Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424
Telex 24-5454

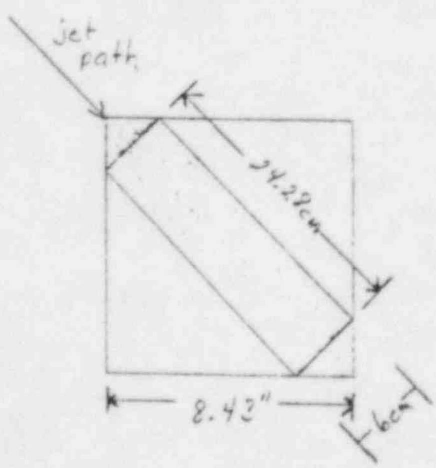
September 10, 1982

Mr. Carl B. Sawyer
Division of Safeguards, NMSS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Carl:

Enclosed are three copies of the draft report on Task 3 of the program entitled "Analysis of Safeguards Needs for Transport of High Level Waste". It contains the revisions we have discussed over the past few days. Other drafts can now be discarded without loss of information.

In our telephone conversation earlier today, you asked about two points: (1) the name of the reference shaped charge, which is M3-A1, and (2) the volume of spent fuel disrupted shown in Table 2.7, 742.5 cm^3. I believe that value is correct. The diagram from which it is calculated is shown below.



shaded area represents disrupted fuel

If you have further questions, please call me.

Sincerely,

Audeen Walters

Audeen Walters

AW:erc

xc: Mary Jo Mattia, NRC ✓
Office of the Director, NMSS

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TASK THREE REPORT

on

RANK ORDERING OF WASTE TYPES ACCORDING TO
PUBLIC HEALTH CONSEQUENCES

and

TASK 4 AND 5 PLANNING

to

U.S. NUCLEAR REGULATORY COMMISSION

(Contract No. NRC-02-81-030)

September, 1982

by

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Onio 43201

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TASK THREE REPORT

on

RANK ORDERING OF WASTE TYPES ACCORDING TO PUBLIC HEALTH CONSEQUENCES

and

TASK 4 AND 5 PLANNING

1.0 INTRODUCTION

The objective of this project is to provide information to assist the NRC in determining whether there is a need to safeguard shipments of highly radioactive wastes to or from licensed facilities. If a need exists, the project will provide a technical basis for comprehensive regulations for safeguarding highly radioactive waste shipments.

Previous task reports have provided a background for the Task 3 report. The Task 1 report, "Volumes and Characteristics of Highly Radioactive Wastes to be Shipped in the Future", provided information on source term characteristics of the various waste types. The Task 2 report, "Shipping Containers for the Transport of High Level Wastes", provided information on cask materials and construction.

This Task 3 report completes Phase 1 of the "Analysis of Safeguard Needs for Transport of High-Level Wastes" project. The Task 3 report is divided into two major sections designated Section 2 and Section 3. Section 2 deals with the rank ordering of the various waste types according to public health consequences and Section 3 deals with Task 4 and 5 planning. The objectives of Task 3 are: to identify those waste types which appear to be sufficiently hazardous to warrant safeguards considerations; to plan for Task 4; and to plan for Task 5.

2.0 WASTE FORM RANKING

This section of the report will discuss Subtasks 3.a, 3.b, 3.c, and 3.d and the results derived from the performance of these subtasks. Source terms for each waste form were estimated based on a shaped charge attack.

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Public health effects were then estimated, and waste forms were ranked according to the severity of health effects for both the maximum individual and the population at large. Finally an identification has been made of those waste forms which appear sufficiently hazardous to warrant safeguards.

2.1 Waste Form Source Terms

The Task 1 report described seven waste forms for highly-radioactive wastes. These include: spent fuel, borosilicate glass, Synroc, compacted cladding hulls, concrete, demineralizer cartridges, and sheet steel. Characteristics of these wastes have been covered previously in the Task 1 report and will not be reiterated here.

Using the information generated during Task 1, source terms, on the basis of curies per cubic centimeter of waste form were developed for each of the seven highly radioactive wastes identified in the Task 1 report. These source terms are presented in Tables 2.1 through 2.6.

Four source terms, presented in Table 2.1, are given for spent LWR fuel: once through and U-Pu recycle for 0.5 and 6.5 years of decay. The 0.5-year decay time is representative of that being shipped from the reactor to off-site storage or reprocessing. The 6.5 year represents fuel shipped from storage to reprocessing or disposal. The source terms were calculated from the data in Table 4.2 of the Task 1 report assuming a fuel density of 10.4 g/cc. Specific activities less than 10^{-10} curies/cc are ignored. In developing these source terms, it should be noted that for a Westinghouse 15 x 15 fuel assembly, 30.2 percent of the volume is UO_2, and 9.5 percent of the volume is Zircaloy.

Four source terms, also presented in Table 2.1, are given for HLW: wastes from once-through and U-Pu recycle fuel in borosilicate glass and Synroc. The source term calculations were based on the data in Table 4.2 of the Task 1 report for 6.5 year decay assuming waste from 1 MTHM is contained in 209 kg of glass (ρ = 3.0 g/cc) and in 523 kg of Synroc (ρ = 4.2 g/cc) as given in the report. Note that structural metals are not included in HLW.

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TABLE 2.1. SOURCE TERM FOR SPENT FUEL AND HIGH-LEVEL WASTE FISSION PRODUCTS, Ci/CC

	Spent Fuel, 0.5 Years Decay		Spent Fuel, 6.5 Years Decay		HLW, 6.5 Years Decay			
	LWR_0*	LWR_1	LWR_0*	LWR_1	$Glass_0$	$Glass_1$	$Synroc_0$	$Synroc_1$
H3	4.6E-3	4.7E-3	3.2E-3	3.3E-3	--	--	--	--
Kr-85	9.9E-2	9.3E-2	6.8E-2	6.3E-2	--	--	--	--
Sr-89	5.7E-1	5.5E-1	--	--	--	--	--	--
Sr-90	7.0E-1	6.4E-1	6.0E-1	6.0E-1	8.4E-1	8.4E-1	4.7E-1	4.7E-1
Y-90	7.0E-1	6.4E-1	6.0E-1	6.0E-1	8.4E-1	8.4E-1	4.7E-1	4.7E-1
[illegible]-91	9.9E-1	9.7E-1	--	--	--	--	--	--
Zr-93	1.8E-5	1.7E-5	1.8E-5	1.7E-5	2.5E-5	2.3E-5	1.4E-5	1.3E-6
Zr-95	1.8	1.8	--	--	--	--	--	--
Nb-95m	3.7E-1	3.7E-1	--	--	--	--	--	--
Nb-95	3.4	3.4	2.8E-10	2.8E-10	3.9E-10	3.9E-10	2.1E-10	2.2E-10
Tc-99	1.4E-4	1.4E-4	1.4E-4	1.4E-4	1.9E-4	1.9E-4	1.0E-4	1.0E-4
Ru-103	4.5E-1	4.6E-1	--	--	--	--	--	--
Ru-106	3.5	3.8	5.5E-2	6.1E-2	7.7E-2	8.6E-2	4.3E-2	4.[illegible]E-2
Rh-103M	4.5E-1	4.6E-1	--	--	--	--	--	--
Rh-106	3.5	3.8	5.5E-2	6.1E-2	7.7E-2	8.6E-2	4.3E-2	4.7E-2
Ag-110m	1.9E-2	2.3E-2	4.6E-5	5.7E-5	6.4E-5	8.0E-5	3.5E-5	4.4E-5
Ag-110	2.4E-3	3.0E-3	5.9E-6	7.4E-6	8.3E-6	1.0E-5	4.6E-6	5.7E-6
Cd-113m	1.2E-4	1.1E-4	6.4E-5	8.4E-5	9.0E-5	1.2E-4	5.0E-5	6.5E-5
Sn-119m	8.9E-5	9.5E-5	2.1E-7	2.2E-7	2.9E-7	3.0E-7	1.6E-7	1.7E-7
Sn-123	2.8E-2	3.0E-2	1.5E-7	1.6E-7	2.0E-7	2.2E-7	1.1E-7	1.2E-7
Sb-124	4.5E-4	5.0E-4	--	--	--	--	--	--
Sb-125	7.1E-2	7.9E-2	1.5E-2	1.7E-2	2.0E-2	2.3E-2	1.1E-2	1.3E-2

* The subscript "0" is for once-through fuel cycle and the "1" is for U-Pu recycle fuel.

TABLE 2.1. SOURCE TERM FOR SPENT FUEL AND HIGH-LEVEL WASTE FISSION PRODUCTS, Ci/CC (Continued)

	Spent Fuel, 0.5 Years Decay		Spent Fuel, 6.5 Years Decay		HLW, 6.5 Years Decay			
	LWR_0	LWR_1	LWR_0	LWR_1	$Glass_0$	$Glass_1$	$Synroc_0$	$Synroc_1$
Te-125m	2.9E-2	3.2E-2	6.2E-3	7.1E-3	8.7E-3	9.9E-3	4.8E-3	5.5E-3
Te-127m	4.4E-2	4.6E-2	3.9E-8	4.1E-8	5.5E-8	5.6E-8	3.1E-8	3.1E-8
Te-127	4.4E-2	4.6E-2	3.8E-8	4.1E-8	5.4E-8	5.6E-8	3.0E-8	3.1E-8
Cs-134	1.8	1.8	2.3E-1	2.3E-1	3.2E-1	3.2E-1	1.8E-1	1.8E-1
Cs-137	9.8E-1	9.9E-1	8.5E-1	8.6E-1	1.2	1.2	6.6E-1	6.7E-1
Ba-137m	9.2E-1	9.3E-1	8.1E-1	8.0E-1	1.1	1.1	6.3E-1	6.2E-1
Ce-141	2.5E-1	2.5E-1	--	--	--	--	--	--
Ce-144	6.3	6.1	3.0E-2	2.9E-2	4.2E-2	4.1E-2	2.3E-2	2.2E-2
Pr-144	6.3	6.1	3.0E-2	2.9E-2	4.2E-2	4.1E-2	2.3E-2	2.2E-2
Pm-147	9.4E-1	9.4E-1	2.0E-1	1.9E-1	2.8E-1	2.6E-1	1.5E-1	1.4E-1
Pm-148m	1.8E-2	1.9E-2	--	--	--	--	--	--
Pm-148	1.5E-3	1.6E-3	--	--	--	--	--	--
Sm-151	1.2E-2	1.2E-2	1.1E-2	1.2E-2	1.6E-2	1.7E-2	8.8E-3	9.6E-3
Eu-152	1.4E-4	1.8E-4	9.4E-5	1.2E-4	1.3E-4	1.7E-4	7.2E-5	9.6E-5
Eu-154	6.0E-2	6.7E-2	4.6E-2	5.1E-2	6.4E-2	7.1E-2	3.5E-2	3.9E-2
Eu-155	5.9E-2	6.4E-2	5.9E-3	6.4E-3	8.3E-3	9.0E-3	4.6E-3	4.9E-3
Gd-153	2.0E-4	1.8E-4	3.6E-7	3.3E-7	5.1E-7	4.6E-7	2.8E-7	2.6E-7
Tb-160	1.9E-3	2.2E-3	--	--	--	--	--	--
TOTAL	(34.3)	(34.3)	3.6	3.5	5.1	4.9	2.8	2.7
			Actinides, Ci/CC					
U-237	2.9E-5	4.8E-5	2.2E-5	3.6E-5	3.0E-7	5.0E-8	1.7E-7	2.8E-7
Np-239	1.5E-4	4.9E-4	1.5E-4	4.9E-4	2.0E-4	6.8E-4	1.1E-4	3.8E-4
Pu-238	2.2E-2	5.6E-2	2.2E-2	5.6E-2	3.0E-4	7.8E-4	1.7E-4	4.3E-4

FISSION PRODUCTS, Ci/CC (Continued)

	Spent Fuel, 0.5 Years Decay		Spent Fuel, 6.5 Years Decay		HLW, 6.5 Years Decay			
	LWR_0	LWR_1	LWR_0	LWR_1	$Glass_0$	$Glass_1$	$Synroc_0$	$Synroc_1$
Pu-239	3.0E-3	3.7E-3	3.0E-3	3.7E-3	4.2E-5	5.2E-5	2.3E-5	2.9E-5
Pu-240	4.7E-3	7.6E-3	4.7E-3	7.7E-3	6.5E-5	1.1E-4	3.6E-5	5.9E-5
Pu-241	1.1	1.9	8.7E-1	1.5	1.2E-2	2.0E-2	6.7E-3	1.1E-2
Pu-242	1.7E-5	4.1E-5	1.7E-5	4.1E-5	2.3E-7	5.6E-7	1.3E-7	3.1E-7
Am-241	2.1E-3	3.7E-3	1.1E-2	2.1E-2	1.6E-2	2.9E-2	8.8E-3	1.6E-2
Am-242m	1.1E-4	5.1E-4	1.0E-4	5.0E-4	1.4E-4	6.9E-4	8.0E-5	3.9E-4
Am-242	1.1E-4	5.1E-4	1.0E-4	5.0E-4	1.4E-4	6.9E-4	8.0E-5	3.9E-4
Am-243	1.5E-4	4.9E-4	1.5E-4	4.9E-4	2.0E-4	6.8E-4	1.1E-4	3.8E-4
Cm-242	1.8E-1	4.9E-1	1.0E-4	4.5E-4	1.4E-4	6.2E-4	8.0E-5	3.4E-4
Cm-243	4.2E-5	1.0E-4	3.6E-5	9.0E-5	5.0E-5	1.3E-4	2.8E-5	7.0E-5
Cm-244	1.3E-2	7.7E-2	1.0E-2	6.1E-2	1.4E-2	8.5E-2	8.0E-3	4.7E-2
Cm-245	1.9E-6	1.9E-5	1.9E-6	1.9E-5	2.6E-6	2.6E-5	1.4E-6	1.4E-5
TOTAL	1.4	2.5	9.3E-1	1.04	4.3E-2	1.4E-1	2.4E-2	7.6E-2

Activated Metals, Ci/CC

Mn-54	3.1E-3	2.1E-5	Same as Column 1	Same as Column 2				
Fe-55	6.2E-2	1.0E-2						
Co-58	2.0E-2	--						
Co-60	5.3E-2	2.1E-2						
Ni-59	3.1E-5	3.1E-5						
Ni-63	4.1E-3	4.2E-3						
Zn-65	2.0E-4	4.2E-7						
Nb-93m	9.1E-2	3.1E-7						
Zr-95	7.1E-2	--						
Nb-95	7.1E-2	--						
Cd-133m	4.1E-5	2.1E-5						
Sb-125	4.1E-4	8.3E-5						
Te-125m	2.0E-4	3.1E-5						
TOTAL		3.5E-2	--	--				

TABLE 2.2. SOURCE TERM FOR HULLS (SHIPPED SIX MONTH OUT OF REACTOR, COMPACTED FORM, FROM RECYCLE FUEL)

Activated Metal		Fission Products	
Nuclides	Ci/CC	Nuclides	Ci/CC
Mn-54	3.1E-3	H-3	2.3E-6
Fe-55	6.2E-2	Kr-85	4.5E-5
Co-58	2.0E-2	Sr-89	2.7E-4
Co-60	5.3E-2	Sr-90	3.2E-4
Ni-59	3.1E-5	Y-90	3.2E-4
Ni-63	4.1E-3	Y-91	4.7E-4
Zn-65	2.0E-4	Zr-93	8.2E-9
Zr-95	4.1E-2	Zr-95	8.7E-4
Nb-93m	9.2E-2	Nb-95m	1.8E-5
Nb-95	7.1E-2	Nb-95	1.7E-3
Cd-133m	4.1E-5	Tc-99	6.6E-8
Sb-125	4.1E-4	Ru-103	2.2E-4
Te-125m	2.0E-4	Ru-106	1.9E-3
TOTAL	(3.5E-1)	Rh-103m	2.2E-4
		Rh-106	1.9E-3
		Ag-110m	1.1E-5
Actinides		Ag-110	1.5E-6
		Cd-113m	5.6E-8
		Sn-119m	4.6E-8
U-237	2.3E-8	Sn-123	1.5E-5
Nb-239	2.4E-7	Sb-124	2.4E-7
Pu-238	2.8E-5	Sb-125	3.9E-5
Pu-239	1.8E-6	Te-125m	1.6E-5
Pu-240	3.7E-6	Te-127m	2.2E-5
Pu-241	9.2E-4	Te-127	2.2E-5
Pu-242	2.0E-8	Cs-134	8.7E-4
Am-241	2.1E-6	Cs-137	4.8E-4
Am-242m	2.5E-7	Ba-137m	4.5E-4
Am-242	2.5E-7	Ce-141	1.2E-4
Am-243	2.4E-7	Ce-144	3.0E-5
Cm-242	2.4E-4	Pr-144	3.0E-5
Cm-243	5.0E-8	Pm-147	4.6E-4
Cm-244	3.8E-5	Pm-148m	9.2E-6
Cm-245	9.2E-9	Pm-148	7.6E-7
TOTAL	(1.2E-3)	Sm-151	6.1E-6
		Eu-158	8.7E-8
		Eu-154	3.3E-5
		Eu-155	3.2E-5
		Gd-153	8.7E-8
		Tb-160	1.1E-6
		TOTAL	(1.7E-2)

TABLE 2.3 SOURCE TERM FOR LLW (HIGH ACTIVITY) FROM REPROCESSING FORM-CONCRETE

Nuclides	Ci/CC
Sr-90/Y-90 (50% Sr-90, 50% Y-90	5.0 10^{-6}
Zr-95/Nb-95 (31.6% Zr-95, 68.4% Nb-95	4.1 10^{-5}
Ru-106/Rh-106 (50% Ru-106, 50% Rh-106)	1.4 10^{-6}
Cs-134/Cs-137/Ba-137m (13.2% Cs-134, 44.8% Cs-137, 42.0% Ba-137m)	1.2 10^{-5}
Ce-144/Pr-144 (50% Ce-144, 50% Pr-144)	1.9 10^{-5}
Other fission products	4.0 10^{-6}
Pu-239	1.5 10^{-6}
Pu-241	6.9 10^{-4}
Other Pu	2.4 10^{-5}
Other actinides	1.0 10^{-7}
Fe-55	1.5 10^{-6}
Co-60	1.5 10^{-6}
Other actinide products	1.5 10^{-6}

TABLE 2.4. SOURCE TERM FOR LWR LLW (INTERNALS)
NORMAL OPERATIONS

Nuclides	Ci/CC
C-14	2.6×10^{-7}
Fe-55	2.2×10^{-3}
Ni-59	1.4×10^{-6}
Co-60	1.6×10^{-3}
Ni-63	2.1×10^{-4}
Nb-94	8.2×10^{-9}

TABLE 2.5. SOURCE TERM FOR LWR (TMI-1) WATER DECON WASTE, POST ACCIDENT CONDITIONS

(Assumes a demineralizer cartridge with 60,000 Ci per 8 ft^3 of 95% Cs-137 (57,000 Ci) and 5% Sr90 (3,000 Ci) with other isotopes from Table 4.5 in proportion to the Cs-137 (and shipped at this conc.)

Nuclides	Ci/CC
H-3	1.5×10^{-3}
Cs-134	3.8×10^{-2}
Cs-137	2.5×10^{-1}
Sr-89	1.1×10^{-4}
Sr-90	4.1×10^{-3}
Zr-95	3.1×10^{-8}
Nb-95	3.1×10^{-8}
Ru-106	4.7×10^{-6}
Sb-125	3.1×10^{-5}
Te-125m	7.9×10^{-7}
Te-127m	7.9×10^{-7}
Te-129m	3.1×10^{-7}
Ce-144	3.1×10^{-6}
I-129	1.9×10^{-8}

TABLE 2.6. SOURCE TERM FOR LWR COMPONENT WASTE, D&D

(Assume core shroud components shipped 10 years after shutdown.)

Nuclides	Ci/CC BWR	PWR
Fe-55	4.5×10^{-3}	1.1×10^{-2}
Co-60	1.5×10^{-2}	3.6×10^{-2}
Ni-63	5.0×10^{-3}	1.7×10^{-2}

The source term for cladding hulls is based on the data in Table 4.2 of the Task 1 report for 0.5 year decay assuming the hulls are compacted (ρ3.3 g/cc). This is representative of the most hazardous form. The source term includes activity from all structural metals and 0.05 percent of the fission products and actinide nuclides, and can be developed from the activated metals in Table 2.1 using the following factors:

Mn-54 x 0.01	Zr-95 x 1.0
Fe-55 x 0.02	Nb-93m x 1.0
Co-58 x 0.03	Nb-95 x 0.5
Co-60 x 0.04	
Ni-59 x 0.01	
Ni-63 x 0.01	

The source term for highly radioactive LLW from reprocessing is based in the data in Table 4.3 of the Task 1 report, assuming the waste is immobilized in concrete (ρ = 1.9 g/cc).

The source term for LWR wastes during normal reactor operations is based upon data for the activity estimated in internal nonfuel core components (control rods, poison curtains, instruments, etc.).

The source term for LWR wastes resulting from accident conditions is based on the data in Table 4.5 (revised) of the Task 1 report and assumes those nuclides are present in proportion to the Cs-137 content with 57,000 curies of Cs-137 concentrated in 8 cubic feet of demineralizer resin.

The source term for LWR D&D wastes is based on the data in paragraph 4.4 and Table 4.6 of the Task 1 report for the most radioactive components (shrouds) shipped 10 years after shutdown.

In order to make use of the source terms/cm^3 for each waste form, estimates were next made of the volume and mass of each waste form disrupted and/or ejected from a shipping container due to a sabotage event. These estimates are based on experiments conducted for other NRC programs[1].

(1) Shipping Cask Sabotage Source Term Experiments.

The sabotage device postulated for Task 3 calculations was an Army M3-A3 30 lb shaped charge. Previous NRC studies have agreed that this device may be defined as a suitable reference threat[1]. These devices are available in armories around the U.S. and could be stolen as easily as other light military equipment. Data available on the M3-A1 indicates it will easily penetrate one wall and the contents of a shipping cask. Because of the variability associated with the performance of the M3-A1, i.e., depth of penetration, it is assumed such a device could penetrate both walls of a shipping container and the contained waste form for each of the seven waste forms of interest in this study. In other words, complete penetration of the shipping container and its contents by the shaped charge jet is assumed. This assumption is conservative, although still realistic. Recent information also suggests that new NATO shaped charge devices similar to the M3-A1 will completely penetrate a spent fuel shipping cask in a consistent fashion.

Experimental studies have shown that the M3-A1 jet creates a hole having $\sim$3 cm radius through materials such as steel or spent fuel[1]. It is assumed, therefore, that the M3-A1 will create a 3 cm hole through each of the seven waste forms. In reality, the hole radius will be somewhat different for each waste form but it cannot be precisely estimated without testing. In general, approximately 20 to 40 percent of the mass of material contained in the 3 cm hole through each waste form will be ejected from the shipping container except for the steel and Zircaloy which, in addition to breaking up, will deform. Table 2.7 presents the volume and mass of material disrupted for each waste form based on the waste form dimensions and densities also provided in the Table.

A fraction of the waste form material disrupted will be in the form of a respirable aerosol, i.e., <10 μm diameter particle size. This mass of respirable material will cause the majority of the health effects. Particles >10 μm will settle out quickly and provide a local contamination problem but affect few people. Ejection of material in local waters will cause contamination problems but restrictions on contaminated water usage will mitigate health effects.

TABLE 2.7 VOLUME AND MASS DISRUPTED DUE TO M3-A3 ATTACK

Waste Form	Dimensions	Volume Disrupted By M3-Al Jet -- 3 cm Radius (cm^3)	Density (g/cm^3)	Waste Form Mass Disrupted (g)
Spent Fuel (PWR)	160." x 8.43" x 8.43"	742.5	3.12*	2,320
Glass	118" long, 12" diameter	861.8	3.0	2,585
Synroc	118" long, 12' diameter	861.8	4.2	2,620
Concrete	48" long, 24' diameter	1,723.6	2.05	3,533
Cladding Hulls	60" long, 24' diameter	1,723.6	3.3	5,688
Zeolite	60" long, 48' diameter	3,447.2	1.5**	5,171
Steel	12 plates 8'x8'x2" each	1,763.6	7.86	13,547

* Average density of PWR assembly including void space.

** Based on TMI resin liner received at BCL Hot Cell.

In order to estimate the mass of respirable material ejected from a shipping container for each waste form, a comparative approach was used. First, based on preliminary calculations from data collected in other studies done for the NRC[1], the ratio of the mass of respirable aerosol generated to the mass of spent fuel disrupted is estimated to be ~0.005. Applying this ratio to the mass of 2320 g spent fuel disrupted, as shown in Table 2.7, the result is 11.6 g of spent fuel in the form of respirable aerosol.

Second, three BCL explosives scientists, all experienced in the effects of shaped charge devices, were consulted to estimate the relative quantity of respirable aerosol generated for each waste form relative to spent fuel. Each explosives scientist was consulted independently and the results obtained and their average are shown in Table 2.8.

In making such estimations, it should be understood that explosives scientists are not generally concerned with respirable aerosols; rather, they are concerned with such things as penetration, fragmentation (macro), and shock waves.

TABLE 2.8. RELATIVE QUANTITY OF RESPIRABLE AEROSOL

Waste Form	Scientist 1	Scientist 2	Scientist 3	Average	Mass Aerosol Generated / Mass Waste Ejected/Deformed
Spent fuel	1.0	1.0	1.0	1.0	0.005
Glass	1.0	1.0	1.0	1.0	0.005
Synroc	0.60	0.80	0.60	0.67	0.0034
Concrete	0.40	0.30	1.2	0.63	0.0032
Cladding	0.030	0.010	0.060	0.033	0.00017
Zeolite	0.20	0.30	0.80	0.43	0.0022
Steel	0.010	0.010	0.020	0.013	0.00007

Also shown in Table 2.8 is the ratio of the mass of aerosol generated to the mass of waste form material disrupted for each waste form, based on the value of 0.005 for spent fuel. The third and final step in determining the mass of respirable material ejected from a shipping container is to multiply the ratios given in Table 2.8 (final column) by the masses given in Table 2.7. The resulting list of the mass of respirable aerosol for each waste form is presented as Table 2.9.

TABLE 2.9. MASS OF RESPIRABLE AEROSOL GENERATED BY M3-A1 ATTACK ON SHIPPING CONTAINER

Waste Form	Mass of Respirable (<10 μm) Aerosol (g)
Spent Fuel	11.6
Glass	12.9
Synroc	8.78
Concrete	11.2
Cladding Hulls	0.94
Zeolite	7.41
Steel	0.88

Before the masses listed in Table 2.9 can be used to estimate health effects, estimates must be made of the particle size distribution of the respirable aerosol. Based on previous experiments[1], the approximate particle size distribution of respirable aerosol for spent fuel is given in Table 2.10. After some discussion, and in lieu of any other experimental information, it was decided that the particle size distribution given in Table 2-10 should be used for each waste form.

TABLE 2.10. PARTICLE SIZE DISTRIBUTION FOR SPENT FUEL RESPIRABLE AEROSOL

Particle Size (Diameter)	Percent of Aerosol Mass
0.0 - 0.2 μm	10
0.2 - 0.5 μm	20
0.5 - 1.0 μm	20
1.0 - 2.0 μm	20
2.0 - 5.0 μm	20
5.0 - 10.0 μm	10

2.2 Public Health Effects

A sabotage attack on a high level waste shipment could occur in either an urban or rural area. Therefore, a search was made to identify a typical urban and rural area through which high level waste may someday be shipped. Both present and proposed regulations pertinent to spent fuel and high level waste shipment and local laws were considered in selecting the urban site in particular. The urban area chosen to estimate health effects was Philadelphia, Pennsylvania, and the rural area chosen was 50 miles directly west of Philadelphia.

The population distributions within 50 miles of each site were estimated using a method and computer program described by Hill(2) and Corley et al(3). The program and associated census data tape were developed by the Department of Commerce and subsequently modified by the Environmental Protection Agency and Hill. The population distributions generated are given in Tables 2.11 and 2.12 for the urban (Philadelphia) and rural (50 miles west of Philadelphia) sites, respectively. The urban population site shows a large density of people near the site with a lower density at the larger distances.

TABLE 2.11 POPULATION DISTRIBUTION FOR URBAN SITE (PERSONS PER AREA ELEMENT)

Downwind Sector	Distance Interval (miles) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	6386	5207	26758	33508	23836	65138	46038	23437	12029	109280
NNE	13760	15862	17955	15997	8905	43973	69579	17387	19418	35731
NE	2532	17819	21898	22173	16890	94735	99395	178620	50157	180830
ENE	3212	9467	14477	18391	40292	155600	179562	139537	46168	75099
E	10454	1494	11725	18080	24579	42596	85556	19528	56654	37935
ESE	5642	16920	29711	9065	1945	44123	41858	11602	3786	3615
SE	5282	19307	38592	11612	7496	87095	77456	17619	14035	15091
SSE	3311	25514	30673	5436	14669	118437	128543	22083	39787	5725
S	1380	19713	30487	15483	42477	144747	83262	17848	46305	40875
SSW	3632	29285	37739	26922	32696	94427	23009	9133	18908	4039
SW	7268	34707	15622	25226	52264	261654	221095	204644	169581	24503
WSW	6604	5966	2621	5880	34530	155147	77738	30813	35975	21640
W	1290	9152	8835	4810	10005	67353	61138	72240	46399	28040
WNW	2234	2913	6544	23532	12417	22514	64575	52922	38396	181900
NW	1474	8717	9437	5552	3737	27264	96430	34132	49916	39768
NNW	960	15670	21971	21544	18570	36188	67079	44516	48670	289337

TABLE 2.12 POPULATION DISTRIBUTION FOR RURAL SITE (PERSONS PER AREA ELEMENT)

Downwind Sector	Distance Interval (miles) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	0	0	0	0	3078	6596	14414	19406	16086	56542
NNE	0	0	0	0	0	2363	8921	168242	30574	23787
NE	0	0	0	0	0	2816	5627	29964	57171	75618
ENE	0	1430	0	0	1456	0	11979	18910	97752	198889
E	0	0	0	1022	0	2182	32231	72014	163825	1554637
ESE	0	0	0	0	0	3580	5439	29326	314590	53873
SE	0	0	0	0	0	3189	8739	83697	92999	12528
SSE	0	0	0	0	1838	1641	8688	18845	9624	11291
S	0	0	0	0	0	0	4029	24688	32615	6290
SSW	0	0	0	0	986	3287	1793	14158	40473	249119
SW	0	0	0	0	0	1395	4898	7657	13556	62729
WSW	0	0	0	0	0	1447	2856	14671	20923	43484
W	0	0	0	0	0	4606	20130	41849	114348	33098
WNW	0	2321	0	0	0	5299	102479	32210	44757	224291
NW	0	0	0	0	0	8991	25746	24064	59048	10946
NNW	0	0	0	0	0	1785	23661	23643	21283	17937

The rural site shows few people near the site but more people at large distances, particularly east of the site (Philadelphia). The sparse population within 5 miles of the release site is reflected in the large size of the census enumeration districts in the rural area. The method used to estimate the distribution places the people in the spatial interval where the center of the enumeration district is located. However, redistribution of these people across adjacent intervals would not result in a significant change in the results.

Meteorological observation data from the U.S. National Weather Service for Philadelphia was used for both the urban and rural release sites. This data was used to estimate normalized dispersion factors (E/Q) as a function of distance and direction from the release site. The resulting values represent the probable air concentrations assuming that the accident could happen at any time during the year. The EPA computer program CRSTER[4] was used to perform the dispersion calculation. This program can be used to describe either urban or rural settings using a given meteorological data base. The program was run in both urban and rural modes for this study. Results of the dispersion calculation are presented in Tables 2.13 and 2.14 for the urban and rural sites, respectively.

The maximally exposed individual was assumed to be located 100 meters downwind of the release site and to remain there during the passing of the released puff of radioactivity. The wind was assumed to be blowing at 1 meter per second under Pasquill Type F stability conditions (stable air). These are considered to be worst case conditions for both urban and rural sites. No credit was taken for enhanced dispersion in the wake of the shipment vehicle (about a 20 percent reduction in the dispersion factor). The normalized dispersion factor for the maximally exposed individual was calculated to be 6.0E-2 seconds/cubic meter.

Dose calculations were performed assuming the inhalation exposure pathway to be the principal mode of exposure. The external exposure to the passing cloud would be small compared to the inhalation pathway because there are practically no noble gas radionuclides in the waste inventories. The terrestrial food pathways were not included because time would be available after the release to interdict use of highly contaminated food products.

TABLE 2.13 ATMOSPHERIC DISPERSION FACTORS FOR URBAN SITE

Normalized Dispersion Factors, E/Q, (sec/cubic meter)
at Midpoint of Indicated Distance Interval

Downwind Sector	Distance Interval (miles) 0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	3.3-6	5.3-7	2.4-7	1.4-7	9.6-9	4.5-8	1.7-8	8.8-9	5.8-9	4.3-9
NNE	3.4-6	5.4-7	2.4-7	1.5-7	1.0-7	4.8-8	1.9-8	1.0-8	6.9-9	5.2-9
NE	6.6-6	1.1-6	5.1-7	3.1-7	2.2-7	1.1-7	4.4-8	2.4-8	1.6-8	1.2-8
ENE	3.4-6	5.7-7	2.7-7	1.7-7	1.2-7	5.9-8	2.5-8	1.4-8	9.5-9	7.2-9
E	3.2-6	5.4-7	2.5-7	1.5-7	1.1-7	5.3-8	2.2-8	1.2-8	8.4-9	6.3-9
ESE	2.7-6	4.4-7	2.0-7	1.2-7	8.3-8	3.9-8	1.6-8	8.1-9	5.4-9	4.0-9
SE	2.2-6	3.5-7	1.6-7	9.8-8	6.8-8	3.3-8	1.4-8	7.3-9	4.9-9	3.7-9
SSE	2.1-6	3.4-7	1.5-7	9.1-8	6.3-8	3.0-8	1.2-8	6.1-9	4.0-9	3.0-9
S	1.4-6	2.3-7	1.1-7	6.6-8	4.6-8	2.3-8	9.4-9	5.0-9	3.4-9	2.6-9
SSW	6.3-7	9.9-8	4.5-8	2.8-8	1.9-8	9.6-9	4.1-9	2.3-9	1.6-9	1.2-9
SW	2.0-6	3.5-7	1.6-7	1.0-7	7.2-8	3.6-8	1.5-8	8.4-9	5.8-9	4.5-9
WSW	1.7-6	2.7-7	1.2-7	7.2-8	4.9-8	2.3-8	8.6-9	4.3-9	2.8-9	2.1-9
W	1.5-6	2.5-7	1.2-7	7.0-8	4.8-8	2.3-8	9.0-9	4.6-9	3.0-9	2.2-9
WNW	2.1-6	3.5-7	1.6-7	1.0-7	7.1-8	3.5-8	1.5-8	8.2-9	5.6-9	4.3-9
NW	1.6-6	2.6-7	1.2-7	7.4-8	5.2-8	2.5-8	1.0-8	5.6-9	3.8-9	2.8-9
NNW	2.5-6	3.9-7	1.7-7	1.0-7	6.7-8	3.1-8	1.2-8	6.0-9	3.9-9	2.9-9

TABLE 2.14 ATMOSPHERIC DISPERSION FACTORS FOR RURAL SITE

Normalized Dispersion Factors, E/Q, (sec/cubic meter)
at Midpoint of Indicated Distance Interval

Downwind	Distance Interval (miles)									
Sector	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	3.8-6	6.3-7	2.9-7	1.8-7	1.3-7	6.2-8	2.5-8	1.4-8	9.2-9	6.9-9
NNE	4.1-6	6.7-7	3.0-7	1.8-7	1.3-7	6.1-8	2.5-8	1.3-8	8.6-9	6.4-9
NE	9.4-6	1.6-6	7.6-7	4.7-7	3.3-7	1.7-7	7.0-8	3.8-8	2.5-8	1.9-8
ENE	6.6-6	1.4-6	7.3-7	4.7-7	3.4-7	1.8-7	7.3-8	3.8-8	2.5-8	1.8-8
E	4.3-6	7.3-7	3.4-7	2.1-7	1.5-7	7.2-8	3.0-8	1.6-8	1.1-8	8.0-9
ESE	3.7-6	6.1-7	2.8-7	1.7-7	1.2-7	6.0-8	2.5-8	1.3-8	9.1-9	6.8-9
SE	2.6-6	4.1-7	1.8-7	1.1-7	7.5-8	3.5-8	1.4-8	7.0-9	4.5-9	3.3-9
SSE	2.8-6	4.5-7	2.1-7	1.3-7	8.7-8	4.2-8	1.7-8	8.7-9	5.7-9	4.2-9
S	1.6-6	2.5-7	1.1-7	6.7-8	4.6-8	2.1-8	7.7-9	3.8-9	2.5-9	1.8-9
SSW	7.9-6	1.2-7	5.6-8	3.3-8	2.3-8	1.1-8	4.1-9	2.1-9	1.4-9	1.0-9
SW	3.1-6	6.6-7	3.5-7	2.3-7	1.8-7	9.9-8	4.8-8	2.9-8	2.1-8	1.6-8
WSW	2.1-6	3.4-7	1.6-7	9.4-8	6.5-8	3.1-8	1.2-8	6.2-9	4.1-9	3.0-9
W	1.7-6	3.1-7	1.5-7	9.4-8	6.7-8	3.3-8	1.3-8	6.7-9	4.3-9	3.1-9
WNW	2.9-6	4.9-7	2.3-7	1.4-7	9.7-8	4.7-8	1.9-8	9.9-9	6.6-9	4.9-9
NW	1.6-6	2.7-7	1.3-7	7.9-8	5.5-8	2.7-8	1.1-8	5.9-9	3.9-9	2.9-9
NNW	3.3-6	5.5-7	2.5-7	1.5-7	1.1-7	5.2-8	2.1-8	1.1-8	7.0-9	5.2-9

Inhalation dose commitment factors were calculated for each waste form assuming an acute inhalation period and a 50-year dose commitment period using the computer program DACRIN[5]. DACRIN takes meteorological and population distribution information and calculates inhalation doses for a given radionuclide source term. It uses the model of the ICRP Task Group on Lung Dynamics[6] to model radionuclide movements through the respiratory system. Once radionuclides reach the bloodstream, the doses to organs other than the lungs are calculated using a single exponential retention function[7]. A breathing rate of 330 cubic cm/sec[8] was assumed corresponding to moderate activity during an 8 hour working period. Based on the particle size distribution given in Table 2.10, the respirable aerosol was assumed to be particulate with a mean diameter of 1 micron (AMAD). Released material was also assumed to be in an insoluble or highly oxidized form with respect to behavior in the respiratory tract. Normalized dose commitment factors were calculated for each waste form assuming release of 1 cm^3 of waste and an atmospheric dispersion factor of 1 sec/cubic meter.

The doses for each defined waste form release are presented in Table 2.15 for the maximally exposed individual and were calculated as follows:

Dose = (Dose Factor)(Volume Released)(Dispersion Factor)

The calculations were performed for each organ of interest. The population doses were calculated in a similar manner with the dispersion factor replaced by a population/dispersion factor defined for each release site. The population factor was calculated as the sum of the population times the dispersion factor for each area element about the site. The population factor for the urban site was 0.53 and for the rural site 0.054. This method of population dose calculation is appropriate because radiological decay during plume transport is not significant for the radionuclides in the waste forms studied. The doses for the postulated urban and rural populations are presented in Tables 2.16 and 2.17, respectively.

TABLE 2.15 FIFTY-YEAR INHALATION DOSE COMMITMENT TO MAXIMUM INDIVIDUAL FROM SABOTAGE OF HLW SHIPMENTS (REM)

Release Description	Decay Time (Yr)	Organ of Reference Total Body	Bone	Lungs	GI LLI
Spent Fuel:					
No Recycle	0.5	4.6E+1	8.7E+2	1.8E+3	2.5E+1
Recycle	0.5	9.4E+1	1.9E+3	4.0E+3	2.5E+1
No Recycle	6.5	4.3E+1	8.7E+2	6.7E+2	1.4E+0
Recycle	6.5	8.7E+1	1.9E+3	1.8E+3	1.5E+0
High Level Waste Glass:					
No Recycle	6.5	1.0E+2	1.9E+3	1.9E+3	7.2E+0
Recycle	6.5	2.0E+2	4.1E+3	5.4E+3	7.8E+0
High Level Waste Synroc:					
No Recycle	6.5	1.2E+2	2.2E+3	2.1E+3	8.4E+0
Recycle	6.5	2.3E+2	4.8E+3	6.6E+3	9.0E+0
Concrete	-	1.1E-1	2.7E+0	1.6E+0	4.6E-4
Cladding Hulls	0.5	1.3E-2	2.3E-1	1.5E+0	1.9E-2
Zeolite	-	1.6E+0	5.6E+0	2.9E+0	1.9E-5
Steel:					
BWR	10.	1.3E-4	9.9E-4	9.9E-2	7.9E-4
PWR	10.	3.6E-4	3.4E-3	2.4E-1	1.9E-3

TABLE 2.16 FIFTY-YEAR INHALATION DOSE COMMITMENT TO THE POPULATION FOR URBAN RELEASE (MAN-REM)

Release Description	Decay Time (Yr)	Organ of Reference			
		Total Body	Bone	Lungs	GI LLI
Spent Fuel:					
No Recycle	0.5	4.1E+2	7.7E+3	1.6E+4	2.2E+2
Recycle	0.5	8.3E+2	1.7E+4	3.5E+4	2.2E+2
No Recycle	6.5	3.8E+2	7.7E+3	5.9E+3	1.2E+1
Recycle	6.5	7.7E+0	1.7E+4	1.6E+4	1.4E+1
High Level Waste Glass:					
No Recycle	6.5	9.2E+2	1.7E+4	1.6E+4	6.4E+1
Recycle	6.5	1.8E+3	3.7E+4	4.8E+4	6.9E+1
High Level Waste Synroc:					
No Recycle	6.5	1.1E+3	1.9E+4	1.9E+4	7.5E+1
Recycle	6.5	2.0E+3	4.3E+4	5.6E+4	8.0E+1
Concrete	-	9.6E-1	2.4E+1	1.4E+1	4.0E-1
Cladding Hulls	-	1.1E-1	2.1E+0	1.3E+1	1.7E-1
Zeolite	-	1.4E+1	4.9E+1	2.6E+1	1.7E-4
Steel:					
BWR	10.	1.2E-3	8.7E-3	8.7E-1	7.0E-3
PWR	10.	3.1E-3	3.0E-2	2.1E+0	1.7E-2

TABLE 2.17 FIFTY-YEAR INHALATION DOSE COMMITMENT TO THE POPULATION FOR RURAL RELEASE (MAN-REM)

Release Description	Decay Time (Yr)	Organ of Reference: Total Body	Bone	Lungs	GI LLI
Spent Fuel:					
No Recycle	0.5	4.1E+1	7.8E+2	1.6E+3	2.2E+1
Recycle	0.5	8.4E+1	1.7E+3	3.6E+3	2.2E+1
No Recycle	6.5	3.8E+1	7.8E+2	6.0E+2	1.3E+0
Recycle	6.5	7.8E-1	1.7E+3	1.6E+3	1.4E+0
High Level Waste Glass:					
No Recycle	6.5	9.2E+1	1.7E+3	1.6E+3	6.4E+0
Recycle	6.5	1.8E+2	3.7E+3	4.8E+3	6.9E+0
High Level Waste Synroc:					
No Recycle	6.5	1.1E+2	2.0E+3	1.9E+3	7.7E+0
Recycle	6.5	2.1E+2	4.4E+3	5.8E+3	8.2E+0
Concrete	-	9.9E-2	2.4E+0	1.4E+0	4.2E-2
Cladding Hulls	-	1.1E-2	2.1E-1	1.3E+0	1.7E-2
Zeolite	-	1.4E+0	4.9E+0	2.6E+0	1.7E-5
Steel:					
BWR	10.	1.2E-4	8.9E-4	8.9E-2	7.1E-4
PWR	10.	3.2E-4	3.1E-3	2.1E-1	1.7E-3

2.3. Rank Ordering of Waste Forms

The results of the public health consequence calculations indicate that the waste forms can be easily grouped into two categories with respect to radiological consequences. Spent fuel, glass, and Synroc comprise one group and concrete, cladding hulls, zeolite, and steel comprise the second group.

Group 1	Group 2
Spent fuel	Concrete
Glass	Cladding hulls
Synroc	Zeolite
	Steel

Table 2.15 shows that a sabotage attack on Group 2 waste forms results in a 50 year inhalation dose commitment to the maximum individual of $\leq$1.9 rem (whole body), $\leq$45 rem (bone), $\leq$ 26 rem (lungs), and $\leq$0.31 rem (GI LLI). As a point of comparison, individuals exposed to 50-100 rem acute external radiation exposure during a criticality accident at the Wood River Junction Plant in Rhode Island (1964) showed no permanent and only minor temporary health effects. Current radiation safety guidelines permit maximum permissible doses as shown in Table 2.18[9].

TABLE 2.18. MAXIMUM PERMISSIBLE DOSES (NEUTRON, GAMMA, OR BETA)

Organ	Annual Dose, rem
Gonads, bone marrow, whole body	5
Skin, bone, thyroid	30
Hands, forearms, feet, ankles	75
Other organs (including lungs)	15

From Table 2.18, it is clear that a sabotage attack on a Group 2 waste form will present negligible health effects to the maximum individual. Similarly, health consequences to the general public, shown in Tables 2.16 and 2.17, either urban or rural, appear negligible for Group 2 waste forms.

Local contamination due to a sabotage attack on a Group 2 waste form will require trained decontamination personnel for cleanup, but should present relatively few problems. Cleanup costs should not be excessive.

For the reasons stated above, it is recommended that no additional study be given to Group 2 waste forms in this program. Additional safeguards measures are clearly not warranted for the Group 2 waste forms.

Table 2.15 indicates that a sabotage attack on spent fuel, a Group 1 waste form, results in a 50 year inhalation dose commitment to the maximum individual ranging from 43-94 rem (whole body), 870-1900 rem (bone), 670-4000 rem (lungs), and 1.4-25 rem (GI LLI). Comparison of these dose ranges with Table 2.18 shows that the whole body dose is acceptable, the bone dose is marginally acceptable, the lung dose ranges from marginally acceptable to unacceptable, and the GI-LLI dose is acceptable. The higher dose values are for recycle material in each case. Current once-through spent fuel shipments appear to present an acceptable risk with respect to the consequences of a sabotage attack based on dose to the maximum individual. Future shipments of recycle spent fuel appear to present a marginally acceptable risk with respect to the consequences of a sabotage attack based on dose to the maximum individual.

Table 2.16 shows that the 50 year inhalation dose commitment to the urban public has maxima of 830 rem (whole body), 17,000 rem (bone), 35,000 rem (lungs), and 220 rem (GI LLI). Reference 10 indicates that a population dose of 10^6 man rem to the whole body accumulated over 75 years will produce 121.6 latent cancer fatalities (lcf's); 10^6 man rem to bone will produce 6.9 lcf's, 10^6 man rems to the lungs or GI tract will produce 22.2 or 3.4 lcf's, respectively. The number of expected lcf's caused by the release of radioactive material from a sabotaged spent fuel shipment was calculated using the values from Reference 10 and found to be approximately 1. The population dose calculated in this work is integrated over 50 years and Reference 10 gives lcf's for a dose integrated over 75 years. Even if the dose over 75 years were 1.5 times the dose for 50 years, the number of expected lcf's would change from 1 to 1.5. But the dose for the last 25 years will not be as great as that for the first or second 25. Given the approximations made in calculating the source term and the uncertainty in the number of lcf's per 10^6 man rem, spending more time to determine whether the expected number of lcf's is 1.0, 1.5, or some number between those two is not justifiable. This risk of latent cancer death is very small compared to other health risks facing the general population and can be considered to be negligible.

Cleanup costs associated with a shaped charge sabotage attack on a spent fuel shipping container may be relatively expensive. Based on previous experiments[1], ~16,000-32,000 Ci of spent fuel material may be ejected locally as non-respirable debris for 0.5 year decay spent fuel (and 1600-3200 curies for 6.5 year spent fuel) from the shipping cask due to a shaped charge attack. Great care will be required to decontaminate the local area. A sizeable quantity of transuranic and non-transuranic waste may be generated during cleanup. Use denial may be required for an extended period of time in the immediate vicinity. Repair or replacement costs for contaminated buildings, streets, etc., are difficult to estimate.

In summary, for spent fuel, health effects appear acceptable to marginally acceptable for the maximum exposed individual, public health effects are negligible, and cleanup costs (including use denial) may be relatively expensive and should be further evaluated. Because of cleanup cost considerations, it is recommended that spent fuel waste be further examined in Tasks 4 and 5 of this program.

Table 2.15 shows that a shaped charge sabotage attack on a high-level waste glass or high-level waste Synroc shipment, both Group 1 waste forms, results in a 50 year inhalation dose commitment to the maximum individual ranging from 100-230 rem (whole body), 1900-4800 rem (bone), 1900-6600 rem (lungs), and 7.2-9.0 rem (GI-LLI). Reference to Table 2.18 indicates that the whole body dose is acceptable, the bone dose in unacceptable (by a factor of 1.3-3.2), the lung dose is unacceptable (by a factor of 2.5-8.8), and the GI-LLI dose is acceptable. The maximum exposed individual faces some possible health consequences from a shaped charge attack on a shipment of high-level waste glass or high-level waste Synroc.

Table 2.16 shows that the 50 year inhalation dose commitment to the urban population ranges from 920-2000 rem (whole body), 17,000-43,000 rem (bone), 16,000-56,000 rem (lungs), and 64-80 rem (GI-LLI). If these doses are totaled, the range is from 34,000-101,000 rem to the urban population. For the 6.6×10^6 urban population considered, approximately 0.5 to 2 latent cancers may be expected over 75 years. This risk of cancer is very small compared to other health risks facing the general population and can be considered negligible.

Cleanup costs associated with a shaped charge attack on a high-level waste glass or high-level waste Synroc container will be less expensive than for 0.5 year cooled spent fuel. On the basis of previous experiments with spent fuel[(1)], it is estimated that ~2600-5200 Ci of high-level waste glass or 2000-4000 Ci of high-level waste Synroc may be ejected as nonrespirable debris from a shaped charge attack on a shipping container. As discussed for spent fuel, cleanup costs may be relatively expensive and use denial may be required. Repair and replacement costs will be difficult to estimate.

In summary, for high-level waste glass or Synroc, health effects to the maximum individual are unacceptable by a factor of approximately 10-100 times, health effects to the general public are negligible, and cleanup costs may be relatively expensive. Because of the potential health effects to the maximum individual and potential high cleanup costs, it is recommended that high-level waste glass and Synroc both be further examined in Task 4 and 5 of this program.

3.0 PLANS FOR TASKS 4 AND 5

Phase 1 of this program (Tasks 1, 2, and 3) was designed to determine whether the sabotage of a shipment of any form of highly radioactive waste could present a severe threat to the public health and safety. The results of Phase 1 indicate that the three waste forms in Group 1 (spent fuel, HLW in glass, and HLW in Synroc) do present a hazard to the maximally exposed individual. This high dose appears to indicate that there would also be significant contamination in the immediate vicinity of the breached cask. However, no estimate of the contamination was made. The contamination and public health consequences resulting from attacks on waste forms in Group 1 appear to be sufficiently severe to require further investigation.

Phase 2 (Tasks 4 and 5) of the program will provide a more detailed analysis of the radiological releases and their consequences. In addition, it will identify and analyze safeguards measures designed to reduce the consequences of the sabotage of highly radioactive waste shipments. This section of the report outlines the plans for Tasks 4 and 5.

3.1 Task 4

Task 4 will provide a more detailed analysis of the radiological releases from the sabotage of shipments of spent fuel or of HLW fixed in either glass or Synroc. It will also provide an estimate of the consequences of the releases. Each subtask required for the performance of this task is described below.

Subtask 4.a. A literature search will be made for documents that may supply information on methods of radiological material dispersal, capabilities and resources required to implement those methods, source term characterizations, response of shipping casks to various types of attack, impact of meteorological conditions and radiological consequence evaluation. The search will focus on documents resulting from studies sponsored by the NRC but may include others.

Subtask 4.b. A variety of methods for dispersing highly radioactive waste intercepted during transport will be identified and studied. The project team will consider methods designed to breach the shipping container. It will also consider methods that could be used to enhance dispersal of material from a breached cask, including transporting the cask to a more "favorable" location. Weapons that will be considered for breaching the container include shaped charges, platter charges, breaching charges, burning bars, and ANFO. Dispersion enhancement methods include removing the waste from the container, crushing it and scattering it in air or water; or burning the waste. For each of these threats, the project team will consider the capabilities and resources required for a "successful" attack.

Subtask 4.c. For attack methods identified in Subtask 4.b as having potentially severe consequences, source terms will be estimated for three waste forms (spent fuel, HLW in glass, and HLW in Synroc) sealed in representative shipping casks. The source term definition will include the amount

Results of the study of the impact of meteorological conditions on consequences will be used to select the conditions that will produce the most severe consequences in each case.

Subtask 4.f. In this subtask, the interim report for Task 4 will be written. This report will contain estimates of the extent and impact of public health consequences, contamination, use denial and cleanup costs resulting from malevolent dispersion of HLW. These estimates will be provided for both rural and urban environments. It is understood that the data presented in this report will form the basis for NRC policy decisions on the need for HLW safeguards measures. Accordingly, the data will be of sufficient quality for this use.

3.2 Task 5

The purpose of Task 5 is to identify and evaluate safeguards measures that can reduce the consequences estimated in Task 4. Plans for each of the subtasks under Task 5 are presented below.

Subtask 5.a. Safeguards measures that may reduce the consequences of sabotage of high-level waste or spent fuel shipments will be identified. These will be drawn from existing safeguards measures described in Title 10, Part 23 of the Code of Federal Regulations (10CFR73), as well as from measures not currently required by NRC but consistent with existing NRC policy. These measures may include physical protection, access denial, and consequence mitigation techniques.

Currently, there are neither existing nor publicly proposed NRC safeguards requirements for HLW shipments. However, NRC has published a final interim rule for safeguarding shipments of irradiated reactor fuel (10CFR73.37)(*). This rule was accompanied by interim guidance to aid licensees with its implementation (NUREG-0561, Revision 1). These documents, together with other elements of 10CFR73 will be useful in identifying existing safeguards, measures, and suggesting others.

(*) 45 FR 37408, June 3, 1980.

Identified safeguards measures are expected to affect different sabotage risk elements. Those that are identified as physical protection and access denial measures are expected to reduce primarily the motivations to sabotage HLW shipments, and thus reduce the likelihood of such attacks occurring. Those safeguards measures that are identified as consequence mitigation measures are expected to reduce primarily the consequences of sabotage. All measures are expected to raise the price to an adversary for executing a successful sabotage act; these measures are also expected to have some effect on all sabotage risk elements (likelihood of a sabotage attempt, likelihood of sabotage success given a sabotage attempt, and sabotage consequences given a successful attempt).

Subtask 5.b. The objective of Subtask 5.b is to do a comaprative analysis of the safeguards measures identified in Subtask 5.a. Three parameters, public health consequences, measure effectiveness, and cost/benefit relationship, will be analyzed for each combination of safeguards measure, waste type, and attack mode. Only the three waste types identified as potentially hazardous in Phase 1 of the study and the attack modes determined to be the most effective (in Subtask 4.e) will be considered.

When a cask containing highly radioactive waste is breached and some material is released, the effects on public health can be expressed in terms of population dose. To analyze the impact of a safeguards measure on public health consequences, the extent to which the measure reduces that population dose will be estimated.

In planning the analysis of the "measure effectiveness", it is assumed that the term effectiveness refers to success in reducing the risk associated with a malevolent act. Risk is generally expressed as the product of the probability that an event will occur and the consequences of that event. The analysis of measure effectiveness will, therefore, involve estimating the degree to which the measure reduces both the probability and the consequences of a successful attack. The consequences considered in this analysis will include contamination, land use denial, and cleanup costs. Public health consequences will be analyzed separately, as indicated above, because of their great importance. Reducing the probability of a successful attack refers to both reducing the chances that an attack will be made and reducing the chances that an attempted attack will be successful. A data base of sabotage incidents involving all aspects of the energy industry, worldwide, during the past two decades is available. It may be useful in evaluating the effectiveness of existing or proposed safeguards measures.

The final part of this subtask will be a cost/benefit analysis of various safeguards measures. For each measure, the cost will be estimated in terms of dollars, resource utilization, and risk to the people charged with guarding the shipments. The benefits of each measure will be the reduction of probability and consequences of an attack which were determined in earlier analyses.

Each cost and each benefit can be quantified. We recognize however, that several different units will be required. For example, some costs will be measured in dollars while one of the benefits, reduction of public health consequences, will be measured in man-rems. We do not believe that it is necessary or useful to convert all costs and benefits to a common unit so that a quantitative cost/benefit analysis can be done. A thorough treatment of each cost and benefit will make possible a qualitative cost/benefit analysis that will be useful in deciding which safeguards measures to employ.

Subtask 5.c. Following the analysis of safeguards measures, the final report will be written. It will present a description of the example safeguards measures selected and the results of the analysis of those measures. In addition, the final report will include the revised versions of the Task 1, 2, 3, and 4 reports.

Subtask 5.d. This subtask is included to allow "fine tuning" of the final report if the NRC requests revisions.

This completes the outline of proposed Tasks 4 and 5. Tasks 1 through 3 indicate that the consequences of an attack on a shipment of spent fuel or HLW could be severe. We have recommended that these consequences be studied in greater detail and that safeguards measures to reduce the consequences be proposed and evaluated. Tasks 4 and 5 have been designed to accomplish these objectives. We believe that information and technical data developed in these two tasks will be suitable to serve as a basis for policy decisions on safeguards requirements for HLW shipments.

4.0 REFERENCES

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