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HAZARD ANALYSIS FOR CESIUM SHIPMENTS

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HAZARD ANALYSIS FOR CESIUM SHIPMENTS

I. INTRODUCTION

The rail shipment of large quantities of radiocesium involves a potential accidental release of this material in a readily available form to the biosphere. The magnitude of the associated potential damage to man and his environment is evaluated in this report.

II. SUMMARY

The evaluation of the consequences of an accidental release of Cs-137 from the Shielded Transfer Tank, Model II (STT) assumes loss of Cs-137 to the atmosphere or to surface water. Release to the atmosphere could result from a collision followed by fire or explosion. In the event of a fire, a small fraction of the Cs-137 would be volatilized. An explosion would disperse the Cs-137 still adsorbed to Decalso as particulates. In either case, the material is assumed to be dispersed by atmospheric mechanisms which can be described by modified Sutton equations.

The accident involving a fire or explosion assumes that 1 percent or 10 percent, respectively, of 90,000 curies of Cs-137 is dispersed in a metropolitan area. Contamination of the surrounding suburban area is also involved. Damage estimates amount to about 60 million dollars and 400 million dollars, corresponding to a 1 percent and a 10 percent release respectively.

Another possible type of accident involves the release of the Decalso (an inorganic ion exchange carrier for the cesium) into a river. However, the release of Cs-137 by elution into the river results in minor damage compared to the atmospheric release cases.

III. NATURE OF THE SHIPMENT AND CASK

The Cs-137 is adsorbed as the cation on Decalso, an inorganic aluminosilicate ion exchange resin. There are 400 gallons of Decalso in each shipping cask. The cask is known as the Shielded Transfer Tank, Model II (STT), which is six feet in diameter by seven feet high and weighs 38,000 pounds. Six of these casks are available and gondola cars are equipped to carry three casks per car⁽¹⁾.

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The inner vessel contains about 270 gallons of demineralized water as a heat transfer medium. The vessel atmosphere is air. Lead shielding is provided which is 3-3/4 inches thick. Resistance of the cask to impact has been calculated on the basis of impact with an unyielding object at a velocity of three miles per hour which is equivalent to a free fall of about three inches.

Four casks have been loaded with supernatant liquid from the HAPO waste storage tanks to approximately 30,000 curies of Cs-137 per vessel. Analytical data on the cask loadings⁽²⁾ are summarized in Table 1.

Table 1

CASK LOADINGS - THOUSANDS OF CURIES

<u>Cask</u>	<u>Cs-137</u>	<u>ZrNb</u>	<u>Ru</u>	<u>Sr</u>	<u>Ce</u>
45-A	29.9	3.2	2.0	1.9	3.6
48	30.2	---	4.5	---	0.4
44	31.0	---	1.0	0.6	---
47	29.0	---	1.3	---	---

The loading of radioelements was determined by comparing measurement of the influent and effluent concentrations in the loading solutions. The Decalso (10 to 30 mesh) was loaded to full ion exchange capacity, including the content of non-radioactive cations. After the ion exchange resin was loaded and washed, the vessel was filled with demineralized water. The equilibrium content of Cs-137 in the water is estimated to be about 0.012 curies of Cs-137.

A pressure buildup was observed in the casks as a result of radiolytic decomposition of water (approximately 1 psig per day). The equilibrium pressure was not determined. If equilibrium is not reached, it is possible to exceed the maximum allowable shipping pressure of 25 psig assuming significant delays are encountered en route. In some casks, the hydrogen concentration exceeded the lower explosive limit about ten days after loading. Temperature buildup was insignificant.

IV. TYPES OF ACCIDENTS WHICH COULD BE ENCOUNTERED IN RAIL SHIPMENTS

If the gondola car carrying three casks is involved in a collision of any appreciable magnitude, the casks will be fractured and their contents may be released. Examination of accident reports shows that railroad collisions are sometimes followed by fire and/or an explosion. In the case of a fire it has been assumed that petroleum products would be a possible fuel source and that the flame temperature would not

exceed 2500°F. In such a fire, a fraction of the cesium would be released by volatilization. If the casks were not fractured prior to the flame impingement, they would then fail because of steam pressure. Failure could be by the loss of gasketing material, by fracturing the vessel, or by thermal expansion of the lead. The temperature (pressure) at which the vessel would fail under these conditions is uncertain, and the mechanism of the vessel failure is not predictable. The explosion could result in the dispersal of fine particles of Decalso (with the Cs-137 adsorbed) to the atmosphere.

Collision or a landslide type of accident could occur along portions of the route where the railroad closely parallels or crosses a stream. In such an event, a fraction or all of the ion exchange medium could be exposed to the stream. Leaching of the Cs-137 into the river water is another source of potential damage.

V. RELEASE TO THE ATMOSPHERE

Materials released to the atmosphere will spread downwind of the source area, diffusing and depositing according to the meteorological conditions existing at the time and subsequent to the release. Recent investigations of the structure of the atmosphere in and surrounding large cities have shown that the heat island of an urban area has a considerable effect on the vertical temperature differences observed at night, so that the normal diurnal range of stability conditions encountered over an urban area is much smaller than that over open country⁽³⁾. Consequently the strength of the temperature inversion that provides minimum dilution conditions within the city is no greater than the "moderate" stability classification used at Hanford for calculating accident consequences⁽⁴⁾.

Dispersal by Volatilization. The cask car is assumed to be involved in a railroad accident, resulting in rupture of the three casks with an attendant fire of unspecified intensity. Some of the cesium is released as a result of the fire and dispersed to the atmosphere with the combustion products. Experiments on the release of cesium from Decalso heated to temperatures up to 2500°F for two hours have shown that less than 1 percent of the cesium would be released by this mechanism⁽⁵⁾. The experimental results indicated that heating for longer periods would not release additional amounts of cesium unless higher temperatures were reached. The volatilized radionuclides were analyzed by gamma spectrometry. Only Cs-137 was released in detectable quantities. In the presence of the Cs-137, the detection limit for ruthenium was such that < 1 percent of the ruthenium was released. Therefore, the contamination from radionuclides other than Cs-137 was not considered in this evaluation.

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A fire would cause the released material to be entrained in the plume of combustion products and rise to some height, depending on the heat generated by the fire and the vertical density stratification of the atmosphere. Using the results reported by Vehrencamp⁽⁶⁾, estimates were made of the height to which the combustion products would rise under a typical vertical environmental temperature structure characterized by instability in the lower 600 feet and an inversion above. Complete combustion of the contents of a tank truck and trailer, or a railroad car filled with petroleum products within one hour would give rise to a plume that would level off at heights of 1400 to 2100 feet. Fractional burning or a slower rate of combustion would result in leveling-off at lower elevations.

Topographical features in the immediate vicinity of the accident may well offset any advantage that might be gained from considering an elevated release. Therefore, calculations for this type of accident are based on a ground level release which should estimate the maximum damage.

Dispersal by Explosion. The casks are assumed to be involved in an explosion that spreads fragments of the cask and disperses the contents over some area in the vicinity of the accident. The explosion could be of either internal or external origin. Dispersal is visualized as fragmentation of the Decalso such that approximately 10 percent of the Cs-137 is released on particles smaller than several microns. There is no experimental information on which to base an assumption on the fraction of aerosol size particles created by the explosion. Aside from the initial fallout in the immediate vicinity of the explosion, the small particles are assumed to disperse and deposit as an aerosol.

Damage Estimates. The damage caused by the atmospheric dispersion of Cs-137 through either the volatile or explosive release mechanism may result in personnel injury or contamination of property. Damage caused by the accident per se is not considered in this analysis (e.g., fire damage or building destruction from blast effects).

Personnel injury, ranging from minor to lethal effects, may be caused by exposure to ionizing radiations. However, the usual criteria such as the LD_{50/30} (i.e., lethal dose to 50 percent of the population in thirty days) are not directly applicable in this case because the dose from internally deposited Cs-137 is not comparable to the dose received in an acute exposure. Although the criteria used for defining the zones of personnel injury were selected arbitrarily, they are not inconsistent with data obtained from animal experiments. Table 2 illustrates the zones and the estimated doses to people remaining within the zone for a 24-hour period following the accident.

Criteria for Zone A were selected on the basis of a total dose greater than 1000 rads whole body exposure. One thousand rads was selected as the approximate LD₅₀ considering the fact that only about 1/10 of the whole body exposure is acute with the remainder distributed according to the 70-day effective half-life of Cs-137 in the

body. Zone B was chosen after similar considerations with the idea that the persons in this zone would require prompt hospitalization and could be hospitalized for a considerable period of time. There would be some prompt lethalties but late effects (e.g., leukemia, life shortening) would predominate. No prompt sickness would be expected in Zone C. However, the radiation level is such that late effects could again be expected. Hospitalization at a later date of persons exposed in Zone C is possible. No detectable biological effects would be expected in Zone D. However, some costs due to minor damage claims and medical examinations, would probably be incurred. Persons outside of Zone D would receive a dose of less than 5 rads and accordingly, no personnel damages would be anticipated.

For all zones, a deposition velocity of 0.03 cm/sec was chosen to calculate the ground deposition. Also, evacuation within one day was assumed for purposes of estimating the external dose from deposited material on the ground.

Property damage criteria are based on confiscation of milk for agricultural areas and on residual dose rates for city areas. The acceptable level of contamination in milk is assumed to be 1.5×10^{-4} μC Cs-137/cc of milk. Unlimited consumption of milk at this initial level by small children will result in whole body doses of < 10 rads(7). Table 3 shows the zones and corresponding dose rates involved.

Table 3

CRITERIA FOR PROPERTY DAMAGE

<u>Zone</u>	<u>Cs-137 Deposited ($\mu\text{C}/\text{m}^2$)</u>	<u>Initial External Dose Rate (rads/yr)</u>	<u>Rural</u>	<u>Urban</u>
E	> 170	> 15	Confiscation of crops for several years. Evacuate residents. Decontaminate land.	Evacuate residents. Extensive decontamination of buildings, streets, etc.
F	55 - 170	5 - 15	Confiscation of current crops. Some evacuation of residents. Decontaminate land.	Evacuate residents. Decontaminate buildings, streets.
G	1.7 - 55	< 5	Confiscation of current milk supplies. Some decontamination of land.	Minor decontamination of property. Some evacuation.

It may not be necessary to evacuate Zone G; however, confiscation of the existing crops, plowing of land, and other decontamination measures would be required. In urban and suburban areas, decontamination measures would include fire hosing of buildings and machinery and plowing open ground.

Persons in Zone F should be evacuated; however, there would be much less urgency in removing the people from this zone as compared to the more highly contaminated zones. Again, this contamination level would require confiscation of crops with the probability of confiscating crops from the succeeding year's harvest.

Zone E would require removing the soil from production for an indefinite period of time on the basis that about 0.1 percent of the deposited cesium would appear in the succeeding crops each year⁽⁸⁾. In urban areas, rigorous decontamination procedures would be required such as fire hosing, removal of surface areas of streets, destruction of wooden buildings, and the use of chemical agents. Data on the capabilities of various reclamation methods are available from tests conducted on debris from radioactive fallout from nuclear weapons testing⁽⁹⁾. This information was used in preparing cost estimates⁽¹⁰⁾.

Economics. The capability of describing the damages from an accident in economic terms is quite limited. Intangible liabilities were not taken into account because of lack of information. Actual claims would probably be settled in court. For the present purpose some estimates for personnel damages are used which were developed for reactor safeguards analyses⁽¹¹⁾. Property damage estimates are based on a local study⁽¹⁰⁾.

The evaluation of both personal injury and property damages in terms of dollars is subject to uncertainties in the significance of radiation levels, in meteorological and biological factors affecting deposition, removal or concentration of Cs-137 in crops, and in the distribution of population and wealth. In any accidental release of Cs-137, criteria for decontamination, confiscation of crops and property, dose levels requiring treatment or hospitalization will be determined by public health authorities and will probably be conservative. It is thought that such conservatism has been incorporated in the criteria developed here.

The conversion of damage to dollar values is further complicated by the inherent mobility of cask shipments. An accidental release in an unpopulated, uncultivated area obviously would result in a much different dollar estimate than a similar release in a metropolitan area. The factors used in this analysis for converting damages to dollars are shown in Table 4. Such factors do not relate specifically to the individual injured or displaced. Rather the factors are intended to apply to the average for all individuals within the zone.

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Table 4

UNIT COSTS FOR PERSONNEL AND PROPERTY DAMAGE

<u>Zone</u>	<u>Type of Damage</u>	<u>Effect</u>	<u>Conversion Factor</u>
A	Personnel	Lethal	\$25,000/person ⁽¹¹⁾
B		Injury	\$50,000/person ⁽¹¹⁾
C		Medical Attention	\$5,000/person ⁽¹¹⁾
D		Evacuation, indefinite	\$1,000/person ⁽¹¹⁾
G		Evacuation, temporary	\$100/person
E	Property ⁽¹⁰⁾	Confiscation of crops for an indefinite period.	\$570,000,000/mi ² - urban
		Extensive decontamination of property. Extended evacuation.	\$300,000/mi ² - rural
F		Confiscation of current crops. Some evacuation of residents. Decontaminate property.	\$4,500,000/mi ² - urban \$200,000/mi ² - rural
G		Confiscation of milk production following accident. Some decontamination of land.	\$4,500,000/mi ² - urban \$450,000/mi ² - suburban
		Small fraction of people evacuated.	\$150,000/mi ² - rural

Table 5 summarizes the dollar evaluations of an accidental release of one percent or ten percent of 90,000 curies of Cs-137 (three casks). The area for each zone was estimated by the diffusion equations as discussed in reference (4). The population density was assumed to be 12,000 and 1,200 people per square mile for urban and suburban areas respectively. These values are typical of Midwestern metropolitan areas. Rural areas were assumed to contain from 20 to 300 people per square mile.

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Table 5

ESTIMATED COSTS OF DAMAGE

Zone	Percent Release	Area Involved (mi ²)	Dollar Value (In Millions of Dollars)					
			Urban*			Rural		
			Personnel	Property	Total	Personnel	Property	Total
A	1	< 10 ⁻⁵	--**		--	--		--
	10	6 x 10 ⁻⁵	--	N.A.***	--	--	N.A.	--
B	1	< 10 ⁻⁵	--		--	--		--
	10	2 x 10 ⁻⁴	--	N.A.	--	--	N.A.	--
C	1	6 x 10 ⁻⁵	--		--	--		--
	10	4 x 10 ⁻³	0.25	N.A.	0.25	--	N.A.	--
D	1	0.01	0.10		0.10	--		--
	10	0.4	5.0	N.A.	5.0	0.1	N.A.	0.1
E	1	3 x 10 ⁻⁴		0.17	0.17		--	--
	10	2 x 10 ⁻²	N.A.	11.0	11.0	N.A.	--	--
F	1	0.1		0.45	0.45		--	--
	10	2.0	N.A.	9.0	9.0	N.A.	0.4	0.4
G	1	10	10	45	55	0.3	1.5	1.8
	10	100	80	280	360	3.0	15.0	18.0
Total		1			60			2
		10			400			20

* The urban area is considered to be 60 square miles.

** The dash lines indicate insignificant values.

*** Not applicable. Damages are included in a larger zone.

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VI. RELEASE TO A RIVER

The release of Cs-137 into a river could take place on a bridge or along portions of the railroad which closely parallel a stream. The rate at which Cs-137 would be eluted from Decalso can be estimated by comparison with Sr-90 elution reported in reference (1) which states in part, "on the basis of a single experiment using water containing 23 ppm calcium, 6 ppm sodium and 3 ppm magnesium, the time required to elute 50 percent of the Sr-90 from the Decalso in a flowing stream is indicated to be about 40 hours . . . The rate of elution of the Sr-90 will be about 1.04×10^4 $\mu\text{c}/\text{second}$ based on the experimental data".

Comparative elution rates of Cs-137 and Sr-90 observed at HAP0^(12,13,14) indicate that Cs-137 would be eluted at about four times the rate for Sr-90 on the basis of $\mu\text{c}/\text{g}$ Decalso. The elution rate studies at HAP0 were conducted using simulated river water which had about the same calcium content but 10 times more sodium than the Clinch River (ORNL studies). The elution rate in other rivers could be greater than that in the Clinch River, but it probably differs by less than an order of magnitude.

Using these elution rates and assuming that three STT casks, each loaded with 30,000 curies of Cs-137, are involved in the same accident, the concentration in streams is estimated as shown in Table 6.

Table 6

CONCENTRATION OF Cs-137 IN RIVER WATER

<u>River Flow</u>	<u>Initial Concentration*</u>
(cfs)	($\mu\text{c}/\text{cc}$)
10^3	4×10^{-2}
10^4	4×10^{-3}
10^5	4×10^{-4}

* Based on an estimated elution rate of 4,500 curies/hour.

The data contained in Table 6 indicate that the concentration of Cs-137 would exceed the maximum permissible concentration for continuous occupational exposure (MPC_w); 2×10^{-4} μc Cs-137/cc. The actual concentration of Cs-137 would depend upon the flow rate of the river

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at the time of the incident and the mineral content. The maximum concentration of Cs-137 would persist for about a day.

The MPC_w was derived on the basis that continuous consumption of water at that level would result in a whole body dose of approximately 5 rem per year or a corresponding body burden of 30 μ c. The dose to persons who consume water from municipal plants deriving their supply from the river of interest would therefore be insignificant because of the short duration of the peak concentrations.

In the process of water treatment, the concentration of Cs-137 would be reduced to about one-half the concentration in the river water, depending primarily on the turbidity of the river and the filtration of the water. Other ordinary means of water treatment are comparatively ineffective for Cs-137 removal⁽¹⁶⁾. Therefore, some costs may be incurred in decontamination of water treatment plants.

In the larger rivers involving a major portion of the commercial fishing industry, uptake of Cs-137 in food fish would be minor. Studies in a pond-type aquatic community have shown that more than three weeks exposure is required to approach an equilibrium concentration of Cs-137 in fish^(17,18).

Because of the short duration of the peak concentrations, the uptake of Cs-137 by irrigated produce would be minor.

The damages which would be incurred from the release of Cs-137 to a river are estimated to be considerably less than the damages resulting from release to the atmosphere. The major costs associated with damages from such an accident (other than direct cask recovery operations) would probably be the provision of monitoring to assure that exposure is within appropriate limits after passage of the contaminated river water.

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