TRU	non-TRU	All	TRU	non-TRU	
Normalized Activity (mCi/cu-ft)						
0.	0.	0.	0.	0.	0.	0.0
5.45	0.482	0.999	9.42	2.74	0.00231	0.10
5.55	0.528	4.87	33.2	14.7	0.0166	0.20
5.74	0.567	4.94	90.8	40.0	0.0398	0.30
5.89	0.651	5.07	191.	99.3	0.0476	0.40
6.20	0.740	5.22	491.	195.	0.0505	0.50
6.29	0.854	5.46	647.	496.	0.0659	0.60
7.26	2.29	5.50	808.	646.	0.993	0.70
12.5	8.55	5.57	1070.	819.	23.9	0.80
35.6	18.4	5.87	1630.	1130.	762.	0.90
712.	183.	672.	45800.	1770.	45800.	0.98
1910.	285.	1960.	299000.	2320.	299000.	0.995
22000.	1010.	21100.	390000.	2540.	389000.	0.999
26300.	1921.	25300.	390000.	2540.	389000.	1.000
P(Activity > 0)						
0.0236	0.0236	0.0230	0.000670	0.000670	0.000659	
BET (Bettis Atomic Power Lab)			CPP (Chem. Processing Plant)			non-TRU Cond. Cum. Probability
All	TRU		non-TRU	All	TRU	
Normalized Activity (mCi/cu-ft)						
0.	0.	0.	0.	0.	0.	0.0
14.5	1.26	14.5	0.428	0.195	0.233	0.10
20.4	1.26	20.4	0.581	0.260	0.321	0.20
27.8	1.26	27.8	0.581	0.260	0.321	0.30
33.3	1.26	33.3	0.872	0.391	0.321	0.40
38.0	1.26	38.0	0.872	0.391	0.481	0.50
49.7	1.26	49.7	0.872	0.391	0.481	0.60
56.8	1.26	56.8	1.23	0.997	0.481	0.70
69.2	60.6	69.2	100.	1.95	0.483	0.80
249.	2570.	249.	2920.	14.8	3070.	0.90
344.	2570.	344.	5310.	2920.	5120.	0.98
510.	2570.	510.	22800.	2920.	22800.	0.995
2630.	2570.	510.	22800.	2920.	22800.	0.999
55900.	2570.	54800.	22800.	2920.	22800.	1.000
P(Activity > 0)						
0.00669	0.0000815	0.00669	0.000752	0.000752	0.000622	

Table 6. (Cont.)

MRC (Mound Laboratory)			RFO (Rocky Flats)			Cond. Cum. Probability
All	TRU	non-TRU	All	TRU	non-TRU	
Normalized Activity (mCi/cu-ft)						
0.	0.	0.	0.	0.	0.	0.0
5.76	5.76	0.000960	0.416	0.129	0.282	0.10
13.5	13.1	0.00569	0.948	0.308	0.657	0.20
26.5	22.9	0.220	10.2	2.82	6.62	0.30
38.2	36.3	0.828	21.4	6.34	14.4	0.40
59.0	58.6	1.47	30.3	9.19	20.6	0.50
82.9	79.7	2.70	52.3	15.8	33.9	0.60
143.	138.	5.42	104.	27.9	53.6	0.70
301.	288.	12.5	206.	74.8	97.0	0.80
1090.	1050.	34.6	446.	228.	197.	0.90
4130.	3970.	153.	961.	602.	480.	0.98
7820.	7560.	274.	1610.	1010.	943.	0.995
8650.	8360.	290.	4700.	1490.	3590.	0.999
31500.	30300.	1170.	10100.	4260.	7700.	1.000
P(Activity > 0)						
0.0602	0.0602	0.0602	0.837	0.835	0.835	

WMC (Waste Management Complex)			Cond. Cum. Probability
All	TRU	non-TRU	
Normalized Activity (mCi/cu-ft)			
0.	0.	0.	0.0
52.9	17.6	19.7	0.10
83.3	47.8	29.3	0.20
83.3	54.0	29.6	0.30
83.7	54.0	29.9	0.40
84.0	54.0	30.8	0.50
85.0	54.0	31.2	0.60
85.5	54.1	31.5	0.70
85.8	54.1	32.1	0.80
108.	62.2	45.5	0.90
244.	109.	148.	0.98
288.	148.	179.	0.995
447.	161.	300.	0.999
447.	161.	300.	1.000
P(Activity > 0)			
0.0677	0.0677	0.0677	

a. This class occurred in fewer than 20 shipments. The exact distribution is given in Table 10.

Table 7. Distributions of activity by present storage area, mCi/cu-ft.

TSA but not ILTSF		ILTSF		Cond. Cum. Probability
All	TRU	non-TRU	All	
Normalized Activity (mCi/cu-ft)				
0.449	0.135	0.276	0.	0.0
2.25	0.556	0.727	109.	0.10
11.8	3.68	5.28	154.	0.20
24.7	7.71	13.1	181.	0.30
34.5	11.5	20.0	227.	0.40
61.0	19.7	30.0	272.	0.50
91.0	41.3	44.7	338.	0.60
187.	75.0	80.6	554.	0.70
429.	223.	176.	900.	0.80
1020.	691.	455.	2190.	0.90
2820.	1830.	875.	29100.	0.98
7200.	4370.	3520.	96500.	0.995
71400.	30300.	71400.	390000.	0.999
			1090.	1.000
			389000.	
P (Activity > 0)				
0.99881	0.99079	0.99654	0.00119	0.00117

Table 8. Distributions of fissionable nuclides by class, mg/cu-ft.

<u>All</u>	<u>TRU</u>	<u>non-TRU</u>	<u>Cond. Cum. Probability</u>
<u>Normalized Activity (mg/cu-ft)</u>			
0.	0.	0.	0.0
1.50	0.00479	0.00286	0.10
3.81	0.0170	0.00926	0.20
22.6	0.109	0.0750	0.30
65.9	0.201	0.171	0.40
104.	0.309	0.284	0.50
141.	0.509	0.410	0.60
224.	1.69	0.847	0.70
378.	12.9	2.34	0.80
832.	40.4	9.67	0.90
2200.	151.	88.6	0.98
5370.	263.	3030.	0.995
20700.	442.	19700.	0.999
39800.	1770.	38900.	1.000
<u>P(Activity > 0)</u>			
0.99863	0.99198	0.96800	

Table 9. Distributions of individual fissionable nuclides, mg/cu-ft.

<u>Am-241</u>	<u>Cm-244</u> ^a	<u>Pu-238</u>	<u>Pu-239</u>	<u>Pu-241</u>	<u>Cond. Cum. Probability</u>
<u>Normalized Activity (mg/cu-ft)</u>					
0.	0.	0.	0.	0.	0.0
0.00417	0.0000000	0.000141	1.10	0.00281	0.10
0.0106	0.0000000	0.000618	2.99	0.00816	0.20
0.0631	0.0000019	0.00503	16.6	0.0650	0.30
0.146	0.0000019	0.00921	58.9	0.147	0.40
0.247	0.0000117	0.0123	97.2	0.207	0.50
0.339	0.000467	0.0188	126.	0.303	0.60
0.867	0.0290	0.0326	198.	0.459	0.70
7.91	0.117	0.0592	336.	0.830	0.80
35.1	0.151	0.188	708.	1.75	0.90
136.	0.151	7.69	1940.	4.46	0.98
237.	0.338	97.3	3140.	8.78	0.995
379.	881.	254.	11700.	34.7	0.999
984.	881.	1770.	25800.	243.	1.000
<u>P(Activity > 0)</u>					
0.9592	0.00213	0.9694	0.99187	0.9535	
<u>U-233</u>					
<u>Normalized Activity (mg/cu-ft)</u>		<u>Cond. Cum. Probability</u>			
0.		0.0			
0.0169		0.10			
0.0505		0.20			
0.0638		0.30			
0.0734		0.40			
0.146		0.50			
3.84		0.60			
88.1		0.70			
2160.		0.80			
4980.		0.90			
20700.		0.98			
22400.		0.995			
33300.		0.999			
34400.		1.000			
<u>P(Activity > 0)</u>					
0.0245					

a. This nuclide occurred in fewer than 20 shipments. The exact distribution is given in Table 10.

Table 10. Exact distributions for classes occurring in few shipments.

Cm-244			Co-60	
<u>Norm.Act.</u> <u>(mCi/cu-ft)</u>	<u>Norm.Act.</u> <u>(mg/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>	<u>Norm.Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>
0.0000001	0.0000000	0.14778	0.000176	0.84865
0.0000009	0.0000000	0.14778	1.29	0.00589
0.000151	0.0000019	0.14778	6.99	0.03300
0.000944	0.0000117	0.14778	14.0	0.00943
0.00314	0.0000387	0.00003	17.7	0.00943
0.00873	0.000108	0.00014	19.7	0.00589
0.0378	0.000467	0.10563	23.1	0.00589
2.35	0.0290	0.04926	32.1	0.00589
5.47	0.0676	0.00151	43.1	0.00589
9.47	0.117	0.14778	49.6	0.00589
12.2	0.151	0.09852	104.	0.00589
27.4	0.338	0.00151	279.	0.00589
36.8	0.454	0.00151	491.	0.00589
77.3	0.954	0.00151	771.	0.00589
71400.	881.	0.00151	1500.	0.00589
			2010.	0.00867
			2680.	0.00867
			2880.	0.00867
			2940.	0.00867
P(Activity > 0)				
0.00213			0.000371	

Table 10. (Cont.)

<u>Kr-85</u>		<u>Ni-63</u>		<u>Pm-147</u>	
<u>Norm. Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>	<u>Norm. Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>	<u>Norm. Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>
522.	0.5	0.000129	0.98630	507.	0.424
850.	0.5	125.	0.00685	1530.	0.288
		589.	0.00685	3180.	0.288
<u>P(Activity > 0)</u>					
0.00000437		0.000319		0.00000759	
<u>Unidentified β/γ</u>		<u>BET-TRU</u>			
<u>Norm. Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>	<u>Norm. Act.</u> <u>(mCi/cu-ft)</u>	<u>Cond. Pt.</u> <u>Probability</u>		
47.6	0.1762	1.26	0.7492		
63.4	0.1762	3.76	0.0394		
209.	0.1619	60.6	0.0394		
313.	0.1619	379.	0.0268		
319.	0.1619	1090.	0.0268		
731.	0.1619	2570.	0.1183		
<u>P(Activity > 0)</u>					
0.0000198		0.0000815			

Table 11. Overall committed effective dose equivalent from inhalation.

<u>Normalized C.E.D.E. (Mrem/cu-ft)</u>	<u>Cond. Cum. Probability</u>
0.	0.0
0.0717	0.10
0.291	0.20
1.97	0.30
4.11	0.40
5.96	0.50
10.2	0.60
21.0	0.70
37.7	0.80
116.	0.90
360.	0.98
894.	0.995
2010.	0.999
19300.	1.000
<hr/>	
P(C.E.D.E. > 0)	
	1.0000
<hr/>	

For example, in Table 4 consider TRU nuclides and 691 mCi/cu-ft. We have $A = 691$, $P(A) = 0.98$, and $p_{\text{pos}} = 0.99198$. Therefore, from Equation (1) the probability that a random cubic foot of waste will contain at most 691 mCi of TRU nuclides is

$$\begin{aligned} (1 - 0.99198) + 0.99198 \times 0.98 \\ = 0.00802 + 0.97214 \\ = 0.98016 \end{aligned}$$

Similarly from Table 5, the probability that a random cubic foot of waste will contain at most 1.25 mCi of Ba-147m is

$$(1 - 0.0224) + 0.0224 \times 0.30 = 0.9843$$

In this example, the dominant contributor to this probability is $1 - 0.0224$, the probability that the waste will contain no Ba-147m at all.

Eight cases in Tables 4 through 9 involved fewer than twenty shipments: Cm-144 expressed in mCi/cu-ft and in mg/cu-ft, the TRU nuclides from Bettis, and five other individual nuclides listed in Table 5. Therefore, these cases are also presented in Table 10 by giving the discrete distribution. The conditional probability corresponding to the shipment is the volume of the shipment divided by the total volume of those containers containing the class of interest. The value p_{pos} , shown as $P(\text{Activity} > 0)$, is the total volume of containers containing the class of interest divided by the total volume of all containers in the data set. The unconditional probability that a random cubic foot has one of the normalized activities shown is p_{pos} times the conditional point probability. The conditional probabilities in Table 10 were found using a hand calculator, and recalculated later as a check.

HOW TO USE THE TABLES FOR SIMULATIONS

The empirical distribution is approximated from the cumulative values in Tables 4-9 and 11. Consider again TRU nuclides as an example. Let X denote the random activity of TRU nuclides in a random cubic foot of waste. It was found above that

$$\text{Prob}(X \leq 691) = 0.98016.$$

Similarly, we can find that

$$\text{Prob}(X \leq 223) = 0.90080$$

$$\text{Prob}(X \leq 74.9) = 0.80160$$

and so forth. Therefore, the continuous portion of the distribution of X has a density approximated by a histogram, with

$$\text{probability} = 0.98016 - 0.90080 = 0.07936 \text{ between } 223 \text{ and } 691,$$

$$\text{probability} = 0.90080 - 0.80160 = 0.09920 \text{ between } 74.9 \text{ and } 223,$$

and so forth. The entire distribution has a point mass of $1 - 0.99198 = 0.00802$ at zero, and above zero it has a density approximated by the histogram on the left side of Table 12. Note that the 13 cell probabilities on the left side of Table 12 sum to 0.99200, which equals the required 0.99198 except for round off error, and that the sum of these probabilities and the point mass at zero is 1.0, except for round off error. The "density" times the width of any cell equals the cell probability, as is required of a density. We write it in quotation marks because the total area under the density equals 0.99198, not the usual 1.0. No graph of the density is shown, because the both the activity and the density range over orders of magnitude; on ordinary axes, most of the graph would vanish into the axes, and on log-log axes the usual interpretation of the areas would be meaningless.

If the simulation software does not allow a distribution with both a

Table 12. Histogram of distribution for TRU waste.

<u>Continuous portion only</u>			<u>Approx. of full distribution</u>		
<u>Cell bndry.</u> <u>(mCi/cu-ft)</u>	<u>Cell prob.</u>	<u>"Density"</u>	<u>Cell bndry.</u> <u>(mCi/cu-ft)</u>	<u>Cell prob.</u>	<u>Density</u>
0.			0.	0.00802	16.04
	0.09920	0.73480	0.0005	0.09920	0.73755
0.135	0.09920	0.23562	0.135	0.09920	0.23562
0.556	0.09920	0.031754	0.556	0.09920	0.031754
3.68	0.09920	0.024615	3.68	0.09920	0.024615
7.71	0.09920	0.026174	7.71	0.09920	0.026174
11.5	0.09920	0.012097	11.5	0.09920	0.012097
19.7	0.09920	0.0045925	19.7	0.09920	0.0045925
41.3	0.09920	0.0029523	41.3	0.09920	0.0029523
74.9	0.09920	0.0006698	74.9	0.09920	0.0006698
223.	0.07936	0.0001696	223.	0.07936	0.0001696
691.	0.01488	0.1306E-4	691.	0.01488	0.1306E-4
1830.	0.00397	0.1562E-5	1830.	0.00397	0.1562E-5
4370.	0.00099	0.3826E-7	4370.	0.00099	0.3826E-7
30300.			30300.		

continuous and a discrete portion, approximate the entire distribution by a continuous one: change the point mass at zero to a constant density over a very small range, (very small small compared to the 10% point), and construct the density so that the area under the curve in that range equals the required point mass. For example, from Table 12, 0.0005 is very small compared to 0.135. Therefore, let the density be constant in the range 0. to 0.0005, with area under the curve there equal to 0.00802. The value of the density therefore is $0.00802/0.0005 = 16.04$, as shown on the right side of Table 12. The point mass is very small in this example, but it is not small in other examples. Note that the left and right sides of Table 12 are identical except near zero.

Table 13 shows the approximate histogram densities for two other cases: ILTSF non-TRU waste, and committed effective dose equivalent (C.E.D.E) from inhalation. For ILTSF non-TRU waste, the point mass at zero has been approximated by a density over a small range. For the inhalation dose, no such approximation is necessary, because $\text{Prob}(\text{C.E.D.E.} > 0) = 1$. These histograms are not shown graphically, for the same reasons that applied to Table 12. Distributions such as these should be sampled in simulations.

An approximation has been used for the point mass at zero. A similar approximation can be used when two cell boundaries are listed as equal. For example, Table 7 shows 389000 both as the 99.9% point and as the absolute maximum for ILTSF non-TRU waste. To calculate the density in Table 13 we changed these values to 388500 and 389500 (both of which could round off to 389000). This made it possible to calculate the density shown in Table 13.

To simulate a random waste container with a volume of V cubic feet, randomly sample the normalized activity X from this histogram distribution, and multiply the selected value of X by the volume V , to obtain the activity (mCi) in the simulated container.

Table 13. Histograms for ILTSF non-TRU waste and inhalation dose.

<u>ILTSF Non-TRU Waste</u>			<u>Inhalation C. E. D. E.</u>		
<u>Cell bndry.</u> <u>(mCi/cu-ft)</u>	<u>Cell prob.</u>	<u>"Density"</u>	<u>Cell bndry.</u> <u>(Mrem/cu-ft)</u>	<u>Cell prob.</u>	<u>"Density"</u>
0.	0.99883	19.9767	0.		
0.05	0.000117	0.1219E-5	0.10	1.3947	
96.0	0.000117	0.2600E-5	0.0717	0.10	0.45600
141.	0.000117	0.5850E-5	0.291	0.10	0.059559
161.	0.000117	0.2167E-5	1.97	0.10	0.046729
215.	0.000117	0.3441E-5	4.11	0.10	0.054054
249.	0.000117	0.2208E-5	5.96	0.10	0.023585
302.	0.000117	0.6062E-6	10.2	0.10	0.0092593
495.	0.000117	0.3223E-6	21.0	0.10	0.0059880
858.	0.000117	0.8784E-7	37.3	0.10	0.0012771
2190.	0.0000936	0.3531E-8	116.	0.08	0.0003279
28700.	0.00001755	0.2608E-9	360.	0.015	0.2809E-4
96000.	0.00000468	0.1600E-10	894.	0.004	0.3584E-5
388500.	0.00000117	0.1170E-8	2010.	0.001	0.5784E-7
389500.			19300.		

CAUTIONS

To simulate an accident scenario involving a breached waste container, one would want to simulate the various nuclides that might be in the container. However, the distributions of the nuclides are not independent: certain nuclides tend to occur together, and there may be pairs of nuclides that tend not to occur together. An obvious example is given by nuclides in a single decay chain. For example, in Table 2 there are 54 shipments containing U-232. As seen in Table 1,

U-232 decays to Th-228, which spawns a chain of short-lived isotopes, each isotope quickly decaying to the next. Thus, the same 54 shipments contain U-232, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, and Po-212. From Th-228 to Bi-212, all the elements in the chain have exactly the same activity, because whenever a parent nucleus decays, a daughter is created which then also quickly decays.

Therefore, for typical accident simulations it is desirable to use the high-level classes if possible, rather than simulating the individual nuclides. As an example, suppose we wish to simulate a fire, and are concerned about human exposure through inhalation. One high-level class is the class of α -emitters. This class can be simulated directly from the information in Table 4. It is not so simple, however, to use this simulation to estimate the health effects of the simulated release. From Table 1, the most abundant α -emitters are Am-241, Pu-238, and Pu-239, and Pu-240, in that order. One could combine their doses by assuming that their proportions in the release are the same as in the entire population, but this ignores the variability in the composition of the waste.

Therefore, the correct way to simulate the health effect is to use the empirical distribution of committed effective dose equivalent. Such a distribution is developed for the inhalation pathway in Table 11, expressed in Mrem/cu-ft, where 1 Mrem = 10^6 rem. The unit Mrem may seem surprisingly large, but realize that this corresponds to inhalation of a full cubic foot of waste. In reality, the waste would be dispersed in the air, and someone would inhale only a small fraction of a cubic foot, thereby receiving a small fraction of the tabulated megarems.

Inhalation is regarded as the most important path for managed waste that contains many α -emitters. Doses for other pathways could also be developed, but they are not shown here. To compute the committed effective dose equivalent from other paths, modify the programs PREPD.FOR and DOSE.SAS listed in Appendix A.

CONCLUSIONS

This report has analyzed radioactive contents of above-ground containers, as listed in the RWMIS data base. The empirical distributions (mCi/cu-ft) have been given: for important classes of nuclides such as the TRU nuclides, the α -emitters, the β/γ -emitters, and the fissionable nuclides; for the major individual nuclides; and for classes of containers such as those from a particular waste generator or those in a particular location. The empirical distribution expressed in mg/cu-ft has also been given for classes of fissionable nuclides and for the major individual fissionable nuclides. Finally, the empirical distribution of the committed effective dose equivalent has been given for the inhalation pathway, expressed in Mrem/cu-ft, where 1 Mrem = 10^6 rem.

To simulate a random container, randomly sample a normalized activity (mCi/cu-ft), mass (mg/cu-ft), or dose (Mrem/cu-ft) from the tabulated empirical distribution, and multiply this number by the number of cubic feet in the postulated container. This is the simulated activity (mCi), mass (mg), or dose (Mrem) from the container. This can be done for an individual nuclide, some class of nuclides, or some class of containers.

APPENDIX A: DETAILS OF PROGRAMMING

DBASE CALCULATIONS, INCLUDING DECAYED ACTIVITY

An important part of the dBASE calculations was the calculation of decayed activity, as follows. The half-lives of the most of the radionuclides were taken from the Eleventh Edition of *Chart of the Nuclides* (cf. Walker et al., 1984), and had been entered and proof-read for an earlier project (Schlafman, 1992). A few radionuclides had not been encountered in the earlier project. Their half-lives were taken from the Thirteenth Edition (Walker et al. 1984); they were then double checked to make sure they had been entered correctly.

Generation of daughter radionuclides is governed by the Bateman equations, found for example in Stephenson (1958). These equations were programmed in dBASE to yield the decayed nuclide inventory. Several simplifications were noted. First, if a daughter nuclide has a very short half-life, a few days or less, then every atom created will quickly decay. Because curies are proportional to disintegrations per second and because every disintegration of the parent results in an almost immediate disintegration of the daughter, the activity in curies of the daughter equals the activity of the parent. Second, in many cases the activity of the daughter was very small, either because there was little of the parent originally present, or because either the parent or the daughter, or both, decayed slowly. We did not generate daughters with activity less than 2 Ci. Such cases show the daughter as "negl" in Table 1. As a result of these two simplifications, only the first daughter's activity ever needed to be calculated from the Bateman equations, and this only needed to be done for six nuclides. The most striking case is Pu-241, which decays to Am-241 and yields more Am-241 than was originally present.

The activity calculations were verified and validated as follows. The dBASE program HC_Decay.prg was written by Schlafman and then examined by Atwood to ensure that the equations had been correctly encoded. Test cases were run and checked by hand calculations; these cases checked both the decay of nuclides and the summing of activities from different inventories. Finally, to check that the

Bateman equations had been correctly understood and used, the results were compared to results from RadDecay (1987), a public-domain computer program. The results were close, but not exact. Exact agreement cannot be expected because the half-lives in RadDecay are not identical to those used for this project. The above exercise also validated most of H_Decay.prg and C_Decay.prg, described below, because the major portion of all three programs is a call to a single decay procedure.

The only other nontrivial calculation was for shipment volume, because RWMIS reports individual container volumes, often mixing units within a shipment. Test cases were run for the dBASE program that finds the total volume of each shipment. The results agreed with hand calculations.

dBASE Programs

The following programs were used to calculate original and decayed activities and write the data base file information into ASCII text files which were used by the Fortran and SAS programs. The programs were written using the FoxPro 2.0 software. Since no FoxPro-specific commands were used in these programs, the programs could be compiled and run in dBASEIV software.

Verify.prg - The program calculates the totals of all numeric fields in RWMIS download files, checks for matching shipment identifiers in the download files, and calculates record counts for the files. The information is then compared to the values calculated in RWMIS to ensure the data was downloaded correctly.

HC_Decay.prg - The program calculates the original and decayed activities for each nuclide for all shipments in the Historical and Current RWMIS data. It uses information in the Container and Nuclide data files and in the file HC_Nuc.dbf, all described below. It replaces the original and decayed activities in HC_Nuc.dbf, and writes the information to HC_Decay.txt, which was imported electronically to produce Table 1 of this report.

HC_Decay.prg was run first with no generation of daughters. Then each nuclide was individually decayed for the average time described below, using the public domain program RadDecay, to see if more than 2 Ci of a daughter would be generated. If it would, the decay equations for the nuclide were added to HC_Decay.prg, H_Decay.prg, and C_Decay.prg. At the end of this investigation, HC_Decay.prg was rerun to produce a final version of HC_Decay.txt for Table 1.

Ave_time - This takes the original and decayed total activity in HC_Nuc.dbf, (based on many shipments on many dates) and finds a single time span which would have produced the same decay. It enters this "average time" in HC_Nuc.dbf.

This average time was used in simple calculations to determine, for each nuclide, if more than 2 Ci of the daughter would be generated. If it would, the equations for generation of that daughter were programmed into HC_Decay.prg, H_Decay.prg, and C_Decay.prg.

H_Decay.prg - The program calculates the decayed activities for the Historical RWMIS data for each individual shipment. It uses the data files HistNuc.dbf and HistCont.dbf, and writes the decayed activities and the other RWMIS information required to H_Decay.txt. This text file containing the individual shipment information is read by the Fortran programs. For each shipment, it modifies the curies in HC_Nuc.dbf.

C_Decay.prg - The program calculates the decayed activities for the Current RWMIS data for each individual shipment and writes this information and the other RWMIS information required to C_Decay.txt. The individual shipment information is then read by the Fortran programs. Note: The only difference between C_Decay.prg and H_Decay.prg is the RWMIS data file and field names.

RWMIS Download Data Files

Each RWMIS download consists of three files: the Master file, Container file, and Nuclide file. The Master file contains shipment total information such as total shipment curies. No data from this file was used in this study. The Container file contains information by groupings of containers within shipments. The Nuclide file contains information about the individual nuclides in each shipment. Each RWMIS download file contains six key fields which are used to identify unique shipments and relate the information between files. The key fields are generating area, waste type, radioactivity, on/off site, report date, and report time.

CurMstr.dbf

HistMstr.dbf - Only used in verification of RWMIS download.

CurNuc.dbf

HistNuc.dbf - The RWMIS download data base file of the nuclide information. Information used from this file consists of the key fields, nuclide identifier, and nuclide curie amount.

CurCont.dbf

HistCont.dbf - The RWMIS download data base file of the container information. Information used from this file consists of the key fields, disposal location, container volume, volume units, and number of containers.

Other Data Base Files

HC_Nuc.dbf - The data base file contains the nuclide identifier, half-life, original curies, decayed curies, transuranic information, α -emitter information, β/γ -emitter information, fissionable information, daughter product, and average time. Immediately after the file has been modified by HC_Decay.prg, the information is used to produce Table 1. The file is also

modified by Ave_time.prg, H_Decay.prg, and C_Decay.prg. An additional field for the inhalation dose conversion factor was not used for this study but has been added for possible future studies.

- Hold.dbf - The data base file is used in the H_Decay.prg and C_Decay.prg to hold the nuclide identifier, report date, and nuclide curie amount for individual shipments. This file is a temporary file which holds one shipment's information to be used in the decay calculation. The file is cleared and populated for each shipment.

For future studies the following should be considered. The download request could include only the fields and files that are used, which would save disk space. The RWMIS totals of the numeric fields and the number of records downloaded should be requested in order to verify the download. Verify.prg was created to verify a download with all three RWMIS files with all of the fields. Minor modifications to the Verify.prg would be required to verify a subset of the data. The RWMIS download field names should be checked to ensure that they match the fields hardcoded in the programs.

Any nuclide identifiers that were not used in this study, but are required for the next study, will need to be entered in the HC_Nuc.dbf with the related information about the nuclide. After the original and decayed curves had been calculated, Ave_time.prg calculated the average decay time and placed this number in the nuclide average time field in HC_Nuc.dbf. The average time and original decay were then entered into the RadDecay application to obtain information about which nuclides would have daughter products with activity greater than 2 curies. In the future, this process would only be required to find the daughter products for nuclides that were not in the present study or that had large increases in activities. Finally, for this study the inhalation dose conversion factors were added manually to a text file. For possible future studies they have been added to the data base HC_Nuc.dbf.

The dBASE programs are given here.

```

*****
* Program: HC_Decay
*
* This application was written to find total original
* and decayed activities of each nuclide in the study.
*
*****
set decimals to 18
set talk off
set echo off
set safety off
set exclusive on

Public db_file, db_nuc, db_curie

*** This section was written since the file names and fields
*** are different in the Historical and Current data.

select a
use hc_nuc
index on nuc_id2 tag nuc_id

*** HC_Nuc is the data base file which holds the unique nuclide identifiers from the Historical and Current
data. If this program
*** is used with a different data set, any nuclides from that data set which are not in this file would need
to be included.
*** The half-lives and daughter for additional nuclides would also need to be included.

replace all decaycurie with 0, orig_curie with 0

@10,10 say "Calculations for Historical Data"
do decay with 'histnuc', 'nuc_id271', 'nuc_cur271','des_loc'

@12,10 say "Calculations for Current Data"
do decay with 'currnuc', 'nuc_id2', 'nuc_cur2','des_loc0'

select hc_nuc
set order to nuc_id
copy to hc_decay.txt type sdf

close all
clear all

Return

*****
* Procedure Decay
*
* This procedure totals the original activities and
* calculates and totals the decayed activities.
*
* Parameters: db_file - Data base file name (different files for Historical and CURRENT)
*             db_nuc - Nuclide Identifier field name in the data base file
*             db_curie- Nuclide Activity field name in the data base file
*             db_loc - Location field name in data base file
*
*****
Procedure Decay

Parameter db_file, db_nuc, db_curie, db_loc

select e
use &db_file alias nuc_file
go top

do while not eof()

```

```

do while substr(&db_loc,1,3) $'BGP PAD'
  skip
enddo

m_nucid      = &db_nuc
days_elaps  = ctod('02/17/93') - sreport_dt
*days_elaps = date() - sreport_dt
m_act       = &db_curie

&& nuclide fields are named differently
&& 02/17/93 was the date used in study
&& For current date used to decay half life
&& curie field names are different in the files

select hc_nuc
set order to nuc_id
seek alltrim(m_nucid)

if found()
  m_cur = orig_curie + m_act
  if alltrim(m_nucid) = 'MFP'
    && For this study MFP is half Sr90 and half Cs137
    cs137_hl = val('1.100E+04')
    sr90_hl  = val('1.062E+04')
    m_cs_cur = .5*m_act*.5**(days_elaps/cs137_hl) && Decay Calculation for Cs137 part
    m_sr_cur = .5*m_act*.5**(days_elaps/sr90_hl) && Decay Calculation for Sr90 part
    m_hl_cur = m_cs_cur + m_sr_cur
  else
    m_hl_cur = m_act*.5**(days_elaps/val(half_life)) && Decay Calculation
  endif
  replace orig_curie with m_cur, decaycurie with decaycurie + m_hl_cur

  m_daughter = daughter && Get name of daughter
  parnt_half = half_life && Save parent half-life

  *** Case Statement below is used to separate the few nuclides which required different
  *** calculations for their daughter products.

do case
  case 'U-232' = alltrim(m_nucid)
    ** The daughter products Th-228 Ra-224 Rn-220 Po-216 Bi-212 Pb-212 for U-232 all had the
    ** same resulting activity. Tl208 and Po212 had activities which were the
    ** the fractional value below. The values were obtained from the RADDECAY program.

    go top
    seek m_daughter
    l1 = log(2)/val(parnt_half)
    l2 = log(2)/val(half_life)

    m_hl_cur = (l2 * m_act/(l2 - l1))*(exp(-l1 * days_elaps) - exp(-l2 * days_elaps))

    replace decaycurie with decaycurie + m_hl_cur for ;
    alltrim(nuc_id2)$'TH-228 RA-224 RN-220 PO-216 BI-212 PB-212'
    replace decaycurie with decaycurie + .3593*m_hl_cur for alltrim(nuc_id2) = 'TL-208'
    replace decaycurie with decaycurie + .6407*m_hl_cur for alltrim(nuc_id2) = 'PO-212'

  *case 'U-238' = alltrim(m_nucid)
  * ** Needed special case since 2 daughter products
  * replace decaycurie with decaycurie + m_hl_cur for alltrim(nuc_id2) $ 'TH-234 PA-234M'

  case 'MFP' = alltrim(m_nucid)
    ** Needed separate decay calculations for Cs137 and Sr90 parts of MFP
    go top
    seek 'CS-137'
    m_daughter = daughter
    parnt_half = half_life
    go top
    seek m_daughter
    l1 = log(2)/val(parnt_half)
    l2 = log(2)/val(half_life)

    m_hl_cur = decaycurie +(l2 * (.5* m_act)/(l2 - l1)) ;
    * (exp(-l1 * days_elaps) - exp(-l2 * days_elaps))
    replace decaycurie with m_hl_cur

```

```

go top
seek 'SR-90'
m_daughter = daughter
parnt_half = half_life
go top
seek m_daughter
l1 = log(2)/val(parnt_half)
l2 = log(2)/val(half_life)

m_hl_cur = decaycurie + (l2 * (.5* m_act)/(l2 - l1)) ;
              * (exp(-l1 * days_elaps) - exp(-l2 * days_elaps))
replace decaycurie with m_hl_cur

case not alltrim(m_daughter) $ 'STABLE NEGL *1 *2'
** Any nuclide with a single daughter product calculation would use this section
go top
seek alltrim(m_daughter) && find the daughter product information and do the calculation
if found()

    l1 = log(2)/val(parnt_half)
    l2 = log(2)/val(half_life)

    m_hl_cur = decaycurie + (l2 * m_act/(l2 - l1)) ;
              * (exp(-l1 * days_elaps) - exp(-l2 * days_elaps))

    replace decaycurie with m_hl_cur
else
    set print on
    ? "No halflife information for: "+m_nucid && Print Nuclides not found in the data base
    set print off
endif

endcase
else
    set print on
    ? "No halflife information for: "+m_nucid && Print Nuclide if not found in file
    set print off
endif

select nuc_file
skip
enddo
select nuc_file
use
Return

```

```

*****
* Program Ave_time
*
* Calculates average time since arrival of nuclide
*
*****

set decimal to 18
select a
use hc_nuc

do while not eof()
    if decaycurie/orig_curie > 0
        time = -1*(val(half_life)/.693)*log(decaycurie/orig_curie)
        replace ave_time with time
    endif

```

```
        skip
    enddo
```

```
*****
```

```
* Program: H_Decay
```

```
*
```

```
* This application was written to find original and decayed
```

```
* activities of each nuclide for each shipment in the Historical
```

```
* RWMIS data and put this information along with disposal
```

```
* locations and container volumes in to a text file (h_decay.txt).
```

```
*
```

```
*****
```

```
set exclusive on
```

```
set talk off
```

```
set echo off
```

```
set safety off
```

```
set console off
```

```
set decimals to 18
```

```
Mgl_to_ft = 231/1728
```

```
select a
```

```
use histnuc
```

```
*index on sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) tag histnuc
```

```
select d
```

```
use hc_nuc
```

```
select b
```

```
use histcont
```

```
*index on sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) tag histcont
```

```
set order to histcont
```

```
go top
```

```
set alter to h_decay.txt
```

```
set alter on
```

```
do while not eof()
```

```
    do while substr(des_loc171,1,3) '$BGP PAD'
```

```
        skip
```

```
    enddo
```

```
    ?? sarea71
```

```
    ?? ' '
```

```
    ?? sreport_dt
```

```
    ?? ' '
```

```
    ?? sreport_ti
```

```
    ?? ' '
```

```
    ?? substr(des_loc171,1,3)
```

```
    ?? ' '
```

```
    old_key = sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti)
```

```
    ship_vol = 0
```

```
    select histcont
```

```
    do while old_key = sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) ;  
        and not eof()
```

```
        if substr(des_loc171,1,3) '$BGP PAD'
```

```
            skip
```

```
        endif
```

```
***** Calculate Shipment Volume *****
```

```

if type_cont1 = 'BLX'          &&RWMIS container type BLX is entered as 10 * the volume
  If vol_unit17 = "K"
    ship_vol = ship_vol + (no_cont171*(cont_vol17/10)*Mgl_to_ft)
  EndIf
  If vol_unit17 = "F"
    ship_vol = ship_vol + (no_cont171*(cont_vol17/10))
  EndIf
else
  If vol_unit17 = "K"
    ship_vol = ship_vol + (no_cont171*cont_vol17*Mgl_to_ft)
  EndIf
  If vol_unit17 = "F"
    ship_vol = ship_vol + (no_cont171*cont_vol17)
  EndIf
endif
skip
enddo

?? str(ship_vol,13,3)

*****

select c
use hold
zap

select histnuc
set order to histnuc
seek old_key
do while old_key = sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) ;
  and not eof()
  scatter memvar

  select hold
  append blank
  replace nuc_id with m.nuc_id271, sreport_dt with m.sreport_dt, nuc_cur with m.nuc_cur271

  select histnuc
  skip
enddo
select hold
use
***** Calculate Decayed Curie Amounts *****

select hc_nuc
index on nuc_id2 tag nuc_id
replace all decaycurie with 0, orig_curie with 0

do decay with 'hold', 'nuc_id', 'nuc_cur', 'des_loc171' in hc_decay

select hc_nuc
go top
do while not eof()
  if decaycurie > 0
    ?? ' '
    ?? nuc_id2
    ?? ' '
    ?? decaycurie
  endif
  skip
enddo
?
select histcont

enddo
set console on

```



```

set alter off
set alter to
return

```

```

*****

```

```

* Program: C_Decay

```

```

*

```

```

* This application was written to find original and decayed
* activities of each nuclide for each shipment in the Current
* RWMIS data and put this information along with disposal
* locations and container volumes in to a text file (C_decay.txt).
*

```

```

*****

```

```

set exclusive on
set talk off
set echo off
set safety off
set console off
set decimals to 18

```

```

Mgl_to_ft = 231/1728

```

```

select a
use curnuc
*index on sarea + swaste_tp + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) tag curnuc
*index on sarea71 + swaste_tp7 + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) tag curnuc

```

```

select b
use curcont
*index on sarea + swaste_tp + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) tag curcont

```

```

select d
use hc_nuc

```

```

select curcont
set order to curcont
go top

```

```

set alter to c_decay.txt

```

```

set alter on

```

```

do while not eof()
  do while substr(des_loc1,1,3) '$BGP PAD'
    skip
  enddo

```

```

  ?? sarea

```

```

  ?? ' '

```

```

  ?? sreport_dt

```

```

  ?? ' '

```

```

  ?? sreport_ti

```

```

  ?? ' '

```

```

  ?? substr(des_loc1,1,3)

```

```

  ?? ' '

```

```

  old_key = sarea + swaste_tp + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti)

```

```

  ship_vol = 0

```

```

  select curcont

```

```

  do while old_key = sarea + swaste_tp + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti) ;
    and not eof()

```

```

    if substr(des_loc1,1,3) '$BGP PAD'

```

```

      skip

```

```

    endif

```

```

***** Calculate Shipment Volume *****
if type_cont1 = 'BLX' &&RWMIS container type BLX is entered as 10 * the volume
  If vol_unit1 = "K"
    ship_vol = ship_vol + (no_cont1*(cont_vol1/10)*Mgl_to_ft)
  EndIf
  If vol_unit1 = "F"
    ship_vol = ship_vol + (no_cont1*(cont_vol1/10))
  EndIf
else
  If vol_unit1 = "K"
    ship_vol = ship_vol + (no_cont1*cont_vol1*Mgl_to_ft)
  EndIf
  If vol_unit1 = "F"
    ship_vol = ship_vol + (no_cont1*cont_vol1)
  EndIf
endif

skip
enddo

?? str(ship_vol,13,3)

*****
select c
use hold
zap

select curnuc
set order to curnuc
seek old_key
do while old_key = sarea + swaste_tp + sradio_act + sonoff_sit + dtoc(sreport_dt) + str(sreport_ti)
  scatter memvar

  select hold
  append blank
  replace nuc_id with m.nuc_id2, sreport_dt with m.sreport_dt, nuc_cur with m.nuc_cur2

  select curnuc
  skip
enddo
select hold
use
***** Calculate Decayed Curie Amounts *****

select hc_nuc
index on nuc_id2 tag nuc_id
replace all decaycurie with 0, orig_curie with 0

do decay with 'hold', 'nuc_id', 'nuc_cur', 'des_loc1' in hc_decay
select hc_nuc
go top
do while not eof()
  if decaycurie > 0
    ?? ' '
    ?? nuc_id2
    ?? ' '
    ?? decaycurie
  endif
  skip
enddo
?
select curcont

enddo
set console on
set alter off
set alter to
return

```

FORTRAN PROGRAMS TO SUMMARIZE DATA AND GET NORMALIZED ACTIVITIES

Three programs were used to read the output of the dBASE programs and prepare files for SAS to analyze. One program, PREP, wrote files for classes of nuclides, such as TRU nuclides, α -emitters, and fissionable nuclides. The second, PREPI, wrote files for the individual nuclides. The third, PREPD, wrote inhalation doses for the shipments. The programs were compiled using the Lahey (1992) Fortran compiler, but they are written in ANSI standard Fortran, except for the use of lower case for debug lines, and so should run with any modern compiler. The only problem might be with the number of files simultaneously open.

Other short Fortran programs were used: TALLY summarizes the data, as presented in Table 2. PNZERO calculates the probability that a random cubic foot would contain non-zero activity of the class of interest; these probabilities are shown in Tables 4 through 11.

Two inputs for the programs were H_Decay.txt and C_Decay.txt, created by the dBASE programs. A third input for the program is nucinf.dat, a file modified from HC_Decay.txt, which was created by the dBASE program HC_Decay.prg. HC_Decay.txt was turned into nucinf.dat by electronically moving columns, and by manually adding the inhalation dose conversion factors. These conversion factors (rem/ μ Ci), give the committed effective dose equivalent (C.E.D.E.). They are taken from DOE/EH-0071 (1988). That report lists factors for all the nuclides in the decayed RWMIS inventory except for Ba-137m, Kr, the Po isotopes 212 through 218, Rh-106, Rn, and Tl-208. These isotopes have only small activities in the decayed RWMIS data set. The factors were copied to the file nucinf.dat by John Poloski and C. Atwood. When there were several factors, corresponding to different possible retention periods or chemical forms, the maximum listed value was used. Atwood then proofread the file nucinf.dat, finding and correcting four errors. Only the high-activity isotopes are important for this study; including factors for all the isotopes does not change Table 11 at all, but could be important if the inventory were different. The file nucinf.dat is shown below as Table A1.

PREP, PREPI, PREPD, and TALLY were all run first using only the first ten shipments of the Historic Data and the first ten shipments of the Current Data. The output, including intermediate output printed for debugging purposes, was examined, and was found to be correct: the nuclides in the data bases were tallied, the mCi/cu-ft and (for fissionable nuclides) mg/Cu-ft and (for shipments) rem/cu-ft were calculated correctly, and everything was summed correctly and written to the proper files. Then the programs were run with the debug print statements turned off, and using the entire data base. The file for Y-90 (the last of the nuclides with high enough activity to be treated individually) was examined; it was seen that the first and last instances of Y-90 in both the Historic and Current data sets were correctly written to the Y-90 file. The output from PNZERO was checked in a few cases and found to be correct; this program only computes ratios of volumes, and so is easy to check.

The output file from TALLY was edited slightly with a text editor, and transferred electronically into Table 2 of this report. The output from PNZERO was entered manually into Tables 4 through 10, and every entry was checked on a later day. Out of 78 entries, 2 errors were found and corrected.

Table A1 and the Fortran programs are listed here.

Table A1. The file nucinf.dat

AC-227	7.947E+03	.F.	.F.	.F.	0.04079081028	6.7e+3
AM-241	1.580E+05	.T.	.T.	.T.	89781.13529897256	5.2e+2
AM-242M	5.146E+04	.T.	.T.	.F.	0.00030014875	5.1e+2
AM-243	2.690E+06	.T.	.T.	.F.	0.37986297170	5.2e+2
BA-137M	1.771E-03	.F.	.F.	.F.	2245.77511697818	0.
BI-212	4.205E-02	.F.	.F.	.F.	26.55180072599	2.1e-2
BI-214	1.375E-02	.F.	.F.	.F.	0.00000000000	6.3e-3
BK-249	3.200E+02	.F.	.F.	.F.	0.00057094575	1.3e00
C-14	2.091E+06	.F.	.F.	.F.	0.00004224624	2.1e-3
CE-144	2.850E+02	.F.	.F.	.F.	27.06352985230	3.5e-1
CF-249	1.281E+05	.T.	.T.	.F.	0.00972888594	5.5e+2
CF-252	9.636E+02	.F.	.T.	.F.	0.00407666951	1.3e+2
CM-242	1.630E+02	.F.	.T.	.F.	0.00000143566	1.7e+1
CM-243	1.040E+04	.T.	.T.	.F.	0.01530852458	3.5e+2
CM-244	6.606E+03	.F.	.T.	.T.	538.99248475109	2.7e+2
CM-246	1.744E+06	.T.	.T.	.F.	0.00152990262	5.4e+2
CM-248	1.241E+08	.T.	.T.	.F.	0.00000004170	1.9e+3
CO-58	7.090E+01	.F.	.F.	.F.	0.00000011008	7.1e-3
CO-60	1.930E+03	.F.	.F.	.F.	94.30234207016	1.5e-1
CR-51	2.770E+01	.F.	.F.	.F.	0.00000000000	2.6e-4
CS-134	7.540E+02	.F.	.F.	.F.	110.74067620797	4.7e-2
CS-137	1.100E+04	.F.	.F.	.F.	2003.00961321957	3.2e-2
EU-150	5.250E-01	.F.	.F.	.F.	0.00000000000	2.7e-1

EU-152	4.928E+03	.F.	.F.	.F.	0.06756042914	2.2e-1
EU-154	3.135E+03	.F.	.F.	.F.	0.71041973487	2.6e-1
EU-155	1.719E+03	.F.	.F.	.F.	0.18629208191	3.9e-2
FE-55	9.970E+02	.F.	.F.	.F.	1.13167058750	2.6e-3
FE-59	4.450E+01	.F.	.F.	.F.	0.00000000000	1.5e-2
H-3	4.490E+03	.F.	.F.	.F.	0.79779881007	6.3e-5
KR-85	3.906E+03	.F.	.F.	.F.	6.85660232651	0.
MAP	1.930E+03	.F.	.F.	.F.	1.28001878301	1.5e-1
MFP	1.100E+04	.F.	.F.	.F.	483.32117589191	6.66e-1
MN-54	3.120E+02	.F.	.F.	.F.	0.22870126168	6.4e-3
NB-95	3.500E+01	.F.	.F.	.F.	0.00000000000	4.5e-3
NI-63	3.650E+04	.F.	.F.	.F.	3.57242150533	6.3e-3
NP-237	7.811E+08	.T.	.T.	.T.	0.35519815316	4.9e+2
PA-233	2.700E+01	.F.	.F.	.F.	0.00000000000	8.6e-3
PB-210	8.140E+03	.F.	.F.	.F.	0.01755985982	1.3e+1
PB-212	4.433E-01	.F.	.F.	.F.	26.55180072599	1.6e-1
PB-214	1.861E-02	.F.	.F.	.F.	0.00000000000	6.7e-3
PM-147	9.563E+02	.F.	.F.	.F.	27.25851802530	3.4e-2
PO-212	4.606E-12	.F.	.T.	.F.	17.01173872514	0.
PO-214	1.895E-09	.F.	.T.	.F.	0.00000000000	0.
PO-216	1.736E-06	.F.	.T.	.F.	26.55180072599	0.
PO-218	2.160E-03	.F.	.T.	.F.	0.00000000000	0.
PR-144	1.200E+00	.F.	.F.	.F.	27.17796338233	4.2e-5
PU-236	1.040E+03	.F.	.T.	.F.	0.01478722382	1.6e+2
PU-238	3.201E+04	.T.	.T.	.T.	60802.74635717693	4.6e+2
PU-239	8.796E+06	.T.	.T.	.T.	40146.41832407012	5.1e+2
PU-240	2.394E+06	.T.	.T.	.F.	9825.29565579516	5.1e+2
PU-241	5.256E+03	.F.	.F.	.T.	161122.35948397170	1.0e+1
PU-242	1.369E+08	.T.	.T.	.F.	0.94505422615	4.8e+2
RA-224	3.660E+00	.F.	.T.	.F.	26.55180072599	2.9e00
RA-226	5.840E+05	.F.	.T.	.F.	0.04789760836	7.9e00
RA-228	2.102E+03	.F.	.F.	.F.	0.03061790908	4.2e00
RH-106	3.461E-04	.F.	.F.	.F.	0.00000000000	0.
RN-220	6.435E-04	.F.	.T.	.F.	26.55180072599	0.
RN-222	3.820E+00	.F.	.T.	.F.	0.00000000000	0.
RU-106	3.723E+02	.F.	.F.	.F.	0.18652829809	4.4e-1
SB-125	1.007E+03	.F.	.F.	.F.	1.64659464414	9.8e-3
SR-90	1.062E+04	.F.	.F.	.F.	1777.53891178629	1.3e00
TA-182	1.140E+02	.F.	.F.	.F.	0.00001547961	3.7e-2
TC-99	7.774E+07	.F.	.F.	.F.	0.00175990688	7.5e-3
TH-228	6.982E+02	.F.	.T.	.F.	26.55180072599	3.1e+2
TH-230	2.752E+07	.F.	.T.	.F.	0.01998005181	3.2e+2
TH-232	5.110E+12	.F.	.T.	.F.	0.33011775515	1.6e+3
TH-234	2.410E+01	.F.	.F.	.F.	0.00000000000	3.3e-2
TL-208	2.120E-03	.F.	.F.	.F.	9.54006200085	0.
U-228	6.319E-03	.F.	.T.	.F.	0.00000000000	0.
U-232	2.555E+04	.F.	.T.	.F.	26.04479556052	6.7e+2
U-233	5.840E+07	.F.	.T.	.T.	898.50468890707	1.3e+2
U-234	8.979E+07	.F.	.T.	.F.	5.77791004370	1.3e+2
U-235	2.570E+11	.F.	.T.	.T.	0.06668774161	1.2e+2
U-236	8.541E+09	.F.	.T.	.F.	0.00119942767	1.2e+2
U-238	1.632E+12	.F.	.T.	.F.	0.11706389623	1.2e+2
UN-10-B+G	1.100E+04	.F.	.F.	.F.	12.44449056014	3.2e-2
Y-90	2.670E+00	.F.	.F.	.F.	2018.60244723459	8.2e-3
ZN-65	2.440E+02	.F.	.F.	.F.	0.00000001868	1.8e-2
ZR-95	6.400E+01	.F.	.F.	.F.	0.00000000234	1.9e-2

PROGRAM PREP

C
C Reads text-file from dBASE message of RWMIS download,
C and normalizes by cubic foot
C

```

C   WRITTEN BY C. ATWOOD, Feb-Mar 1993
C
C   IMPLICIT REAL(A-H,O-Z), INTEGER(I-N)

C****hardwired NNUCS, KLOC, NBOR, NGRP
PARAMETER(NGRP=5, NBMAX = 45, NTHREE = 3,
+         KLOC=2, NORMAX=30, NNUCS=79, NBOR=7 )

CHARACTER*3 LOC, LOCA(KLOC), OR, ORA(NORMAX), BORA(NBOR)
CHARACTER*6 PART
CHARACTER*13 NUCA(NNUCS), NUCT(NBMAX), NUCGRP(NGRP),
+         NUCFIS(NTHREE), NUCBLK
DOUBLE PRECISION CIPF(NNUCS), CIT(NBMAX), GPF(NNUCS),
+         CITOT, CITRU, CINOT, CIALF, CIBEG,
+         GTOT, GTRU, GNOT, CITOTS(NGRP),
+         GTOTS(NTHREE)
EQUIVALENCE (CITOTS(1),CITOT),(CITOTS(2),CITRU),(CITOTS(3),CINOT),
+         (CITOTS(4),CIALF),(CITOTS(5),CIBEG), (GTOTS(1),GTOT),
+         (GTOTS(2),GTRU), (GTOTS(3),GNOT)

C   CITOTS array is equivalent to (CITOT, CITRU, CINOT, CIALF, CIBEG)
C   GTOTS array is equivalent to (GTOT, GTRU, GNOT)

DIMENSION TOTACT(NNUCS), ATNO(NNUCS),
+         HALF(NNUCS), IORM(NORMAX)
LOGICAL TRU(NNUCS), ALF(NNUCS), FIS(NNUCS), BIGACT
logical debug

C   CIPF = mCi/cu-ft, ACT = Ci
DATA NUCGRP/' All',' TRU',' non-TRU',' Alpha',' Beta-gamma'/
DATA NUCFIS/' All Fis',' TRU Fis',' non-TRU Fis'/
DATA LOCA/'TSA','ILT'/
DATA BORA/'ALE','ANL','BET','CPP','MRC','RFO','WMC'/
DATA NUCBLK/' '/
DATA IGBASE/6/,IFBASE/11/,ILBASE/14/,IOBASE/16/

C   Anyone who modifies this program should then run it with
C   debug=.true. before trying it with debug=.false.
C   Setting debug=.true. limits the analysis to 20 shipments, and
C   generates lots of printout for those shipments.
data debug/.false./

C   Statement function defining "big" activities
BIGACT(N) = TOTACT(N) .GT. 2.

C   CITOG * Activ(in mCi) * Halflife(in d) * Atomic number = Mass(in g)
CITOG = (2.798E-9) / 365.24

OPEN (UNIT=6,FILE='mdebug.prp')
OPEN (UNIT=4,FILE='nucinf.dat')

DO 20 N=1,NNUCS
C   Get nuclide name, half-life (d), properties and total activity
C   The file 4 is a massaged version of Table 1 in Atwood & Schlafman

C   If health effects were to be included, this would be a good place
C   to input the health effect of each nuclide, as a multiplier of
C   activity in curies.
READ(4,*) NUCA(N), HALF(N), TRU(N), ALF(N), FIS(N),
+         TOTACT(N)

C   Get atomic numbers from the nuclide names
c   if(debug) write(6,(' nuca(n)=' ,a) ) nuca(n)
READ(NUCA(N),'(A6)') PART
c   if(debug) write(6,(' part=' ,a) ) part
IF(PART.EQ.'LES-TH') THEN
C   Arbitrary atomic number
ATNO(N) = 100
ELSE IF (PART.EQ.'MAP ' ) THEN
C   Treat as Co-60

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      ATNO(N) = 60
      ELSE IF (PART.EQ.'MFP  ') THEN
C      Treat as half Sr-90, half Cs-137
      ATNO(N) = 113.5
      ELSE IF (PART.EQ.'UN-ID-') THEN
C      Treat as Cs-137
      ATNO(N) = 137
      ELSE
      IF(PART(3:3).EQ.'-') THEN
      READ(PART,'(3X,F3.0)') ATNO(N)
      ELSE
      READ(PART,'(2X,F3.0)') ATNO(N)
      ENDIF
      ENDIF
20  CONTINUE

      CLOSE (4)
c      if(debug) then
c      do 30 n=1,nnucs
c      write(6,25) nuca(n), atno(n)
c 25  format(' nuc, atno ',a,f10.1)
c 30  continue
c      endif

      DO 950 IRUN=1,2
C      Do this in 2 passes because Lahey Fortran with DOS restricts
C      number of simultaneous open files
      IF(IRUN.EQ.1) THEN
      IRBASE = 6
      IRMANY = 8
      IRTOP = IRBASE + IRMANY
C      The above terms say that there are 8 files, going from
C      unit=6+1 to unit=6+8. This is used in loops 520 and 530.
C*****hardwired output file names
      OPEN (UNIT=7,FILE='k:\cla\poloski\all.prp',RECL=80)
      OPEN (UNIT=8,FILE='k:\cla\poloski\tru.prp',RECL=80)
      OPEN (UNIT=9,FILE='k:\cla\poloski\not.prp',RECL=80)
      OPEN (UNIT=10,FILE='k:\cla\poloski\alph.prp',RECL=80)
      OPEN (UNIT=11,FILE='k:\cla\poloski\bega.prp',RECL=80)
      OPEN (UNIT=12,FILE='k:\cla\poloski\fis.prp',RECL=80)
      OPEN (UNIT=13,FILE='k:\cla\poloski\truf.prp',RECL=80)
      OPEN (UNIT=14,FILE='k:\cla\poloski\notf.prp',RECL=80)
      DO 40 I=1,NGRP
      IUN = IRBASE + I
      WRITE(IUN,'(A)') NUCGRP(I)
40  CONTINUE
      DO 45 I=1,NTHREE
      IUN = IRBASE + I
      WRITE(IUN,'(A)') NUCFIS(I)
45  CONTINUE
      ELSE IF(IRUN.EQ.2) THEN
      IRBASE = IRTOP
      IRMANY = 9
      IRTOP = IRBASE + IRMANY
C*****hardwired output file names
      OPEN (UNIT=15,FILE='k:\cla\poloski\loc1.prp',RECL=80)
      OPEN (UNIT=16,FILE='k:\cla\poloski\loc2.prp',RECL=80)
      OPEN (UNIT=17,FILE='k:\cla\poloski\orig1.prp',RECL=80)
      OPEN (UNIT=18,FILE='k:\cla\poloski\orig2.prp',RECL=80)
      OPEN (UNIT=19,FILE='k:\cla\poloski\orig3.prp',RECL=80)
      OPEN (UNIT=20,FILE='k:\cla\poloski\orig4.prp',RECL=80)
      OPEN (UNIT=21,FILE='k:\cla\poloski\orig5.prp',RECL=80)
      OPEN (UNIT=22,FILE='k:\cla\poloski\orig6.prp',RECL=80)
      OPEN (UNIT=23,FILE='k:\cla\poloski\orig7.prp',RECL=80)
      DO 50 I=1,KLOC
      IUN = IRBASE + I
      WRITE(IUN,'(A)') LOCA(I)
50  CONTINUE

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```

DO 55 I=1,NBOR
  IUN = IOBASE + I
  WRITE(IUN,'(A)') BORA(I)
55  CONTINUE
ENDIF

ILO = 1
IHI = 2
DO 900 IFILE=ILO,IHI
C*****hardwired file names!
C      From inspection of the files, I know that in the file there are
C      at most NWITHN nuclides in any shipment. The information for
C      each nuclide occupies 35 columns, and there are 38 columns of
C      other information. That's how we determine the max record length.
  IF(IFILE.EQ.1) THEN
    NWITHN = 23
    LRC = 38 + 35*NWITHN
    OPEN (UNIT=5,FILE='m:\jpp1\h_decay.txt',RECL=LRC)
  ELSE IF(IFILE.EQ.2) THEN
    NWITHN = 28
    LRC = 38 + 35*NWITHN
    OPEN (UNIT=5,FILE='m:\jpp1\c_decay.txt',RECL=LRC)
  ENDIF

  if(debug) line = 0
100  CONTINUE
  if(debug .and. line.ge.10) go to 800
  IF(IFILE.EQ.1)
    +   READ(5,110,END=800) OR,LOC,VOL,
    +   (NUCT(I),CIT(I),I=1,NWITHN)
  IF(IFILE.EQ.2)
    +   READ(5,111,END=800) OR,LOC,VOL,
    +   (NUCT(I),CIT(I),I=1,NWITHN)

C*****hardwired formats!
C      The number 23 or 28 is NWITHN from above.
110  FORMAT(A3,18X,A3,F14.3,23(1X,A13,F21.11))
111  FORMAT(A3,18X,A3,F14.3,28(1X,A13,F21.11))
      NF1000 = NINT(1000*VOL)

C      How many nuclides do we find in this shipment?
      NFOUND = 0
      DO 120 I=1,NWITHN
        IF(NUCT(I).EQ.NUCBLK) GO TO 125
        NFOUND = NFOUND + 1
120    CONTINUE
125    CONTINUE
      if(debug) line = line + 1
      if(debug) then
        write(6,130) or, loc, vol, (nuct(i), cit(i),i=1,nfound)
130    format(1x,a,1x,a,1x,f12.3/(1x,a,f25.11) )
      endif

C      The two locations are ILTSF and everything else
      ILOC = 1
      IF(LOC .EQ. 'ILT') ILOC = 2

      DO 230 IOR=1,KOR
        IF(OR .EQ. ORA(IOR) ) GO TO 260
230    CONTINUE
        KOR = KOR + 1
        IF(KOR.GT.NORMAX) THEN
          WRITE(6,'(' Set NORMAX >' ,I3)' ) NORMAX
          STOP
        ENDIF
        IOR = KOR
        ORA(IOR) = OR
C      Set up mapping to compressed array of locations
      IORM(IOR) = 0

```



```

DO 240 I=1,NBOR
  IF(BORA(I).NE.OR) GO TO 240
  IORM(IOR) = I
  GO TO 260
240    CONTINUE
260    CONTINUE

  if(debug) write(6,('' above loop 320'')) )
DO 320 N=1,NNUCS
  CIPF(N) = 0
  GPF(N) = 0
320    CONTINUE
  CITOT = 0

C      If health effects are to be included, initialize them to zero
C      in loop-320, and calculate them in loop 360.
DO 360 I=1,NFOUND
  CITOT = CITOT + CIT(I)
DO 350 N=1,NNUCS
  IF(NUCT(I) .NE. NUCA(N)) GO TO 350
  Successfully read nuclide name in data
  CIPF is mCi/cu-ft, and GPF is g/cu-ft.
  CIPF(N) = 1000*CIT(I)/VOL
  IF(FIS(N)) GPF(N) = CIPF(N)*CITOG*HALF(N)*ATNO(N)
  GO TO 360
350    CONTINUE
  WRITE(6,355) NUCT(I), OR, LOC
355    FORMAT(' Error: ',A,' not found. ',A)
360    CONTINUE
  CITOT = 1000*CITOT/VOL
  IF(CITOT.EQ.0) GO TO 100

C      Sum activities for TRU, non-TRU, alpha, beta-gamma,
C      by loc, by orig, and fissile

  CITRU = 0
  CINOT = 0
  CIALF = 0
  CIBEG = 0
  GTOT = 0
  GTRU = 0
  GNOT = 0

C      Recall CIPF(N) is mCi/cu-ft in the current shipment,
C      for Nth nuclide in list of all nuclides in RWMIS
C      GPF is similar, but g/cu-ft

  if(debug) write(6,('' above loop 500'')) )
DO 500 N=1,NNUCS
  IF(TRU(N)) THEN
    CITRU = CITRU + CIPF(N)
  ELSE
    CINOT = CINOT + CIPF(N)
  ENDIF
  IF(ALF(N)) THEN
    CIALF = CIALF + CIPF(N)
  ELSE
    CIBEG = CIBEG + CIPF(N)
  ENDIF
  IF(FIS(N)) THEN
    GTOT = GTOT + GPF(N)
    IF(TRU(N)) THEN
      GTRU = GTRU + GPF(N)
    ELSE
      GNOT = GNOT + GPF(N)
    ENDIF
  ENDIF
500    CONTINUE
  if(debug) then

```

```

+       write(6,502) citot,citru,cinot,cialf,cibeg,
+           (citots(i),i=1,5)
+       write(6,503) gtot,gtru,gnot,(gtots(i),i=1,3)
502     format(' citot,citru,cinot,cialf,cibet',5g20.10/
+           ' citots(1)...citots(5)           ',5g20.10)
503     format(' gtot,gtru,gnot',3g20.10/
+           ' gtots(1)...(3)',3g20.10)
+
endif

C       Recall the equivalence of the arrays CITOTS and GTOTS to the
C       quantities calculated in the loop-500. That means we can
C       code the WRITE statements by looping through arrays.
510     FORMAT(10,1X,E12.5)
      DO 520 I=1,NGRP
        IUN = IGBASE + I
        IF((IUN.GT. IRBASE) .AND. (IUN.LE. IRTOP) .AND.
+         (CITOTS(I).GT.0) ) WRITE(IUN,510) NF1000, CITOTS(I)
520      CONTINUE
      DO 530 I=1,NTHREE
        IUN = IFBASE + I
        IF((IUN.GT. IRBASE) .AND. (IUN.LE. IRTOP) .AND.
+         (GTOTS(I).GT.0) ) WRITE(IUN,510) NF1000, GTOTS(I)
530      CONTINUE

C       For consistency with the other files, I suppose I should
C       have written a separate file for each location or origin
C       total, or TRU total, or non-TRU total (7x3=21 files).
C       Instead, I wrote 7 files with 3 columns each, and used
C       missing values (coded as '.') for values that are zero.
      IUN = ILBASE+ILOC
      IF(IUN.GT. IRBASE .AND. IUN.LE. IRTOP) THEN
        IF(CITRU.GT.0 .AND. CINOT.GT.0) THEN
          WRITE(IUN,540) NF1000, CITOT, CITRU, CINOT
        ELSE IF(CITRU.GT.0) THEN
          WRITE(IUN,545) NF1000, CITOT, CITRU
        ELSE IF(CINOT.GT.0) THEN
          WRITE(IUN,550) NF1000, CITOT, CINOT
        ENDIF
      ENDIF
      IF(IORM(IOR).NE.0) THEN
        IUN = IOBASE + IORM(IOR)
        IF(IUN.GT. IRBASE .AND. IUN.LE. IRTOP) THEN
          IF(CITRU.GT.0 .AND. CINOT.GT.0) THEN
            WRITE(IUN,540) NF1000, CITOT, CITRU, CINOT
          ELSE IF(CITRU.GT.0) THEN
            WRITE(IUN,545) NF1000, CITOT, CITRU
          ELSE IF(CINOT.GT.0) THEN
            WRITE(IUN,550) NF1000, CITOT, CINOT
          ENDIF
        ENDIF
      ENDIF
      ENDIF
540     FORMAT(10,3(1X,E12.5))
545     FORMAT(10,2(1X,E12.5),7X,'.')
550     FORMAT(10,1X,E12.5,7X,'.',6X,E12.5)

      GO TO 100

800     CONTINUE
C       End of input file.
      CLOSE(5)
900     CONTINUE

      DO 910 I=1,IRMANY
910       CLOSE(IRBASE + I)

950     CONTINUE
      CLOSE(6)
      END

```

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PROGRAM PREPI
C
C Reads text-file from dBASE message of RWMIS download,
C and normalizes by cubic foot
C Writes individual isotopes to files of different lengths,
C for SAS
C This is a modification of PREP. See comments there.
C
C WRITTEN BY C. ATWOOD, Feb 1993
C
IMPLICIT REAL(A-H,O-Z), INTEGER(I-N)

C*****hardwired NNUCS
PARAMETER(NBMAX=45, NFMAX=10, NNUCS=79 )

CHARACTER*3 LOC, OR
CHARACTER*6 PART
CHARACTER*13 NUCA(NNUCS), NUCT(NBMAX), NUCBLK
DOUBLE PRECISION CIPF(NNUCS), CIT(NBMAX), GPF
C CIPF = mCi/cu-ft, CIT is Ci, GPF = g/cu-ft

DIMENSION IBIG(NNUCS), IFIS(NNUCS), TOTACT(NNUCS), ATNO(NNUCS),
+ HALF(NNUCS)
LOGICAL TRU, ALF, FIS(NNUCS), BIGACT
logical debug

DATA NUCBLK/' '/

C*****check file counts!
C IFBASE + 1 is first output file,
C IIBASE + 1 is first nonfissile output file
C This data statement is for 6 fissile nuclides > 2 Ci
DATA IFBASE/6/,IIBASE/12/
C Anyone who modifies this program should then run it with
C debug=.true. before trying it with debug=.false.
C Setting debug=.true. limits the analysis to 20 shipments, and
C generates lots of printout for those shipments.
C data debug/.false./

C Statement function defining "big" activities
BIGACT(N) = TOTACT(N) .GT. 2.

C CITOG * Activ(in mCi) * Halflife(in d) * Atomic number = Mass(in g)
CITOG = (2.798E-9) / 365.24

OPEN (UNIT=6,FILE='midbg.prp')
OPEN (UNIT=4,FILE='nucinf.dat')

DO 20 N=1,NNUCS
C Get nuclide name, half-life (d), properties and total activity
READ(4,*) NUCA(N), HALF(N), TRU, ALF, FIS(N), TOTACT(N)

C Get atomic numbers
if(debug) write(6, '(' nuca(n)=' ',a' ) nuca(n)
READ(NUCA(N), '(A6)') PART
if(debug) write(6, '(' part=' ',a' ) part
IF(PART.EQ.'LES-TH') THEN
C Arbitrary atomic number
ATNO(N) = 100
ELSE IF (PART.EQ.'MAP ') THEN
C Treat as Co-60
ATNO(N) = 60
ELSE IF (PART.EQ.'MFP ') THEN
C Treat as half Sr-90, half Cs-137
ATNO(N) = 113.5
ELSE IF (PART.EQ.'UN-ID-') THEN
C Treat as Cs-137

```

```

        ATNO(N) = 137
    ELSE
        IF(PART(3:3) .EQ. '-') THEN
            READ(PART,'(3X,F3.0)') ATNO(N)
        ELSE
            READ(PART,'(2X,F3.0)') ATNO(N)
        ENDIF
    ENDIF
20    CONTINUE

    CLOSE (4)
    if(debug) then
        do 30 n=1,nnucs
            write(6,25) nuca(n), atno(n)
25        format(' nuc, atno ',a,f10.1)
30        continue
    endif

C    Set up mapping to compressed array of fissile nuclides
    NBIGF=0
    DO 40 N=1,NNUCS
        IF(FIS(N) .AND. BIGACT(N)) THEN
            NBIGF = NBIGF + 1
            IFIS(N) = NBIGF
        ELSE
            IFIS(N) = 0
        ENDIF
        if(debug) write(6,'('' ifis('',i2,'')='',i3)' ) n, ifis(n)
40    CONTINUE
    IF(NBIGF.GT.NFMAX) THEN
        WRITE(6,45) NFMAX
45    FORMAT(' Error. Set NFMAX >', I4)
        STOP
    ENDIF

C    Set up mapping to compressed array of nuclides
    NBIG=0
    DO 50 N=1,NNUCS
        IF(BIGACT(N)) THEN
            NBIG = NBIG + 1
            IBIG(N) = NBIG
        ELSE
            IBIG(N) = 0
        ENDIF
        if(debug) write(6,'('' ibig('',i2,'')='',i3)' ) n, ibig(n)
50    CONTINUE
    IF(NBIG.GT.NBMAX) THEN
        WRITE(6,55) NBMAX
55    FORMAT(' Error. Set NBMAX >', I4)
        STOP
    ENDIF

    DO 950 IRUN=1,3
C    Do this in 3 runs, because Lahey Fortran with DOS only
C    allows 20 files open at a time
        IF(IRUN.EQ.1) THEN
            IRBASE = 6
            IRMANY = 13
            IRTOP = IRBASE + IRMANY
C*****hardwired output file names
C*****order of nuclides must match nuclides > 2 Ci in nucinf.dat
C*****first the fissile nuclides, then all nuclides
            OPEN (UNIT=7,FILE='k:\cla\poloski\am241f.prp',RECL=80)
            OPEN (UNIT=8,FILE='k:\cla\poloski\cm244f.prp',RECL=80)
            OPEN (UNIT=9,FILE='k:\cla\poloski\pu238f.prp',RECL=80)
            OPEN (UNIT=10,FILE='k:\cla\poloski\pu239f.prp',RECL=80)
            OPEN (UNIT=11,FILE='k:\cla\poloski\pu241f.prp',RECL=80)
            OPEN (UNIT=12,FILE='k:\cla\poloski\u233f.prp',RECL=80)
            OPEN (UNIT=13,FILE='k:\cla\poloski\am241.prp',RECL=80)

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OPEN (UNIT=14,FILE='k:\cla\poloski\ba137m.prp',RECL=80)
OPEN (UNIT=15,FILE='k:\cla\poloski\bi212.prp',RECL=80)
OPEN (UNIT=16,FILE='k:\cla\poloski\ce144.prp',RECL=80)
OPEN (UNIT=17,FILE='k:\cla\poloski\cm244.prp',RECL=80)
OPEN (UNIT=18,FILE='k:\cla\poloski\co60.prp',RECL=80)
OPEN (UNIT=19,FILE='k:\cla\poloski\cs134.prp',RECL=80)

DO 60 N=1,NNUCS
  IF(IFIS(N).GT. 0) THEN
    IUN = IFBASE + IFIS(N)
    IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
      WRITE(IUN,'(1X,A)' ) NUCA(N)
      if(debug) write(6,
+       '('' ifis('',i2,'')='',i3,9x,a)' )
+       n, ifis(n), nuca(n)
    )
  )
  ENDF
ENDIF
60 CONTINUE
if(debug) write(6,'('' above loop 65'')' )
DO 65 N=1,NNUCS
  IF(IBIG(N).GT. 0) THEN
    IUN = IIBASE + IBIG(N)
    IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
      WRITE(IUN,'(1X,A)' ) NUCA(N)
      if(debug) write(6,
+       '('' ibig('',i2,'')='',i3,9x,a)' )
+       n, ibig(n), nuca(n)
    )
  )
  ENDF
ENDIF
65 CONTINUE

ELSE IF(IRUN.EQ.2) THEN
  IRSASE = IRTOP
  IRMANY = 13
  IRTOP = IRBASE + IRMANY
c*****hardwired output file names
OPEN (UNIT=20,FILE='k:\cla\poloski\cs137.prp',RECL=80)
OPEN (UNIT=21,FILE='k:\cla\poloski\kr85.prp',RECL=80)
OPEN (UNIT=22,FILE='k:\cla\poloski\mfp.prp',RECL=80)
OPEN (UNIT=23,FILE='k:\cla\poloski\ni63.prp',RECL=80)
OPEN (UNIT=24,FILE='k:\cla\poloski\pb212.prp',RECL=80)
OPEN (UNIT=25,FILE='k:\cla\poloski\pm147.prp',RECL=80)
OPEN (UNIT=26,FILE='k:\cla\poloski\po212.prp',RECL=80)
OPEN (UNIT=27,FILE='k:\cla\poloski\po216.prp',RECL=80)
OPEN (UNIT=28,FILE='k:\cla\poloski\pr144.prp',RECL=80)
OPEN (UNIT=29,FILE='k:\cla\poloski\pu238.prp',RECL=80)
OPEN (UNIT=30,FILE='k:\cla\poloski\pu239.prp',RECL=80)
OPEN (UNIT=31,FILE='k:\cla\poloski\pu240.prp',RECL=80)
OPEN (UNIT=32,FILE='k:\cla\poloski\pu241.prp',RECL=80)

DO 70 N=1,NNUCS
  IF(IFIS(N).GT. 0) THEN
    IUN = IFBASE + IFIS(N)
    IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
      WRITE(IUN,'(1X,A)' ) NUCA(N)
      if(debug) write(6,
+       '('' ifis('',i2,'')='',i3,9x,a)' )
+       n, ifis(n), nuca(n)
    )
  )
  ENDF
ENDIF
70 CONTINUE
DO 75 N=1,NNUCS
  IF(IBIG(N).GT. 0) THEN
    IUN = IIBASE + IBIG(N)
    IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
      WRITE(IUN,'(1X,A)' ) NUCA(N)
      if(debug) write(6,
+       '('' ibig('',i2,'')='',i3,9x,a)' )
+       n, ibig(n), nuca(n)
    )
  )

```

```

        ENDIF
    ENDIF
75    CONTINUE

ELSE IF(IRUN.EQ.3) THEN
    IRBASE = IRTOP
    IRMANY = 10
    IRTOP = IRBASE + IRMANY
c*****hardwired output file names
    OPEN (UNIT=33,FILE='k:\cla\poloski\ra224.prp',RECL=80)
    OPEN (UNIT=34,FILE='k:\cla\poloski\rn220.prp',RECL=80)
    OPEN (UNIT=35,FILE='k:\cla\poloski\sr90.prp',RECL=80)
    OPEN (UNIT=36,FILE='k:\cla\poloski\th228.prp',RECL=80)
    OPEN (UNIT=37,FILE='k:\cla\poloski\tl208.prp',RECL=80)
    OPEN (UNIT=38,FILE='k:\cla\poloski\u232.prp',RECL=80)
    OPEN (UNIT=39,FILE='k:\cla\poloski\u233.prp',RECL=80)
    OPEN (UNIT=40,FILE='k:\cla\poloski\u234.prp',RECL=80)
    OPEN (UNIT=41,FILE='k:\cla\poloski\unidbg.prp',RECL=80)
    OPEN (UNIT=42,FILE='k:\cla\poloski\y90.prp',RECL=80)

    DO 80 N=1,NNUCS
        IF(IFIS(N).GT. 0) THEN
            IUN = IFBASE + IFIS(N)
            IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
                WRITE(IUN,'(1X,A)') NUCA(N)
                if(debug) write(6,
+                   '(', ifis(' ',i2,'')=',' ,i3,9x,a) ' )
+                   n, ifis(n), nuca(n)
            ENDIF
        ENDIF
80    CONTINUE
    DO 85 N=1,NNUCS
        IF(IBIG(N).GT. 0) THEN
            IUN = IIBASE + IBIG(N)
            IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP) THEN
                WRITE(IUN,'(1X,A)') NUCA(N)
                if(debug) write(6,
+                   '(', ibig(' ',i2,'')=',' ,i3,9x,a) ' )
+                   n, ibig(n), nuca(n)
            ENDIF
        ENDIF
85    CONTINUE

    ENDIF

    ILO = 1
    IHI = 2
    if(debug) write(6,'(' above loop 900')' )
    DO 900 IFILE=ILO,IHI
c*****hardwired input file names!
        IF(IFILE.EQ.1) THEN
            NWITHN = 23
            LRC = 38 + 35*NWITHN
            OPEN (UNIT=5,FILE='m:\jpp1\h_decay.txt',RECL=LRC)
        ELSE IF(IFILE.EQ.2) THEN
            NWITHN = 28
            LRC = 38 + 35*NWITHN
            OPEN (UNIT=5,FILE='m:\jpp1\c_decay.txt',RECL=LRC)
        ENDIF

        if(debug) line = 0
100    CONTINUE
        if(debug .and. line.ge.10) go to 800
        IF(IFILE.EQ.1)
+           READ(5,110,END=800) OR,LOC,VOL,
+           (NUCT(I),CIT(I),I=1,NWITHN)
        IF(IFILE.EQ.2)
+           READ(5,111,END=800) OR,LOC,VOL,
+           (NUCT(I),CIT(I),I=1,NWITHN)

```

```

C*****hardwired formats!
110    FORMAT(A3,18X,A3,F14.3,23(1X,A13,F21.11))
111    FORMAT(A3,18X,A3,F14.3,28(1X,A13,F21.11))
      NF1000 = NINT(1000*VOL)
      NFOUND = 0
      DO 120 I=1,NWITHN
        IF(NUCT(I).EQ.NUCBLK) GO TO 125
        NFOUND = NFOUND + 1
120    CONTINUE
125    CONTINUE
      if(debug) line = line + 1
      if(debug) then
        write(6,130) or, loc, vol, (nuct(i), cit(i),i=1,nfound)
130    format(1x,a,1x,a,1x,f12.3/(1x,a,f25.11) )
      endif

      if(debug) write(6,('' above loop 320'')) )
      DO 320 N=1,NNUCS
        CIPF(N) = 0
1320    CONTINUE
      DO 360 I=1,NFOUND
        DO 350 N=1,NNUCS
          IF(NUCT(I) .NE. NUCA(N)) GO TO 350
          Successfully read nuclide name in data
          Convert Ci to mCi/cu-ft
          CIPF(N) = 1000*CIT(I)/VOL
          GO TO 360
1350    CONTINUE
1355    WRITE(6,355) NUCT(I), OR, LOC
1360    FORMAT(' Error: ',A,' not found. ',A)
      CONTINUE

C      Put nuclides with large total activities in files
      if(debug) write(6,('' above loop 400'')) )
      DO 400 N=1,NNUCS
        IF(CIPF(N).EQ.0) GO TO 400
        IF(IBIG(N).GT.0) THEN
          if(debug) write(6,('' cipf('',i2,'')='',g14.6''))
          +      n,cipf(n)
          IUN = IIBASE + IBIG(N)
          IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP)
          +      WRITE(IUN,'(I10,E12.5)') NF1000, CIPF(N)
          ENDF
          IF(IFIS(N).GT.0) THEN
            GPF = CIPF(N)*CITOG*HALF(N)*ATNO(N)
            if(debug) write(6,('' gpf('',i2,'')='',g14.6''))
            +      n, gpf
            IUN = IFBASE + IFIS(N)
            IF(IUN.GT.IRBASE .AND. IUN.LE.IRTOP)
            +      WRITE(IUN,'(I10,E12.5)') NF1000, GPF
          ENDF
1400    CONTINUE

      GO TO 100

800    CONTINUE
C      End of input file.
      CLOSE(5)
900    CONTINUE

      DO 910 I=1,IRMAN
910    CLOSE(IRBASE + I)

950    CONTINUE

      CLOSE(6)

      END

```

```

PROGRAM PREPD
C
C Reads text-file from dBASE message of RWMIS download,
C   and normalizes by cubic foot
C Calculates dose from inhalation, based on dose conversion factors
C
C WRITTEN BY C. ATWOOD, Feb-Apr 1993
C
C IMPLICIT REAL(A-H,O-Z), INTEGER(I-N)

C*****hardwired NNUCS
PARAMETER(NBMAX = 45, NNUCS=79)

CHARACTER*3 LOC, OR
CHARACTER*13 NUCA(NNUCS), NUCT(NBMAX), NUCBLK
DOUBLE PRECISION CIT(NBMAX), DCFINH(NNUCS)

LOGICAL TRU, ALF, FIS
logical debug

DATA NUCBLK/'          '/

C Anyone who modifies this program should then run it with
C debug=.true. before trying it with debug=.false.
C Setting debug=.true. limits the analysis to 20 shipments, and
C generates lots of printout for those shipments.
C data debug/.false./

OPEN (UNIT=6,FILE='mdebug.prp')
OPEN (UNIT=4,FILE='nucinf.dat')

DO 20 N=1,NNUCS
C   Get nuclide name, other junk,
C   and DCFINH, the conversion factor for inhalation (rem/microCi)
C   The file 4 is a messaged version of Table 1 in Atwood & Schlafman

  READ(4,*) NUCA(N), HALF, TRU, ALF, FIS, TOTACT, DCFINH(N)
20  CONTINUE

CLOSE (4)

OPEN (UNIT=7,FILE='k:\cla\poloski\inhal.prp',RECL=80)
WRITE(7,('Inhalation effect (rem)'))

ILO = 1
IHI = 2
DO 900 IFILE=ILO,IHI
C*****hardwired file names!
C   From inspection of the files, I know that in the file there are
C   at most NWITHN nuclides in any shipment. The information for
C   each nuclide occupies 35 columns, and there are 38 columns of
C   other information. That's how we determine the max record length.
  IF(IFILE.EQ.1) THEN
    NWITHN = 23
    LRC = 38 + 35*NWITHN
    OPEN (UNIT=5,FILE='m:\jpp1\h_decay.txt',RECL=LRC)
  ELSE IF(IFILE.EQ.2) THEN
    NWITHN = 28
    LRC = 38 + 35*NWITHN
    OPEN (UNIT=5,FILE='m:\jpp1\c_decay.txt',RECL=LRC)
  ENDIF

  if(debug) line = 0
100 CONTINUE
  if(debug .and. line.ge.10) go to 800
  IF(IFILE.EQ.1)

```



```

+      READ(5,110,END=800) OR,LOC,VOL,
+      (NUCT(I),CIT(I),I=1,NWITHN)
      IF(IFILE.EQ.2)
+      READ(5,111,END=800) OR,LOC,VOL,
+      (NUCT(I),CIT(I),I=1,NWITHN)

C*****hardwired formats!
C      The number 23 or 28 is NWITHN from above.
110     FORMAT(A3,18X,A3,F14.3,23(1X,A13,F21.11))
111     FORMAT(A3,18X,A3,F14.3,28(1X,A13,F21.11))
      NF1000 = NINT(1000*VOL)

C      How many nuclides do we find in this shipment?
      NFOUND = 0
      DO 120 I=1,NWITHN
        IF(NUCT(I).EQ.NUCBLK) GO TO 125
        NFOUND = NFOUND + 1
120     CONTINUE
125     CONTINUE
      if(debug) line = line + 1
      if(debug) then
        write(6,130) or, loc, vol, (nuct(i), cit(i),i=1,nfound)
130     format(1x,a,1x,a,1x,f12.3/(1x,a,f25.11) )
      endif

C      Get dose for this shipment
      if(debug) write(6,(' above loop 360'))
      DOSINH = 0
      DO 360 I=1,NFOUND
        DO 350 N=1,NNUCS
          IF(NUCT(I) .NE. NUCA(N)) GO TO 350
          Successfully read nuclide name in data
          CIT is Ci, DCFINH is rem/microCi, DOSINH is megarem for now
          DOSINH = DOSINH + CIT(I)*DCFINH(N)
          if(debug) write(6,300) dcfinh(n), dosinh
300     format(' dcfinh, dosinh =',2g14.6)
          GO TO 360
350     CONTINUE
        WRITE(6,355) NUCT(I), OR, LOC
355     FORMAT(' Error: ',A,' not found. ',A)
360     CONTINUE

C      Convert DOSINH to rem/cu-ft
      DOSINH = (1.E6)*DOSINH/VOL
      if(debug) write(6,380) dosinh
380     format(' final dosinh =',g14.6,' rem/cu-ft')
510     FORMAT(I10,1X,E12.5)
      WRITE(7,510) NF1000, DOSINH

      GO TO 100

800     CONTINUE
C      End of input file.
      CLOSE(5)
900     CONTINUE

      CLOSE(7)
      CLOSE(6)
      END

```

PROGRAM TALLY

```

C
C      Reads text-file from dBASE message of RWMIS download
C      Counts shipments by originator, by location, and
C      by nuclide
C

```

C WRITTEN BY C. ATWOOD, March 1993
C

```

      IMPLICIT DOUBLE PRECISION(A-H,O-Z), INTEGER(I-N)
C*****hardwired NNUCS; it was a choice of that or hardwiring a format
C*****for the read in do-loop 10
      PARAMETER ( NORIGS=40, NNUCS=79, NNMAX=NNUCS, NLOCS=5, NWMAX=28)

      CHARACTER*3 OR, ORA(NORIGS), LOC, LOCA(NLOCS)
      CHARACTER*13 NUC(NNMAX), NUCT(NWMAX), NUCBLK
      CHARACTER*13 DECOMP(5)
      DIMENSION KNTO(NORIGS,3), KNTN(NNMAX), KNTL(NLOCS,3), KNTOTS(5),
+       KNTFIS(3)
      DIMENSION VOLO(NORIGS,3), VOLN(NNMAX), VOLL(NLOCS,3), VOLTOT(5),
+       VOLFIS(3)
      DIMENSION HALF(NNMAX)
      DOUBLE PRECISION CIN(NNMAX), CIO(NORIGS,3), CIL(NLOCS,3),
+       CIFIS(3), CITOTS(5),
+       CIT(NWMAX), TOTAC(NNMAX), DRCI, DROUND
      LOGICAL TRU(NNMAX), ALF(NNMAX), FIS(NNMAX)
      LOGICAL GOTTRU, GOTNOT, GOTALF, GOTBEG, GOTFIS, GOTTF, GOTNF

      logical debug
      data debug/.false./

      DATA KLOC/0/, KOR/0/
      DATA NUCBLK /'          '/
      DATA DECOMP /' Total',' TRU',' Non-TRU',' Alpha',' Beta/gamma'/

      OPEN (UNIT=7,FILE='decaym.tal')

      OPEN (UNIT=4,FILE='nucinf.dat')
      DO 10 N=1,NNUCS
C       Get nuclide name, half-life (d), properties and total activity
        READ(4,*) NUC(N), HALF(N), TRU(N), ALF(N), FIS(N),
+       TOTAC(N)
      10  CONTINUE

      if(debug) then
        do 18 n=1,nnucs
          write(7,17) nuc(n), half(n), totac(n)
      17   format(1x,a,e12.4,f28.11)
      18   continue
        endif

      DO 20 IORIG=1,NORIGS
      DO 20 I=1,3
        KNTO(IORIG,I) = 0
        VOLO(IORIG,I) = 0
        CIO (IORIG,I) = 0
      20  CONTINUE

      DO 30 N=1,NNUCS
        KNTN(N) = 0
        VOLN(N) = 0
        CIN(N) = 0
      30  CONTINUE

      DO 35 ILOC=1,NLOCS
      DO 35 I=1,3
        KNTL(ILOC,I) = 0
        VOLL(ILOC,I) = 0
        CIL(ILOC,I) = 0
      35  CONTINUE

      DO 40 I=1,5
        KNTOTS(I) = 0
        CITOTS(I) = 0
        VOLTOT(I) = 0

```

```

40    CONTINUE

      if(debug) write(7,(' Above loop 800'))
      DO 800 IFILE=1,2

C*****hardwired file names!
      IF(IFILE.EQ.1) THEN
        NWITHN = 23
        LRC = 38 + 35*NWITHN
        OPEN (UNIT=5,FILE='m:\jpp1\h_decay.txt',RECL=LRC)
      ELSE IF(IFILE.EQ.2) THEN
        NWITHN = 28
        LRC = 38 + 35*NWITHN
        OPEN (UNIT=5,FILE='m:\jpp1\c_decay.txt',RECL=LRC)
      ENDIF

      if(debug) line = 0
100    CONTINUE
      if(debug .and. line.ge.10) go to 800
      IF(IFILE.EQ.1)
+      READ(5,110,END=700) OR,LOC,VOL,(NUCT(I),CIT(I),I=1,NWITHN)
      IF(IFILE.EQ.2)
+      READ(5,111,END=700) OR,LOC,VOL,(NUCT(I),CIT(I),I=1,NWITHN)

C*****hardwired formats!
110    FORMAT(A3,18X,A3,F14.3,23(1X,A13,F21.11))
111    FORMAT(A3,18X,A3,F14.3,28(1X,A13,F21.11))
      NFOUND = 0
      DO 120 I=1,NWITHN
        IF(NUCT(I).EQ.NUCBLK) GO TO 125
        NFOUND = NFOUND + 1
120    CONTINUE
125    CONTINUE
      if(debug) line = line + 1
      if(debug) then
        write(7,130) or, loc, vol, (nuct(i), cit(i),i=1,nfound)
130    format(1x,a,1x,a,1x,f12.3/(1x,a,f25.11) )
      endif
      DO 200 ILOC=1,KLOC
        IF(LOC .EQ. LOCA(ILOC) ) GO TO 210
200    CONTINUE
        KLOC = KLOC + 1
        IF(KLOC.GT.NLOCS) THEN
          WRITE(7,(' Set NLOCS >',13) ) NLOCS
          STOP
        ENDIF
        ILOC = KLOC
        LOCA(ILOC) = LOC
210    CONTINUE

      DO 230 IOR=1,KOR
        IF(OR .EQ. ORA(IOR) ) GO TO 240
230    CONTINUE
        KOR = KOR + 1
        IF(KOR.GT.NORIGS) THEN
          WRITE(7,(' Set NORIGS >',13) ) NORIGS
          STOP
        ENDIF
        IOR = KOR
        ORA(IOR) = OR
240    CONTINUE

      KNTOT(1) = KNTOT(1) + 1
      KNTL(ILOC,1) = KNTL(ILOC,1) + 1
      VOLO(IOR,1) = VOLO(IOR,1) + VOL
      VOLL(ILOC,1) = VOLL(ILOC,1) + VOL
      KNTOTS(1) = KNTOTS(1) + 1
      VOLTOT(1) = VOLTOT(1) + VOL
      if(debug) write(7,(' above loop 250'))

```

260

```

DO 260 I=1,NFOUND
  CIO(IOR,1) = CIO(IOR,1) + CIT(I)
  CIL(ILOC,1) = CIL(ILOC,1) + CIT(I)
  CITOTS(1) = CITOTS(1) + CIT(I)
CONTINUE

GOTTRU = .FALSE.
GOTNOT = .FALSE.
GOTALF = .FALSE.
GOTBEG = .FALSE.
GOTFIS = .FALSE.
GOTTF = .FALSE.
GOTNF = .FALSE.
if(debug) write(7,(' above loop 300'))
DO 300 I=1,NFOUND
  DO 290 N=1,NNUCS
    IF(NUC(N).NE.NUCT(I)) GO TO 290
    KNTN(N) = KNTN(N) + 1
    CIN(N) = CIN(N) + CIT(I)
    VOLN(N) = VOLN(N) + VOL
    IF(STRU(N)) THEN
      IF(.NOT.GOTTRU) THEN
        KNTOTS(2) = KNTOTS(2) + 1
        VOLTOT(2) = VOLTOT(2) + VOL
        KNTOT(IOR,2) = KNTOT(IOR,2) + 1
        VOLOT(IOR,2) = VOLOT(IOR,2) + VOL
        KNTL(ILOC,2) = KNTL(ILOC,2) + 1
        VOLL(ILOC,2) = VOLL(ILOC,2) + VOL
      ENDIF
      GOTTRU = .TRUE.
      CITOTS(2) = CITOTS(2) + CIT(I)
      CIO(IOR,2) = CIO(IOR,2) + CIT(I)
      CIL(ILOC,2) = CIL(ILOC,2) + CIT(I)
    ELSE
      IF(.NOT.GOTNOT) THEN
        KNTOTS(3) = KNTOTS(3) + 1
        VOLTOT(3) = VOLTOT(3) + VOL
        KNTOT(IOR,3) = KNTOT(IOR,3) + 1
        VOLOT(IOR,3) = VOLOT(IOR,3) + VOL
        KNTL(ILOC,3) = KNTL(ILOC,3) + 1
        VOLL(ILOC,3) = VOLL(ILOC,3) + VOL
      ENDIF
      GOTNOT = .TRUE.
      CITOTS(3) = CITOTS(3) + CIT(I)
      CIO(IOR,3) = CIO(IOR,3) + CIT(I)
      CIL(ILOC,3) = CIL(ILOC,3) + CIT(I)
    ENDIF
    IF(ALF(N)) THEN
      IF(.NOT.GOTALF) THEN
        KNTOTS(4) = KNTOTS(4) + 1
        VOLTOT(4) = VOLTOT(4) + VOL
      ENDIF
      GOTALF = .TRUE.
      CITOTS(4) = CITOTS(4) + CIT(I)
    ELSE
      IF(.NOT.GOTBEG) THEN
        KNTOTS(5) = KNTOTS(5) + 1
        VOLTOT(5) = VOLTOT(5) + VOL
      ENDIF
      GOTBEG = .TRUE.
      CITOTS(5) = CITOTS(5) + CIT(I)
    ENDIF
    IF(FIS(N)) THEN
      IF(.NOT.GOTFIS) THEN
        KNTFIS(1) = KNTFIS(1) + 1
        VOLFIS(1) = VOLFIS(1) + VOL
      ENDIF
      GOTFIS = .TRUE.
      CIFIS(1) = CIFIS(1) + CIT(I)
    ENDIF
  END DO
END DO

```

```

        IF(TRY(N)) THEN
            IF(.NOT.GOTTF) THEN
                KNTFIS(2) = KNTFIS(2) + 1
                VOLFIS(2) = VOLFIS(2) + VOL
            ENDIF
            GOTTF = .TRUE.
            CIFIS(2) = CIFIS(2) + CIT(1)
        ELSE
            IF(.NOT.GOTNF) THEN
                KNTFIS(3) = KNTFIS(3) + 1
                VOLFIS(3) = VOLFIS(3) + VOL
            ENDIF
            GOTNF = .TRUE.
            CIFIS(3) = CIFIS(3) + CIT(1)
        ENDIF
    ENDIF
    GO TO 300
290    CONTINUE
    WRITE(7,295) NUCT(1)
295    FORMAT(' Unidentified nuclide: ',A)
300    CONTINUE

    GO TO 100
700    CONTINUE
    CLOSE (5)
800    CONTINUE
C    End of input. Write info.

    WRITE(7,(' Decayed RWMIS data, as of 2/17/93'))
    WRITE(7,('///'))

810    FORMAT(1X,A,5X,I8,' shipments ',F10.2,' cu-ft',F22.11,' Ci')

    DO 820 I=1,5
        RVOL = VOLTOT(I)
        DRCI = DROUND(CITOTS(I),4)
        WRITE(7,810) DECOMP(I), KNTOTS(I), RVOL, DRCI
820    CONTINUE

    WRITE(7,('///'))

    DO 850 N=1,NNUCS
        RVOL = VOLN(N)
        DRCI = DROUND(CIN(N),4)
        WRITE(7,810) NUC(N), KNTN(N), RVOL, DRCI
850    CONTINUE

    WRITE(7,('///'))
    DO 870 ILOC=1,KLOC
        WRITE(7,('A')) LOCA(ILOC)
        DO 860 I=1,3
            IF(KNTL(ILOC,I).EQ.0) GO TO 860
            RVOL = VOLL(ILOC,I)
            DRCI = DROUND(CIL(ILOC,I),4)
            WRITE(7,810) DECOMP(I), KNTL(ILOC,I), RVOL, DRCI
860        CONTINUE
870    CONTINUE

    WRITE(7,('///'))
    DO 900 IOR=1,KOR
        WRITE(7,('A')) ORA(IOR)
        DO 890 I=1,3
            IF(KNTO(IOR,I).EQ.0) GO TO 890
            RVOL = VOLO(IOR,I)
            DRCI = DROUND(CIO(IOR,I),4)
            WRITE(7,810) DECOMP(I), KNTO(IOR,I), RVOL, DRCI
890        CONTINUE
900    CONTINUE

```

```

WRITE(7,'(///)')
WRITE(7,'(' Fissile nuclides')' )
DO 910 I=1,3
  IF(KNTFIS(I).EQ.0) GO TO 910
  RVOL = VOLFIS(I)
  DRCI = DROUND(CIFIS(I),4)
  WRITE(7,810) DECOMP(I), KNTFIS(I), RVOL, DRCI
910  CONTINUE

985 CONTINUE
CLOSE(5)
990 CONTINUE

CLOSE(7)
END
DOUBLE PRECISION FUNCTION DROUND(X,N)

C  Rounds double precision number to N significant digits, for F printing
C  Must have 0 < N < 10 .

IMPLICIT DOUBLE PRECISION(A-H,O-Z), INTEGER(I-N)
CHARACTER*7 FMT
CHARACTER*16 STRING

IF(N.LE.0) THEN
  WRITE(6,'(' Illegal input to DROUND, N= ',15)') N
  DROUND = X
ELSE IF(N.LE.9) THEN
  WRITE(FMT,20) N
  FORMAT( '(E16.',11,')' )
  WRITE(STRING,FMT) X
  READ(STRING,*) DROUND
ELSE
  DROUND = X
ENDIF
RETURN
END

PROGRAM PNZERO

C
C  Reads output of TALLY, finds fraction of cu-ft (out of total cu-ft)
C  for each item whose empirical distribution is found
C
C  WRITTEN BY C. ATWOOD, March 1993
C

IMPLICIT REAL(A-H,O-Z), INTEGER(I-N)

CHARACTER*22 NAME
CHARACTER*1  MARKER, BLANK
DOUBLE PRECISION CUFT, DENOM, TOTACT, FRAC
LOGICAL FIRST
logical debug
data debug/.false./

DATA BLANK/' '/

OPEN (UNIT=5,FILE='decaym.tal')
OPEN (UNIT=6,FILE='pnzero.txt')

FIRST = .TRUE.
50  FORMAT(A,F22.11)
100 CONTINUE
  READ(5,110,END=700) NAME, MARKER, CUFT, TOTACT
110  FORMAT(A,7X,A,7X,F13.2,6X,F22.11)

```

```

        if(debug) write(6,110) name, marker, cuft, totact
        IF(MARKER .EQ. BLANK) THEN
C          Encountered blank line or header. Copy it.
          WRITE(6,'(A)') NAME
        ELSE IF(TOTACT .GT. 2) THEN
C          Encountered cubic feet of item with totact > 2
          IF(FIRST) THEN
            DENOM = CUFT
            FIRST = .FALSE.
          ENDIF
          FRAC = CUFT/DENOM
          WRITE(6,50) NAME, FRAC
        ENDIF
        GO TO 100

700 CONTINUE
CLOSE(5)
CLOSE(6)
END

```

SAS PROGRAMS TO OBTAIN EMPIRICAL DISTRIBUTIONS

Four SAS (1988) programs, differing only in small detail, were written for obtaining the quantiles of the empirical distribution. They are LOCOR, for the files produced by PREP giving data by storage location and by waste originator, FISSIL for the files produced by PREP and PREPI for the fissionable nuclides, ALLELSE for all other nuclide activities produced by PREPI, and DOSE for the committed effective dose equivalent. The SAS programs are reproduced below. When the input file was short, the program could be run under DOS on an IBM PS/2 Model 70 386. When the input file was long, it was necessary to run the program in an Ultrix environment on a DECstation 5500. Therefore, the files read by the programs were not precisely as shown here; files in directory k:\cla\poloski were located on the PC server, while files with no directory shown were located on the DECstation, and some programs were run both places to pick up the appropriate files.

Only a brief effort was deemed necessary for verifying and validating the SAS programs, because SAS is a widely used commercial package and the programs used here were short and simple. Nonetheless, the empirical distributions and maximum values found were compared with the data for some of the nuclides listed in Table 5, and the SAS results were consistent with the data. The SAS programs are listed here.

The output from SAS was not in a convenient format for electronic insertion into report tables. Therefore Atwood manually entered the empirical distributions into Tables 4 through 11. He proofread every number on a later day, finding and correcting 11 errors out of the 1132 entries.

```

/* Program LOCOR */
OPTIONS PAGESIZE=80 LINESIZE=120 ;
%MACRO empirm (ifile, ititl) ;
TITLE "Empirical distr for &ititl, mCi per cu-ft" ;
DATA dat ;
INFILE "&ifile" FIRSTOBS=2 ;
INPUT nf1000 all TRU nonTRU ;
/* nf1000 = 1000 x cu-ft in shipment
   the next three columns are for total activity, TRU activity, and
   non-TRU activity (mCi/cu-ft)
*/

PROC UNIVARIATE ;
  var all TRU nonTRU ;
  freq nf1000 ;
  OUTPUT pctlpts=10 20 30 40 50 60 70 80 90 98 99.5 99.9 ;
  pctlpre=all tru non ;
RUN ;

PROC PRINT ;
RUN ;

%MEND empirm ;

%empirm(loc1.prp,TSA)
%empirm(loc2.prp,ILTSF)
%empirm(orig1.prp,ALE)
%empirm(orig2.prp,ANL)
%empirm(orig3.prp,BET)
%empirm(orig4.prp,CPP)
%empirm(orig5.prp,MRC)
%empirm(orig6.prp,RFO)
%empirm(orig7.prp,WMC)

```

```

/* Program FISSIL */
OPTIONS PAGESIZE=80 LINESIZE=120 ;
%MACRO empirm (ifile, ititl) ;
TITLE "Empirical distr for &ititl, mg per cu-ft" ;
DATA dat ;
INFILE "&ifile..prp" FIRSTOBS=2 ;
INPUT nf1000 activ ;
/* nf1000 = 1000 x cu-ft in shipment
   activ is g/cu-ft
   act is mg/cu-ft
*/
act = activ*1000 ;

PROC UNIVARIATE ;
  var act ;
  freq nf1000 ;
  OUTPUT pctlpts=10 20 30 40 50 60 70 80 90 98 99.5 99.9 ;
  pctlpre=p ;
RUN ;

```

```

PROC PRINT ;
RUN ;

%MEND empirm ;

```

```

%empirm(fis,All Fissionable)
%empirm(truf,TRU Fissionable)
%empirm(notf,Non-TRU Fissionable)
%empirm(am241f,Am-241)
%empirm(cm244f,Cm-244)
%empirm(pu238f,Pu-238)
%empirm(pu241f,Pu-241)
%empirm(u233f,U-233)

```

```

/* Program ALLELSE */
OPTIONS PAGESIZE=80 LINESIZE=120 ;
%MACRO empirm (ifile, ititl) ;
TITLE "Empirical distr for &ititl, mCi per cu-ft" ;
DATA dat ;
INFILE "k:\cla\poloski\&ifile..prp" FIRSTOBS=2 ;
INPUT nf1000 activ ;
/* nf1000 = 1000 x cu-ft in shipment
   activ is mCi/cu-ft
*/

```

```

PROC UNIVARIATE ;
var activ ;
freq nf1000 ;
OUTPUT pctlpts=10 20 30 40 50 60 70 80 90 98 99.5 99.9 ;
pctlpre=p ;
RUN ;

```

```

PROC PRINT ;
RUN ;

%MEND empirm ;

```

```

%empirm(all,All)
%empirm(tru,TRU)
%empirm(not,Non-TRU)
%empirm(alph,Alpha)
%empirm(bega,Beta/Gamma)
%empirm(AM241,Am-241)
%empirm(BA137M,Ba-137M)
%empirm(BI212,Bi-212)
%empirm(CE144,Ce-144)
%empirm(CM244,Cm-244)
%empirm(CO60,Co-60)
%empirm(CS134,Cs-134)
%empirm(CS137,Cs-137)
%empirm(KR85,Kr-85)
%empirm(MFP,MFP)
%empirm(NI63,Ni-63)
%empirm(PA234M,Pa-234M)
%empirm(PB212,Pb-212)
%empirm(PM147,Pm-147)
%empirm(PO212,Po-212)
%empirm(PO216,Po-216)
%empirm(PR144,Pr-144)
%empirm(PU238,Pu-238)
%empirm(PU239,Pu-239)
%empirm(PU240,Pu-240)
%empirm(PU241,Pu-241)
%empirm(RA224,Ra-224)
%empirm(RN220,Rn-220)

```

```

%empirm(SR90,Sr-90)
%empirm(TH228,Th-228)
%empirm(TH234,Th-234)
%empirm(TL208,Tl-208)
%empirm(U232,U-232)
%empirm(U233,U-233)
%empirm(U234,U-234)
%empirm(U238,U-238)
%empirm(UNIDBG,UnidBG)
%empirm(Y90,Y-90)

```

```

/* Program DOSE */
OPTIONS PAGESIZE=80 LINESIZE=120 ;
%MACRO empirm (ifile,ititl) ;
TITLE "Empirical distr for &ititl, rem per cu-ft" ;
DATA dat ;
INFILE "&ifile..prp" FIRSTOBS=2 ;
INPUT nf1000 activ ;
/* nf1000 = 1000 x cu-ft in shipment
   activ is rem/cu-ft
*/

PROC UNIVARIATE ;
var activ ;
freq nf1000 ;
OUTPUT pctlpts=10 20 30 40 50 60 70 80 90 98 99.5 99.9
       pctlpre=p ;
RUN ;

PROC PRINT ;
RUN ;

%MEND empirm ;

%empirm(inhal,Inhalation)

```

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APPENDIX B: ANALYSIS METHODS TRIED

Several methods were attempted to analyze data for Pu-239 from Rocky flats. The results are described here. The more ambitious methods turned out to be unworkable for this restricted data set, and therefore were not attempted for the full RWMIS data. The method called Approach (4) below is the method used in the body of this report, except that the body of the report works with cubic feet instead of gallons.

Each shipment corresponds to one or more records in RWMIS. A record corresponds to a specified number of containers of a given size, for example six 55-gal containers. If the shipment contained various sizes of containers, there is at least one record for each container size. If the containers, even containers of the same size, contain different waste types, or if they are now stored at different locations, or if they differ in other ways deemed noteworthy, there can be many records for the containers, up to one record per container. However, the activity given for the shipment is not broken down by container, or even by record; instead, the only activity reported is the total activity for the shipment. The fundamental problem in analyzing the data is apportioning the total activity for a shipment among the containers.

FIRST TECHNIQUES TRIED

At first, consider shipments that only have one kind of container, such as only 55-gal drums, and estimate the moments of the distribution of the activity in a random container. Three approaches were tried:

- (1) Assume that all the containers within a shipment have exactly the same activity. This assumption gives an estimated activity for each container. The resulting distribution of activities is the empirical distribution.
- (2) Assume that the containers of one type are generated by a process, which produces variability both between shipments and between containers within a shipment. Manipulation of formulas (not shown here) then yields

unbiased estimators of the mean and the variance of the process.

- (3) Some consecutive shipments have exactly the same inventory per container. Call these groups of shipments "super-shipments," and treat them the way shipments are treated in Approach (2). In the Current Data, there are 17,000 shipments but only 10,000 super-shipments; many individual containers are listed as separate shipments, and apparently a single estimated activity was often deliberately used for many such containers officially listed as in different shipments.

The three approaches yield the same estimate of the mean activity, and different variances. Approach (1) gives the smallest estimated variance, because it sets the variability within shipments to zero, and Approach (3) gives the largest. The magnitude of the difference is suggested by the following examples: For containers from Rocky Flats in the Current Data, we have

<u>55-gal Drums</u>		
<u>Approach</u>	<u>Rel. s.d.</u>	<u>Basis</u>
(1)	2.40	16568 containers
(2)	2.61	13891 shipments
(3)	3.76	6743 super-shipments

<u>112-cu-ft Containers</u>		
<u>Approach</u>	<u>Rel. s.d.</u>	<u>Basis</u>
(1)	1.21	3149 containers
(2)	1.35	2529 shipments
(3)	1.36	2497 super-shipments

The next natural step is to try to fit a parametric distribution. The mean and variance, estimated above, can be used to estimate the parameters; this works very neatly when fitting a gamma distribution, because the parameters of a gamma distribution are simple functions of the mean and variance. Alternatively, two quantiles of the empirical distribution can be used to fit a two-parameter distribution; this works very neatly when fitting a lognormal distribution or a truncated lognormal.

PROBLEMS WITH THE FIRST TECHNIQUES

Parametric fits do not necessarily work well. Neither a gamma nor a

lognormal distribution gives a good fit to the Rocky Flats (RFO) Current Data for 55-gal drums or for 112-cu-ft containers. (For each data set the theoretical tails are too long, or equivalently, the observed tails are too short.) A truncated lognormal fits the 55-gal drum data, but nothing has been found that fits the 112-cu-ft container data. Therefore, the empirical distribution seems to be the only option for a general method. Unfortunately, if the model of Approach (2) or (3) is correct, the empirical distribution understates the variance somewhat.

The approaches (1)-(3) are designed for shipments that have only one kind of container. However, some shipments contain several kinds of containers (in the Historical Data, not in the Current Data). This is not a trivial issue. For example, in the Historical Data, RFO generated ninety-four 30-gal barrels. Not one of these barrels came in a shipment of only 30-gal barrels; instead, every one came in a shipment with many 55-gal barrels. Typically a shipment contained one 30-gal barrel and thirty-five 55-gal barrels, or else two 30-gal barrels and seventy 55-gal barrels. This makes it impossible to infer the distribution of activities of RFO 30-gal barrels without making some assumption about the relation of the contents of the two kinds of containers. Typically, the two kinds of containers in one shipment contained qualitatively different waste.

In addition to the main generators and the main container types, there are numerous other generators and container types. For example, there is one container from CFA, one from CPP, etc.; similarly, there is one 378-cu-ft container, one 2-gal container, etc. This is not a serious methodological problem, but it is a nuisance if we try to obtain a separate distribution for each container type or each generator.

NEXT TECHNIQUES TRIED, AND ULTIMATELY USED

- (4) Assume that each shipment is homogeneous, and obtain the empirical distribution of activity per gallon. This allows us to deal with shipments containing a variety of container types. One could work with the gallon or the cubic foot as the basic unit; the gallon is smaller, and

therefore better avoids the problem of shipments with fractional units.

This approach yields the correct overall mean per gallon. It underestimates the variance because it uses the empirical distribution, based on the assumption that each shipment is perfectly homogeneous. To simulate a container using this method, draw a random activity per gallon from the distribution, then multiply that activity by the number of gallons in the container.

To increase the estimated variance, consider a fifth approach:

- (5) Assign different activities to otherwise identical containers within a shipment, so that the total activity is the activity reported by RWMIS, and the individual activities follow a uniform distribution. (The uniform distribution is chosen for simplicity. To make it as wide as possible, given the mean activity, let the lower limit be zero, and therefore let the upper limit be twice the mean.)

When Approach (5) was followed for every shipment with the Pu-239 data, the resulting file had one line per container, and was too large to be manageable on a PS/2 Model 70 with a PS/2 Model 80 Server. If instead it was done only for the shipments with relatively large activity (shipments with multiple containers and mean activity/gallon > 2 mCi/gal), the data file was tripled in length, but could still be analyzed by SAS on a DEC workstation. The resulting distribution differed only moderately from the empirical distribution, as shown below.

Overall distribution of Pu-239, mCi/gal

<u>Value of Pu-239 (mCi/gal)</u>		<u>Cumulative Probability</u>
<u>Approach (4)</u>	<u>Approach (5)</u>	
0.	0.	0.0
0.000082	0.000083	0.10
0.00886	0.00886	0.20
0.0265	0.0265	0.30
0.206	0.206	0.40
0.619	0.596	0.50
0.930	0.876	0.60
1.34	1.19	0.70
2.41	1.88	0.80
5.16	5.02	0.90
15.4	17.9	0.98

23.2	31.1	0.995
91.5	92.2	0.999
220.	220.	1.000

The empirical distribution, from Approach (4), has mean 2.098 mCi/gal and standard deviation 6.257 mCi/gal. The distribution modified by Approach (5) has the same mean, and standard deviation 6.417 mCi/gal. The modification does not differ enough from the empirical distribution to be worth the effort.

The theoretically correct version of Approach (5) would not use the uniform distribution, but instead would use the conditional distribution of the container activities, conditional on the sum of the activities, and estimated by using the empirical distribution for the unconditional distribution. Though theoretically correct, this method would be extremely difficult to implement. Therefore the uniform distribution was used instead of the conditional distribution. The uniform distribution is symmetrical, unlike the presumably skewed conditional distribution, and has a smaller relative standard deviation. Use of the uniform distribution results in only modest changes from the empirical distribution; use of the theoretically correct conditional distribution would probably result in greater changes, but it is not known how great.

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