ontario hydro
research division

UNRESTRICTED

To Mr. F.J. Simpson
Director of Research

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

A.S. Williamson

The bituminization of decontamination and ion exchange resin stripping wastes with four grades of asphalt was investigated to determine the effects of asphalt type on the properties of the final products. All waste forms deformed readily under light loads indicating they would flow if not restrained. It was observed in all cases that product leaching rates increased as the hardness of the asphalt used to treat the waste increased. If bituminization is adopted for any Ontario Hydro aqueous radioactive wastes they should be treated with soft asphalt to obtain optimum leaching resistance and mechanical stability during interim storage should be provided by a corrosion resistant container.

Immobilization of radioactive waste is required to minimize future radionuclide release to the environment particularly in the case of water contact with the waste. The good water resistance and demonstrated long term stability of asphalt created interest in the use of this material as an immobilization agent for low to medium level radioactive wastes and a review of research and operating experience showed substantial acceptance of bituminization as a treatment for many research, power reactor and fuel reprocessing wastes/1/.

Radioactive wastes generated by Ontario Hydro which require immobilization consist of decontamination and possibly ion exchange treatment chemicals which can differ significantly from the wastes processed by others. To assess the suitability of bituminization for Ontario Hydro use, some typical aqueous wastes were treated at AECL, CRNL with a 60-70 penetration direct distilled asphalt and the leaching performance of the products determined over one year/2/. The leach data were sufficiently encouraging that a more comprehensive study involving four grades of asphalt and four aqueous wastes was undertaken. The selected asphalts have the basic characteristics listed in Table I and are a representative cross section of the grades readily available in Ontario.

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TABLE I

ASPHALT SPECIFICATIONS

Designation	Asphalt Emulsion	60-70	BUR III	10 Pen
Type	direct distilled	direct distilled	oxidized	direct distilled
Penetration @25°C ASTM D5	150-200	60-70	16	10
Softening Point (°C) ASTM D36	44	51	95	68
Ductility @25°C ASTM D113	1500+	1500+	28	80
Flash Point (°C) ASTM D92	277	266	260	288
Density @25°C	1.03	1.03	1.02	1.06

The aqueous wastes consisted of three decontamination solutions and an ion exchange resin stripping waste the compositions of which are given in Appendix 1. A CRNL reverse osmosis waste was also incorporated into the asphalt emulsion.

This report describes the preparation of the bituminized products and discusses their physical properties and leaching performance.

EXPERIMENTAL RESULTS

Waste Bituminization

The bituminized waste products were prepared at AECL, CRNL using a Werner and Pfleiderer 28 mm twin screw evaporator/extruder to process the hot melt asphalt materials and a Luwa wiped thin-film evaporator for the asphalt emulsion. Machine operation and other processing details are listed in Appendix 2.

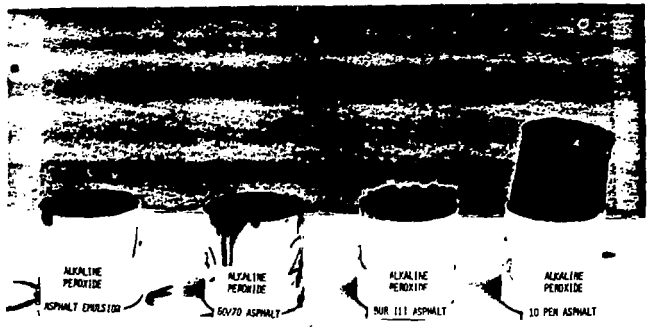
Difficulties were experienced in the bituminization of Turco 4521A with the three grades of hot melt asphalt and satisfactory final products could not be obtained.

In the bituminization of alkaline permanganate waste the substantial viscosity increase during processing with the BUR III and 10 Pen asphalts resulted in rubberlike final products which were difficult to pack into the specimen containers.

Leaching Resistance

Leaching resistance testing was conducted in accordance with the IAEA Intercomparison Method/3/. Incremental and cumulative radionuclide release data for the six month test period are tabulated in Appendix 3. The cumulative release data are also presented in graph form in Appendix 4.

After 28 days immersion in demineralized water the alkaline peroxide waste products formed with the two hard asphalts had swollen. The volume change illustrated by Figure 1 was particularly pronounced in the 10 Pen asphalt product.



(R79-3045)

FIGURE 1

BITUMINIZED ALKALINE PEROXIDE WASTE PRODUCTS AFTER 28 DAYS LEACHING

This swelling phenomenon was not observed with any of the other wastes as shown in Appendix 5 and continued water immersion did not produce further volume increases in the affected products.

Physical Properties

Softening points, auto-ignition temperatures and creep resistance were determined by thermal analysis of the waste forms made with the four asphalts/8/. As shown in Table II, the incorporation of waste into the asphalts consistently increased softening point

and auto-ignition temperatures from the values determined for the pure asphalts.

TABLE II

SOFTENING AND AUTO-IGNITION POINTS OF BITUMINIZED PRODUCTS

	Emulsion			60-70			BUR III			10 Pen		
	Pure	Filled		Pure	Filled		Pure	Filled		Pure	Filled	
		A	B		A	B		A	B		A	B
Softening Pt °C	38	45	51	55	61	91	94	99	>200	103	113	>200
Auto-ignition °C	433	448	502	415	496	521	426	453	482	414	470	482

A: alkaline peroxide B: alkaline permanganate

While part of the softening point and auto-ignition temperature increases may be related to the presence of filler most is probably due to the removal of volatile oils and oxidation of the asphalts during the high temperature processing.

Creep measurements on pure asphalts and bituminized waste products shown in Appendix 6 revealed all materials deformed significantly under relatively small loads with the exception of the 10 Pen asphalt/alkaline permanganate product which exhibited rubberlike behaviour. The creep rates of filled products were only slightly lower than their equivalent pure asphalts.

Discussion

Although bituminization is a relatively simple process where product solidification is achieved by cooling of the mixed material rather than by chemical reaction it cannot be assumed that it will be suitable in all cases. The manufacturing difficulties experienced with certain wastes indicate the need for preproduction trials to determine necessary waste preconditioning, asphalt grade, and operating parameters to obtain a satisfactory final product.

The swelling on leach testing of the alkaline peroxide/hard asphalt waste products is similar to that reported by Karlsruhe Nuclear Research Centre and Brookhaven National Laboratory for products containing sodium sulphate and sodium carbonate/4,5/. In these cases the swelling was attributed to the sodium salts being in the anhydrous form with considerable affinity for water of crystallization

after passage through the bituminization equipment. Any uptake of water increases the volume of the salts with a corresponding rise in product volume. The alkaline peroxide waste contains sodium carbonate and would be subject to the same mechanism. The restriction of product swelling to the hard asphalts suggests they are not as effective as the soft asphalts for encapsulating the salt agglomerates with a waterproof layer.

The leach test data show an interesting relationship between waste product leaching resistance and asphalt hardness with the leach rate for all waste product types increasing with increasing asphalt hardness. As shown in Figure 2 the use of a soft grade of asphalt to bituminize a waste can result in leach rates 2-4 orders of magnitude lower than when the waste is treated with a hard asphalt.

It has been shown that the water solubilities and permeabilities of different asphalts are essentially similar regardless of source, grade, chemical composition or treatment/6,7/. The reduced leaching resistance of the wastes treated with hard asphalt coupled with the swelling of the alkaline peroxide/hard asphalt products suggests hard asphalts have poorer wetting and penetrating ability than soft asphalts. This results in less complete encapsulation of the individual waste particles with a waterproof layer allowing easy water access to some portions of the waste.

The physical properties of bituminized wastes have been of some concern because of the fluidity of asphalt and hard asphalts have generally been selected as the encapsulating media with a view to minimize product creep. It should be recognized that all asphalts are visco-elastic materials which will flow more or less readily unless physically restrained. Even fillers which increase the viscosity of the asphalt will not prevent product creep with the passage of time. It can be postulated that the inherent fluidity of asphalt could be a disadvantage only in the interim storage stage where reliance has to be placed on the waste container to confine the product for easy retrieval. Under disposal conditions it can be assumed the containers will eventually disintegrate allowing the bituminized product to flow. In this situation there will be little difference between asphalt grades in the extent of flow and product resistance to leaching by water will be the most important criterion. These considerations indicate the desirability of using soft asphalt for radwaste bituminization to obtain uniform homogenous products with good leaching resistance. The waste product can be packaged in containers having sufficient mechanical stability and corrosion resistance to withstand interim storage without loss of integrity.

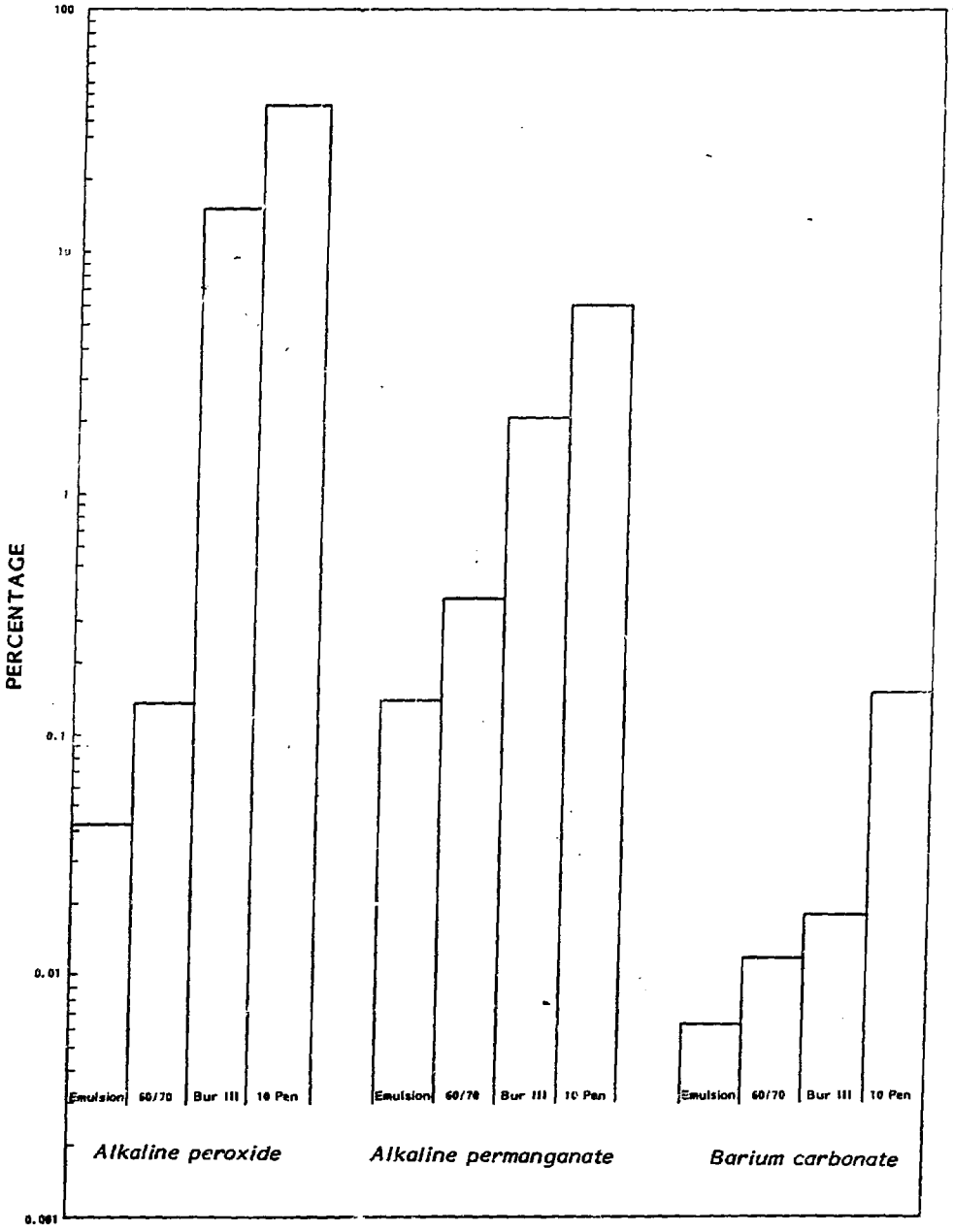


FIGURE 5

CUMULATIVE PERCENTAGE RADIONUCLIDES, LEACHED FROM BITUMINIZED WASTES OVER SIX MONTHS

149816 RD

CONCLUSIONS

The bituminization of several aqueous radioactive wastes with four different grades of asphalt has been investigated to ascertain the influence of asphalt type on processing, product properties, and leaching resistance.

To avoid possible processing difficulties before bituminization of aqueous wastes, preproduction trials should be conducted to determine waste preconditioning requirements, asphalt grade, and operating parameters to obtain a satisfactory final product.

Soft grades of asphalt blend easily with waste feedstocks in most instances, mixture flow through the equipment is uniform and smooth homogenous products are obtained. Hard asphalts can thicken almost to the consistency of rubber during processing giving rise to erratic flow and non-uniform final products.

A relationship between asphalt hardness and leaching performance has been identified. The leach rate of the bituminized waste products increased with increasing hardness of asphalt used to encapsulate the waste.

The types of aqueous radioactive waste generated by Ontario Hydro for which bituminization might be considered should be encapsulated in soft asphalt to obtain best leaching resistance. The necessary mechanical stability required by the waste product during interim storage should be provided by a suitable container.

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REFERENCES

1. Ontario Hydro Research Division Report No 76-437-K.

2. Ontario Hydro Research Division Report No 79-13-K.

3. Hespe, E.D., (Ed), Leach Testing of Immobilized Radioactive Waste Solids, Atom Energy Rev, 9, 1, 1971.

4. Hild, W., Kluger, W., Krause, H., Bituminization of Radioactive Wastes at NRC, Karlsruhe Proc OECD Seminar, Antwerp, 1976.

5. Colombo, P., Neilson, R.M., Properties of Radioactive Wastes and Waste Containers, Progress Report No 7, May, 1978, Brookhaven National Laboratory.

6. Alexander, S.H., and Shurden, J.D., Advances in Petroleum Chemistry and Refining, Vol V, Interscience, New York, p 260-262, 1962.

7. Anderson, A.P., and Wright, K.A., Ind Eng Chem, 33, 991, 1941.

8. Ontario Hydro Research Division Report No 80-319-K.

APPENDIX 1

WASTE FEED COMPOSITIONS

TURCO 4521 A

g	
100	Turco 4521A
900	water
1000	

Original pH 3.9. Adjusted to 9 with sodium hydroxide before bituminization.

ALKALINE PEROXIDE

g	
72	sodium carbonate
21	sodium bicarbonate
3	EDTA
904	water
1000	

Original pH 9.9. No adjustment made.

ALKALINE PERMANGANATE

g	
84	sodium hydroxide
25	potassium permanganate
891	water
1000	

Original pH 14. Adjusted to 9 with sulphuric acid before bituminization.

BARIUM CARBONATE

g	
100	barium carbonate
900	water
1000	

Original pH 8.6. No adjustment made.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Turco 4521A 100 g/kg

pH: 3.5 and adjusted to 9.1 with sodium hydroxide

ASPHALT GRADE: 60/70 pen direct distilled

SCREW SPEED (RPM): 300

TORQUE (N·m): 42

WASTE FEED RATE (kg/h): 4.3

ASPHALT FEED RATE (kg/h): 4.0

EXTRUDER BARREL TEMP (°C):

1	2	3	4	5
100	115	130	160	155

PRODUCT FLOWRATE (kg/h): 1.1

WASTE CONCENTRATION IN PRODUCT (g/kg): 395

CONDENSATE FLOWRATE (kg/h): 3.6

CONDENSATE REMOVAL AT DOMES (%):

1	2	3
--not obtained--		

OBSERVATIONS:

When the Turco was processed at pH 3.5 the product was dry, porous and coke like. After pH adjustments to 8.5 to 9.1, continued unsatisfactory product characteristics and uncontrollable frothing of the mixture resulting in condenser blockage were found at all waste feed rates possible.

Bituminization of Turco 4521A with the 60-70 pen asphalt was discontinued.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline peroxide (100 g/kg) **pH:** 9.9

ASPHALT GRADE: 60/70 pen direct distilled

SCREW SPEED (RPM): 300 **TORQUE (N·m):** 22

WASTE FEED RATE (kg/h): 4.5 **ASPHALT FEED RATE (kg/h):** 0.6

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	122	119	134	157	155

PRODUCT FLOWRATE (kg/h): 1.0

WASTE CONCENTRATION IN PRODUCT (g/kg): 450

CONDENSATE FLOWRATE (kg/h): 3.7

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	38	43	19
CONDENSATE pH AT DOMES:	7	5.2	6.0

OBSERVATIONS:

No processing difficulties. Uniform product with good flow and no visible foam.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline permanganate (100 g/kg) **pH:** 9 (adjusted with sulphuric acid)

ASPHALT GRADE: 60/70 pen direct distilled

SCREW SPEED (RPM): 300 **TORQUE (N·m):** 23

WASTE FEED RATE (kg/h): 4.5 **ASPHALT FEED RATE (kg/h):** 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	117	115	125	170	168

PRODUCT FLOWRATE (kg/h): 1.2

WASTE CONCENTRATION IN PRODUCT (g/kg): 410

CONDENSATE FLOWRATE (kg/h): 4.3

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	38	36	26
CONDENSATE pH AT DOMES:	10.5	10.4	10.2

OBSERVATIONS:

No processing difficulty, uniform product with good flow.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Barium carbonate (100 g/kg) pH: 8.6

ASPHALT GRADE: 60/70 pen direct distilled

SCREW SPEED (RPM): 300 TORQUE (N·m): 19

WASTE FEED RATE (g/h): 4.5 ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	116	118	126	161	169

PRODUCT FLOWRATE (kg/h): 1.2

WASTE CONCENTRATION IN PRODUCT (g/kg): 410

CONDENSATE FLOWRATE (kg/h): 3.3

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	60	2*	38
CONDENSATE pH AT DOMES:	8.3	--	7.4

OBSERVATIONS:

* No 2 dome became blocked as a result of asphalt frothing during the run believed to be due to incomplete removal of Turco 4521A from machine.

Good uniform product obtained which showed slight shrinkage on cooling probably because of air entrainment during processing.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline peroxide (100 g/kg) pH: 9.9

ASPHALT GRADE: BUR III oxidized

SCREW SPEED (RPM): 300 TORQUE (N·m): 23

WASTE FEED RATE (kg/h): 4.5 ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	119	118	132	173	170

PRODUCT FLOWRATE (kg/h): 1.2

WASTE CONCENTRATION IN PRODUCT (g/kg): 420

CONDENSATE FLOWRATE (kg/h): 3.7

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	41	40	19
CONDENSATE pH AT DOMES:	8	6.2	7.1

OBSERVATIONS:

No operating difficulties. Product flow from machine tended to be erratic giving some doubts about product homogeneity.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline permanganate (100 g/kg)

pH: 9.9 (adjusted with sulphuric acid)

ASPHALT GRADE: BUR III oxidized

SCREW SPEED (RPM): 300

TORQUE (N·m): 28

WASTE FEED RATE (kg/h): 4.5

ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	118	116	121	169	167

PRODUCT FLOWRATE (kg/h): 1.0

WASTE CONCENTRATION IN PRODUCT (g/kg): 390

CONDENSATE FLOWRATE (kg/h): 3.9

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	48	40	12
CONDENSATE pH AT DOMES:	8.5	7.9	8.5

OBSERVATIONS:

Product very rubbery and would not flow readily from the extruder into the waste container.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Barium carbonate 100 g/kg pH: 9.7

ASPHALT GRADE: BUR III oxidized

SCREW SPEED (RPM): 300 TORQUE (N·m): 23

WASTE FEED RATE (kg/h): 4.5 ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	118	116	120	171	170

PRODUCT FLOWRATE (kg/h): 1.1

WASTE CONCENTRATION IN PRODUCT (g/kg): 400

CONDENSATE FLOWRATE (kg/h): 3.7

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	45	37	18
CONDENSATE pH AT DOMES:	7.4	7.9	8

OBSERVATIONS:

No extruder operating problems. Product uniform and smooth.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Turco 4521 A (100 g/kg)

pH: 8.6 (adjusted with sodium hydroxide)

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300

TORQUE (N·m): 42

WASTE FEED RATE (kg/h): 4.2

ASPHALT FEED RATE (kg/h): 3.9

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	115	119	135	168	170

PRODUCT FLOWRATE (kg/h): 4.3

WASTE CONCENTRATION IN PRODUCT (g/kg): 97

CONDENSATE FLOWRATE (kg/h): 3.4

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	51	35	14
CONDENSATE pH AT DOMES:	10.6	10.8	11.3

OBSERVATIONS:

Extensive frothing in extruder gave aerated product resulting in considerable shrinkage in containers.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Turco 4521-A (100 g/kg) pH: 8.6

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300 TORQUE (N·m): 28

WASTE FEED RATE (kg/h): 4.2 ASPHALT FEED RATE (kg/h): 1.0

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	116	115	123	146	155

PRODUCT FLOWRATE (kg/h): 1.46

WASTE CONCENTRATION IN PRODUCT (g/kg): 260

CONDENSATE FLOWRATE (kg/h): 3.8

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	47	40	13
CONDENSATE pH AT DOMES:	10.45	10.8	11.0

OBSERVATIONS:

Slight frothing of mixture. Extruded product had poor flow probably due to aeration and had to be packed down in the waste containers.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: TURCO 4521-A (100 g/kg) pH: 8.6

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300 TORQUE (N·m): 28

WASTE FEED RATE (kg/h): 4.2 ASPHALT FEED RATE (kg/h): 1.0

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	116	115	123	146	155

PRODUCT FLOWRATE (kg/h): 1.46

WASTE CONCENTRATION IN PRODUCT (g/kg): 260

CONDENSATE FLOWRATE (kg/h): 3.8

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	47	40	13
CONDENSATE pH AT DOMES:	10.45	10.8	11.0

OBSERVATIONS:

Slight frothing of mixture. Extruded product had poor flow probably due to aeration and had to be packed down in the waste containers.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: TURCO 4521-A (100 g/kg) pH: 8.6

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300 TORQUE (N·m): 24

WASTE FEED RATE (kg/h): 4.2 ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	117	117	123	157	165

PRODUCT FLOWRATE (kg/h): 1.1

WASTE CONCENTRATION IN PRODUCT (g/kg): 400

CONDENSATE FLOWRATE (kg/h): 3.7

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	44	34	22
CONDENSATE pH AT DOMES:	10.3	10.5	10.7

OBSERVATIONS:

Product thick with almost no flow. Two sets of leaching samples prepared:

a) as extruded

b) covered with 5 mm layer of pure 10 pen asphalt.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline peroxide (100 g/kg) **pH:** 9.7

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300 **TORQUE (N·m):** 25

WASTE FEED RATE (kg/h): 4.5 **ASPHALT FEED RATE (kg/h):** 0.7

EXTRUDER BARREL TEMP (°C):

1	2	3	4	5
122	118	128	168	170

PRODUCT FLOWRATE (kg/h): 1.1

WASTE CONCENTRATION IN PRODUCT (g/kg): 380

CONDENSATE FLOWRATE (kg/h): 3.8

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	47	40	13
CONDENSATE pH AT DOMES:	9.4	6.7	8.7

OBSERVATIONS:

No operating difficulties, product appeared to be uniform.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Alkaline permanganate (100 g/kg)

pH: 8.4 (adjusted with sulphuric acid)

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300

TORQUE (N·m): 41

WASTE FEED RATE (kg/h): 4.5

ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	119	118	130	169	168

PRODUCT FLOWRATE (kg/h): 1.12

WASTE CONCENTRATION IN PRODUCT (g/kg): 390

CONDENSATE FLOWRATE (kg/h): 3.7

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	43	40	17
CONDENSATE pH AT DOMES:	8.3	7.7	6.0

OBSERVATIONS:

The extruded product was very spongy and had poor flow so that it had to be packed into the containers.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

TWIN SCREW EXTRUDER PROCESSING DATA

WASTE FEED: Barium carbonate (100 g/kg) pH: 7.8

ASPHALT GRADE: 10 pen direct distilled

SCREW SPEED (RPM): 300 TORQUE (N·m): 25

WASTE FEED RATE (kg/h): 4.5 ASPHALT FEED RATE (kg/h): 0.7

EXTRUDER BARREL TEMP (°C):	1	2	3	4	5
	117	118	125	173	170

PRODUCT FLOWRATE (kg/h): 1.12

WASTE CONCENTRATION IN PRODUCT (g/kg): 390

CONDENSATE FLOWRATE (kg/h): 3.78

	1	2	3
CONDENSATE REMOVAL AT DOMES (%):	43	40	17
CONDENSATE pH AT DOMES:	6.35	6.6	5.5

OBSERVATIONS:

Good uniform product.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

WIPED THIN FILM EVAPORATOR PROCESSING DATA

WASTE FEED: TURCO 4521-A (50 g/kg) pH: 8.6 (adjusted with sodium hydroxide)

ASPHALT GRADE: 150/200 pen direct distilled emulsion (600 g/kg)

WASTE FEED RATE (kg/h): 51.7 ASPHALT FEED RATE (kg/h): 7.1

EVAPORATOR JACKET TEMP (°C): 170

PRODUCT TEMP (°C): 149

PRODUCT FLOW RATE (kg/h): 6.8

WASTE CONCENTRATION IN PRODUCT (g/kg): 380

DISTILLATE FLOW RATE (kg/h): 52.6 pH: 10.7

OBSERVATIONS:

No operating difficulties. Product smooth and uniform.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

WIPED THIN FILM EVAPORATOR PROCESSING DATA

WASTE FEED: Alkaline peroxide (48 g/kg) pH: 9.7

ASPHALT GRADE: 150/200 pen direct distilled emulsion (600 g/kg)

WASTE FEED RATE (kg/h): 52 ASPHALT FEED RATE (kg/h): 7

EVAPORATOR JACKET TEMP (°C): 171

PRODUCT TEMP (°C): 145

PRODUCT FLOW RATE (kg/h): 6.8

WASTE CONCENTRATION IN PRODUCT (g/kg): 400

DISTILLATE FLOW RATE (kg/h): 52 pH: 7.8

OBSERVATIONS:

Smooth uniform product, no shrinkage on cooling.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

WIPED THIN FILM EVAPORATOR PROCESSING DATA

WASTE FEED: Alkaline permanganate (50 g/kg) pH: 11.3

ASPHALT GRADE: 150/200 pen direct distilled emulsion (600 g/kg)

WASTE FEED RATE (kg/h): 53.7 ASPHALT FEED RATE (kg/h): 7

EVAPORATOR JACKET TEMP (°C): 171

PRODUCT TEMP (°C): 143

PRODUCT FLOW RATE (kg/h): 6.9

WASTE CONCENTRATION IN PRODUCT (g/kg): 390

DISTILLATE FLOW RATE (kg/h): 51.7 pH: 8.3

OBSERVATIONS:

Product rubbery with poor flow giving rough textured specimens.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

WIPED THIN FILM EVAPORATOR PROCESSING DATA

WASTE FEED: Barium carbonate (50 g/kg) pH: 7.7

ASPHALT GRADE: 150/200 pen direct distilled emulsion (600 g/kg)

WASTE FEED RATE (kg/h): 52 ASPHALT FEED RATE (kg/h): 6.4

EVAPORATOR JACKET TEMP (°C): 171

PRODUCT TEMP (°C): 121

PRODUCT FLOW RATE (kg/h): 8.5

WASTE CONCENTRATION IN PRODUCT (g/kg): 400

DISTILLATE FLOW RATE (kg/h): 52 pH: 9.4

OBSERVATIONS:

Product had heavy cream-like consistency.

APPENDIX 2

AQUEOUS RADIOACTIVE WASTE BITUMINIZATION

WIPED THIN FILM EVAPORATOR PROCESSING DATA

WASTE FEED: CRNL Reverse Osmosis pH: 6.0

ASPHALT GRADE: 150/200 pen direct distilled emulsion (600 g/kg)

WASTE FEED RATE (kg/h): 50.7 ASPHALT FEED RATE (kg/h): 4.2

EVAPORATOR JACKET TEMP (°C): 196

PRODUCT TEMP (°C): 115

PRODUCT FLOW RATE (kg/h): 5.7

WASTE CONCENTRATION IN PRODUCT (g/kg): 390

DISTILLATE FLOW RATE (kg/h): 46 pH: 6.3

OBSERVATIONS:

Smooth solid uniform product.

APPENDIX 1

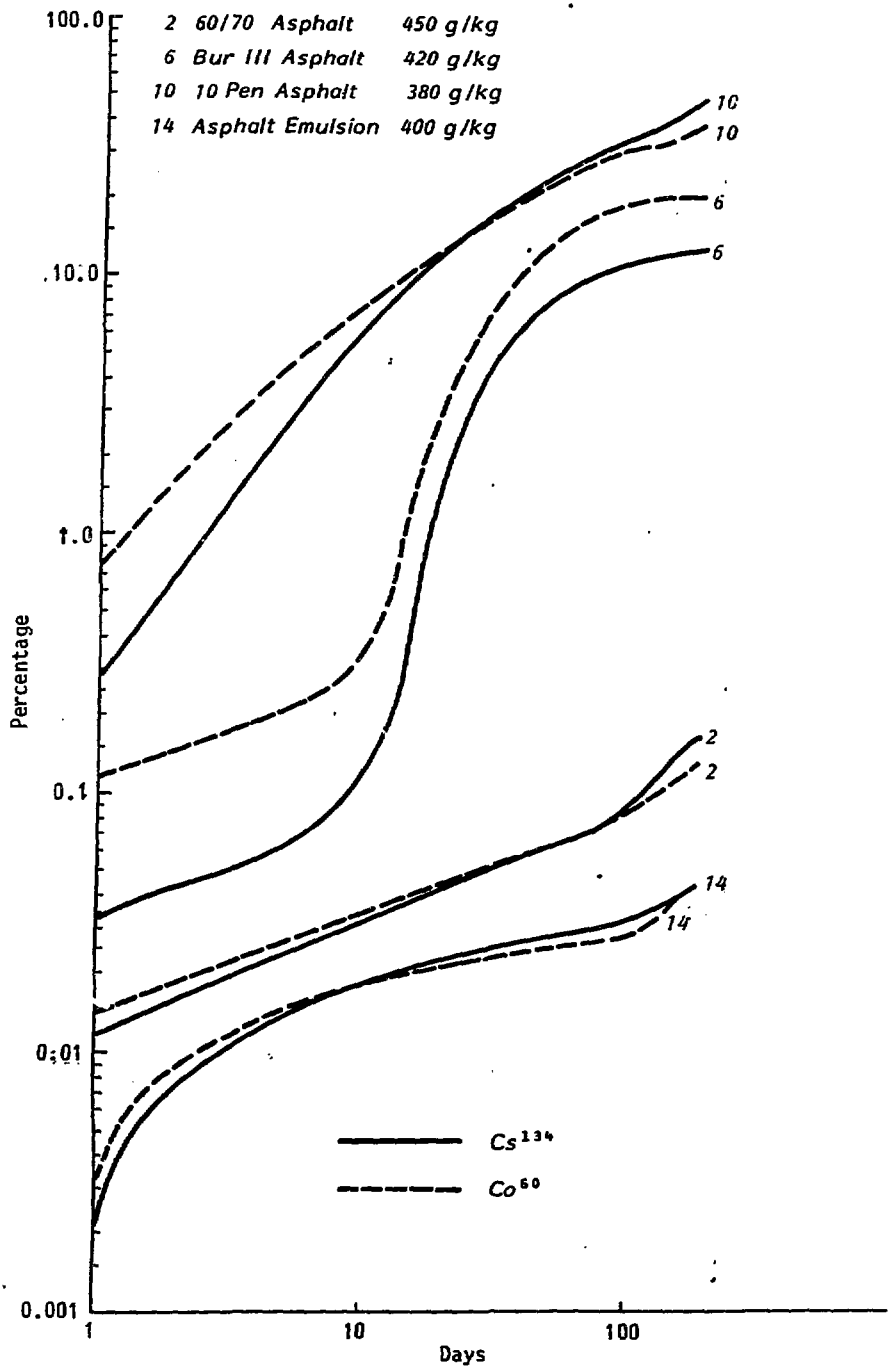
(a) INCREMENTAL ACTIVITY LEACHED FROM WASTE PRODUCTS

		60/70 ASPHALT			BUR III ASPHALT			10 PEN ASPHALT							ASPHALT EMULSION				
		2	3	4	6	7	8	9a	9b	9c	9d	10	11	12	13	14	15	16	
Sample Volume ~100 ml Exposed Surface 24hr		Alkaline Peroxide 450 g/kg	Alkaline Permanganate 410 g/kg	Barium Carbonate 410 g/kg	Alkaline Peroxide 420 g/kg	Alkaline Permanganate 590 g/kg	Barium Carbonate 400 g/kg	Turco 4521 A 37 g/kg	Turco 4521 A 260 g/kg	Turco 4521 A 400 g/kg	4521 A + Lift Pack 400 g/kg	Alkaline Peroxide 380 g/kg	Alkaline Permanganate 390 g/kg	Barium Carbonate 390 g/kg	Turco 4521 A 380 g/kg	Alkaline Peroxide 400 g/kg	Alkaline Permanganate Notek 240 390 g/kg	Barium Carbonate 400 g/kg	Reverse Osmosis 390 g/kg
Weight	g	126.3	152.5	89.5	126.0	122.4	134.0	111.4	114.9	124.9	126.1	133.8	146.7	134.8	125.8	123.0	142.3	92.9	117.1
Sample Activity	Co^{60} pCi	451.3	321.15	341.85	275.4	217.8	332.55	77.85	207.45	116.95	290.15	204.1	224.5	287.25	138.7	540.9	116.3	204.8	130.5
	Cs^{134} pCi	155.4	165.15	100.05	165.5	108.15	147.45	34.5	89.4	142.15	144.75	131.55	91.5	127.05	129.6	231.0	107.1	181.1	130.2
Incremental Activity Released pCi		Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}	Cs^{134} Co^{60}
DAY	1	18 64	16 1.5	0.75 0.48	48 314	17 4.4	0.86 2.1	5.7 12	518 [illegible]	[illegible]	[illegible]	1[illegible] 2000 160	0.89 2.1	5.4	2.98 2.85	5.1 14	11.22 0.67	1.89 1.56	1.48 1.82
	2	7.1 26	14 0.82	0.21 0.23	16.5 119	6.1 1.5	0.37 0.73	1.1 2.4	246 [illegible]	[illegible]	[illegible]	[illegible]	0.69 2.5	[illegible]	0.93 1.04	15.2 19.6	4.55 0.48	0.90 1.02	0.71 0.78
	3	1.2 9.71	6.8 0.55	0.26 0.65	6.8 90.9	8.4 1.2	0.32 0.88	0.7 1.6	196 [illegible]	[illegible]	[illegible]	[illegible]	1.21 0.67	2.25	0.62 0.88	6.9 14	4.17 0.48	0.65 0.74	0.51 0.56
	4	2.3 8.10	6.7 0.92	0.22 1.12	5.59 43.7	6.4 1.1	0.32 1.34	0.78 2.69	179 [illegible]	[illegible]	[illegible]	1030 [illegible]	1.12 0.88	2.71	0.11 0.21	4.1 8.44	5.22 0.12	0.40 0.83	0.52 0.86
	7	5.13 18.5	15.8 0.82	0.21 1.21	13.0 97.7	19.0 1.42	0.52 1.57	1.43 4.12	466 [illegible]	[illegible]	[illegible]	1986 [illegible]	2.22 3.42	10.8	[illegible]	3.7 9.5	[illegible]	[illegible]	[illegible]
WEEK	2	19 52	55 0.89	0.42 1.4	187 185	52 2.4	2.4 5.2	5.4 14.2	992 1510	[illegible]	[illegible]	[illegible]	1.15	10000	191 2.8	5.1 16	1.11 1.44	2.6 5.3	10.9 0.17	0.99 1.20	1.74 1.85
	3	12 32	64 4.1	5.5 0.97	2870 7160	61 2.0	2.6 2.7	17 11	550 [illegible]	[illegible]	[illegible]	9090 9090	117 1.5	24 12	2.74 3.96	8.3 6.0	13.4 0.12	0.54 0.68	1.78 2.03
	4	1.4 3.1	39 0.75	4.7 1.2	2757 10660	45 1.6	1.4 2.6	9.1 23	445 [illegible]	[illegible]	[illegible]	[illegible]	1.6	9000 9000	113 1.2	9.3 13	3.67 3.75	6.6 8.9	17.7 0.14	1.06 1.04	4.55 1.39
MONTH	2	14.3 45	137 0.10	1.8 2.7	7306 22470	178 3.0	2.96 7.5	23.0 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.7	[illegible]	12.0 8.3	8.4 23.4	47.4 0.16	0.55 3.70	32.7 11.6
	3	40.5 90.7	286 2.74	3.6 3.5	2025 5321	927 37	7.12 12.5	48.8 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.0	74.0 39.4	8.2 19.0	69.1 0.13	0.97 2.3	25.1 22.7
	4	← DATA NOT GIVEN →																	
	5	86.2 171.7	334 7.45	1.5 1.8	1564 4096	582 73	8.1 9.9	65.3 [illegible]	2870 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	116.4	67.0 14.0	19.1 51.7	55.0 0.00	1.30 1.50	17.0 16.0
	6	21.0 35.0	176 1.1	1.1 1.1	481 1060	2416 215	4.8 5.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62.0 [illegible]	[illegible]	[illegible]	0.41 1.4	1.2 14.0 14.0
	12																		
	18																		
	24																		

APPENDIX 1

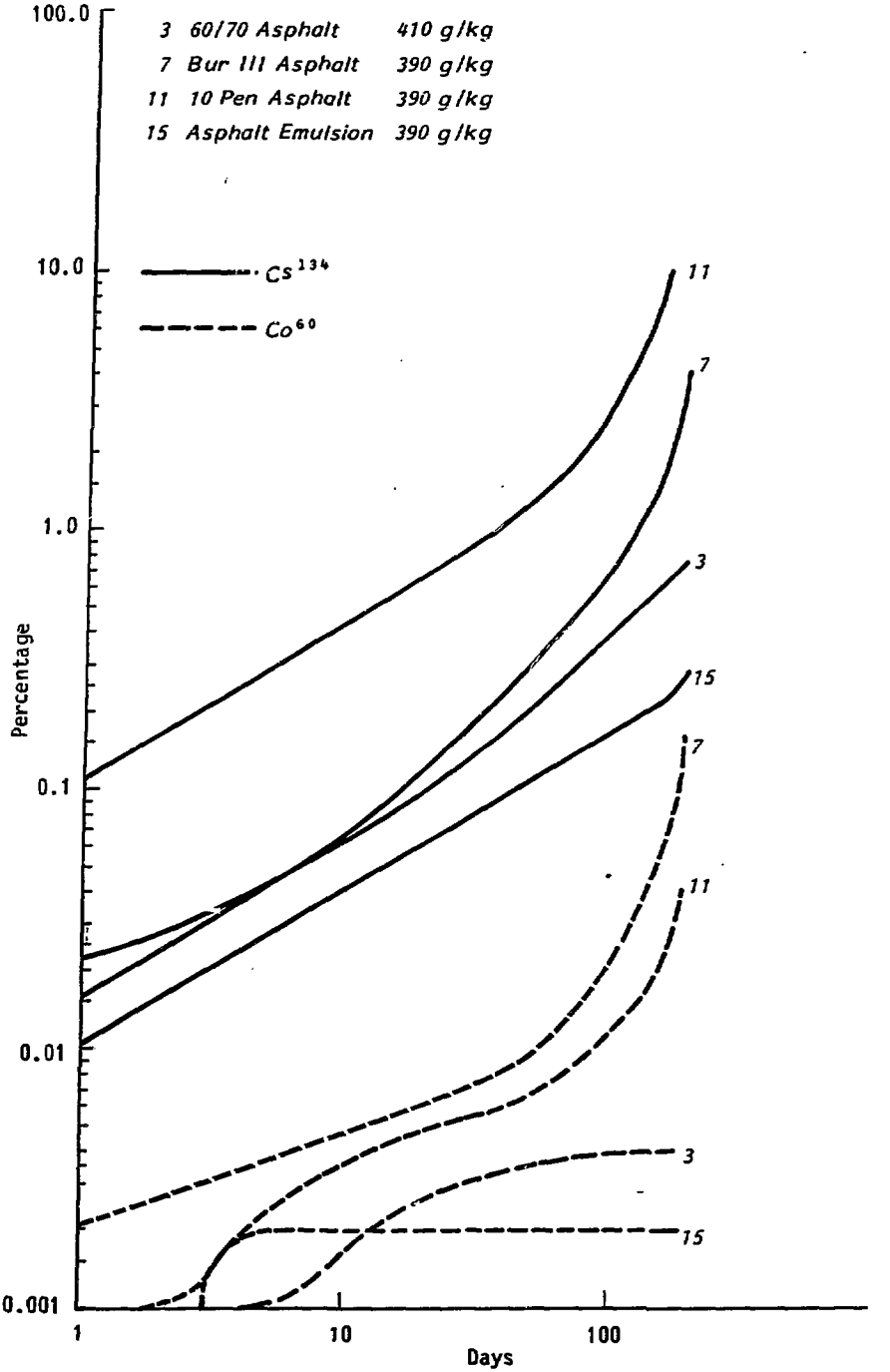
(b) CUMULATIVE PERCENTAGE ACTIVITY LEACHED FROM WASTE PRODUCTS

		60/70 ASPHALT						BUS III ASPHALT						10 PEN ASPHALT												ASPHALT EMULSION											
		2		3		4		6		7		8		9a		9b		9c		9c1		10		11		12		13		14		15		16			
Sample Volume ~100 ml Exposed Surface ~1963 mm^2		Alkaline Peroxide 450 g/kg		Alkaline Permanganate 410 g/kg		Barium Carbonate 410 g/kg		Alkaline Peroxide 420 g/kg		Alkaline Permanganate 590 g/kg		Barium Carbonate 400 g/kg		Turco 4521 A 97 g/kg		Turco 4521 A 260 g/kg		Turco 4521 A 400 g/kg		Turco 4521 A + 1/8 Pure 400 g/kg		Alkaline Peroxide 380 g/kg		Alkaline Permanganate 390 g/kg		Barium Carbonate 390 g/kg		Turco 4521 A 380 g/kg		Alkaline Peroxide 400 g/kg		Alkaline Permanganate Natek 260 390 g/kg		Barium Carbonate 400 g/kg		Reverse Osmosis 390 g/kg	
Weight	g	126.3		152.5		89.5		126.0		122.4		136.4		111.4		114.9		126.9		126.1		133.8		146.7		134.8		125.8		123.0		142.3		162.9		132.1	
Sample	Co^{60} µCi	453.3		321.15		341.85		275.4		217.8		332.55		77.85		207.45		316.95		256.35		264.3		223.5		287.25		138.7		340.9		116.1		202.8		136.5	
Activity	Cs^{134} µCi	155.4		165.15		100.05		145.5		108.15		147.45		34.5		89.4		142.35		144.75		131.55		91.5		127.05		129.6		237.0		207.1		183.2		130.2	
Cumulative Percentage Activity Released		Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}	Cs^{134}	Co^{60}
DAY	1	0.012	0.014	0.022	0.000	0.001	0.000	0.033	0.114	0.016	0.002	0.001	0.001	0.017	0.015	0.579	0.410	0.244	0.181	0.001	0.002	0.257	0.757	0.109	0.000	0.002	0.003	0.002	0.002	0.002	0.003	0.010	0.001	0.001	0.001	0.001	0.001
	2	0.016	0.02	0.03	0.001	0.001	0.000	0.044	0.155	0.022	0.003	0.001	0.001	0.020	0.018	0.855	0.612	0.356	0.2[illegible]	0.001	0.002	0.739	1.635	0.169	0.001	0.002	0.003	0.003	0.003	0.009	0.010	0.015	0.001	0.002	0.001	0.002	0.002
	3	0.018	0.022	0.034	0.001	0.001	0.000	0.049	0.174	0.029	0.003	0.001	0.001	0.022	0.021	1.072	0.773	0.445	0.321	0.002	0.002	[illegible]	2.866	0.231	0.001	0.003	0.004	0.003	0.003	0.012	0.012	0.019	0.001	0.002	0.002	0.004	0.[illegible]
	4	0.020	0.024	0.038	0.001	0.001	0.001	0.053	0.190	0.035	0.004	0.001	0.002	0.024	0.024	1.272	0.930	0.540	0.382	0.002	0.003	2.26	3.977	0.275	0.002	0.003	0.005	0.004	0.004	0.014	0.014	0.024	0.002	0.002	0.002	0.002	0.003
	7	0.023	0.028	0.048	0.001	0.002	0.001	0.062	0.225	0.053	0.006	0.002	0.002	0.028	0.029	1.771	1.324	0.757	0.523	0.002	0.003	3.77	5.846	0.375	0.003	0.006	0.009			0.015	0.016						
WEEK	2	0.033	0.039	0.081	0.002	0.002	0.001	0.190	0.365	0.106	0.005	0.003	0.004	0.044	0.047	2.768	2.052	1.125	0.653	0.002	0.003	8.22	9.856	0.584	0.004	0.010	0.015	0.005	0.005	0.016	0.017	0.053	0.002	0.003	0.003	0.004	0.004
	3	0.043	0.048	0.120	0.003	0.008	0.006	2.163	2.965	0.164	0.006	0.005	0.004	0.091	0.081	3.384	2.423	1.385	0.803	0.004	0.004	12.09	13.28	0.711	0.005	0.029	0.019	0.007	0.007	0.020	0.018	0.065	0.002	0.003	0.003	0.005	0.006
	4	0.044	0.047	0.144	0.003	0.012	0.002	4.056	6.836	0.205	0.007	0.006	0.005	0.119	0.091	3.881	2.746	1.630	0.931	0.007	0.005	15.80	16.852	0.835	0.005	0.036	0.023	0.009	0.010	0.023	0.020	0.082	0.002	0.004	0.003	0.009	0.008
MONTH	2	0.053	0.057	0.227	0.003	0.014	0.003	9.079	14.995	0.370	0.009	0.008	0.007	0.196	0.132	6.370	4.032	3.065	1.551	0.007	0.005	28.80	24.030	1.212	0.006	0.055	0.045	0.019	0.016	0.027	0.024	0.120	0.002	0.004	0.004	0.018	0.016
	3	0.79	0.077	0.400	0.004	0.018	0.004	10.471	16.927	1.227	0.026	0.013	0.011	0.335	0.225	7.453	4.522	3.688	1.796	0.008	0.006	29.03	27.273	1.168	0.012	0.097	0.082	0.076	0.037	0.030	0.027	0.184	0.002	0.004	0.005	0.038	0.033
	4	←																DATA NOT OBTAINED																			→
	5	0.135	0.113	0.432	0.007	0.019	0.004	11.548	18.415	1.765	0.059	0.018	0.014	0.524	0.333	9.77	5.36	4.49	2.07	0.008	0.006	38.89	31.486	9.668	0.020	0.140	0.122	0.128	0.062	0.038	0.037	0.235	0.002	0.005	0.006	0.051	0.044
	6	0.148	0.122	0.738	0.007	0.020	0.004	11.876	19.80	4.0	0.158	0.022	0.015	0.837	0.405	10.59	5.69	4.96	2.21	0.008	0.006	43.94	37.40	10.11	0.040	0.166	0.143	0.175	0.087	0.042	0.041	0.281	0.002	0.006	0.007	0.064	0.055
	12																																				
	18																																				
	24																																				



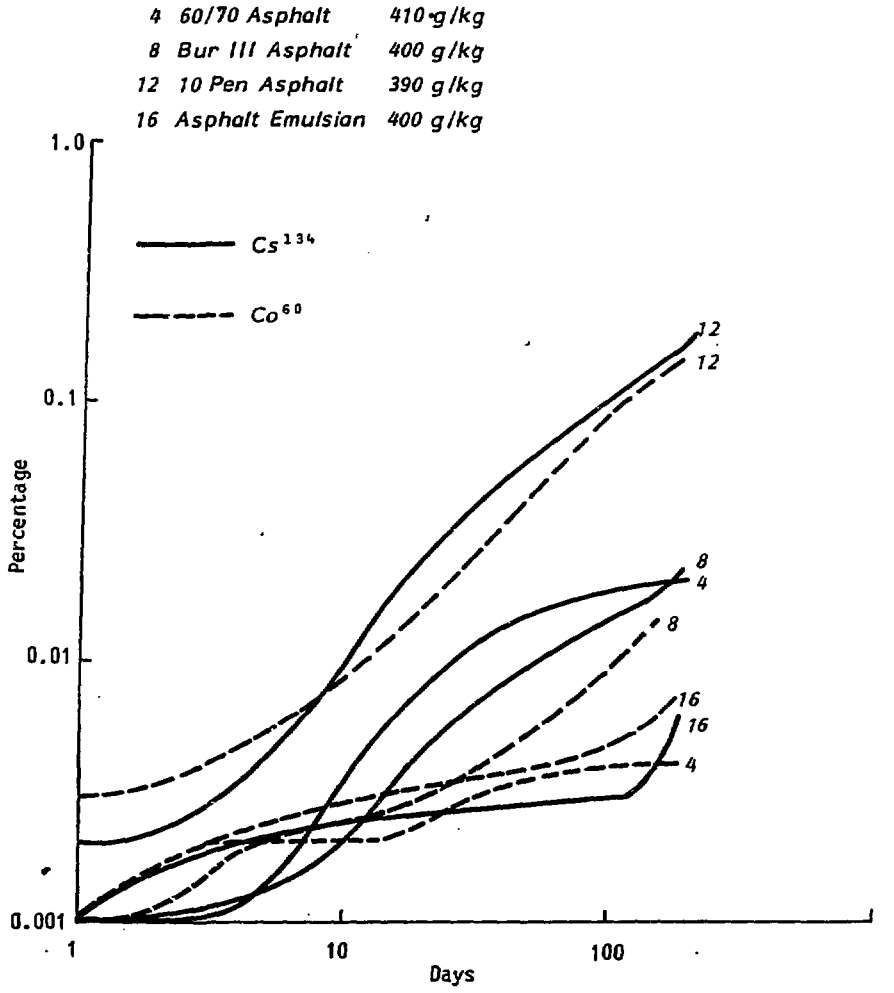
APPENDIX 4

LEACH RESISTANCE
(a) ALKALINE PEROXIDE WASTE PRODUCTS
CUMULATIVE RADIONUCLIDE RELEASE



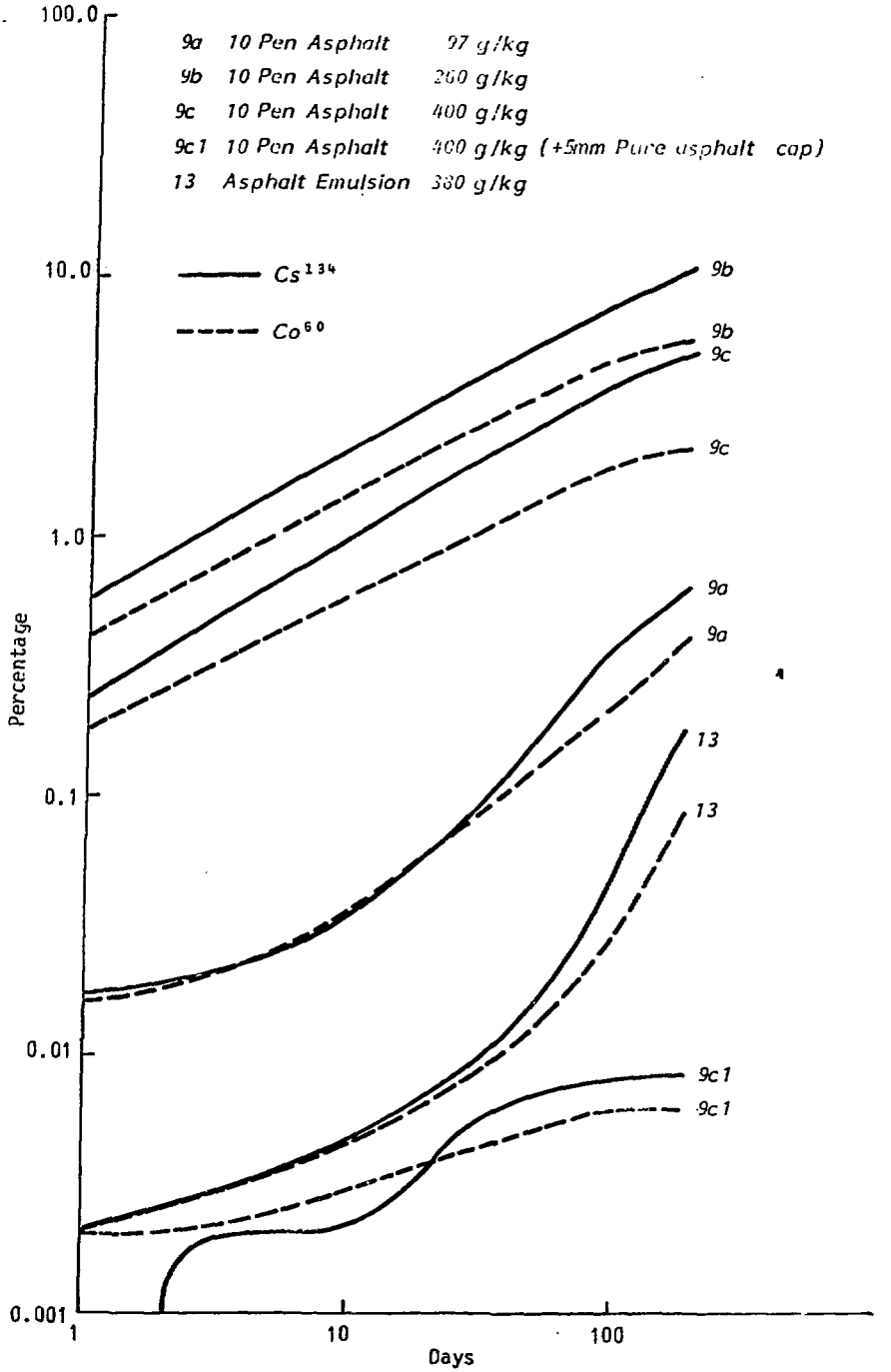
APPENDIX 4

LEACH RESISTANCE
(b) ALKALINE PERMANGANATE WASTE PRODUCTS
CUMULATIVE RADIONUCLIDE RELEASE



APPENDIX 4

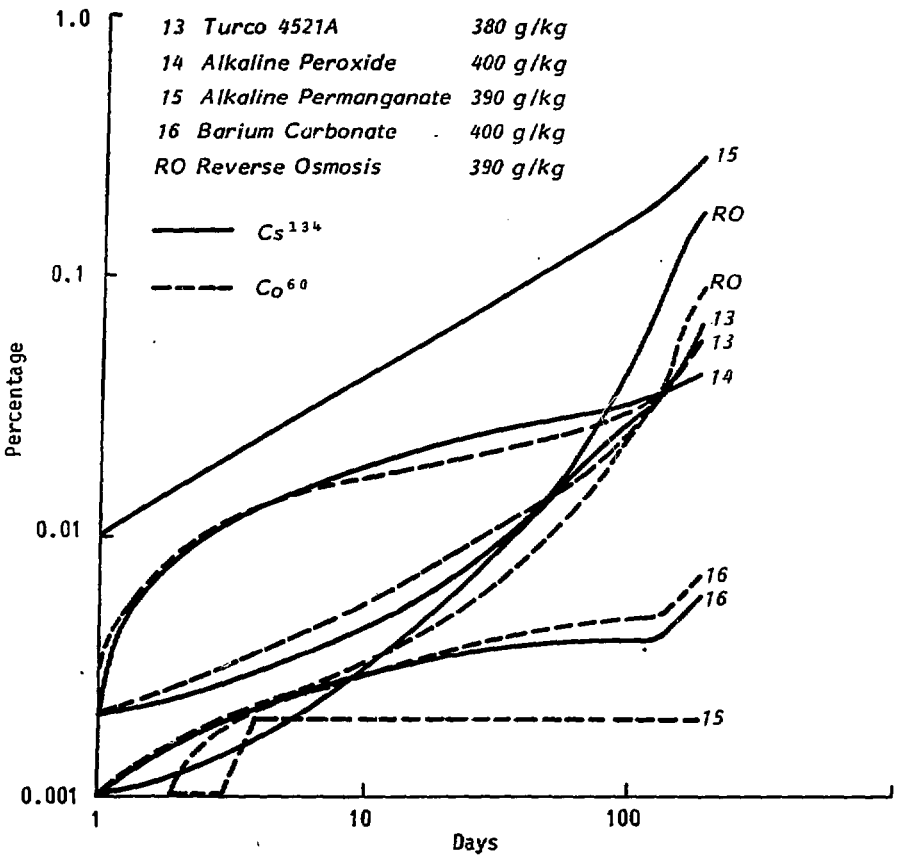
LEACH RESISTANCE
(c) BARIUM CARBONATE WASTE PRODUCTS
CUMULATIVE RADIONUCLIDE RELEASE



APPENDIX 4

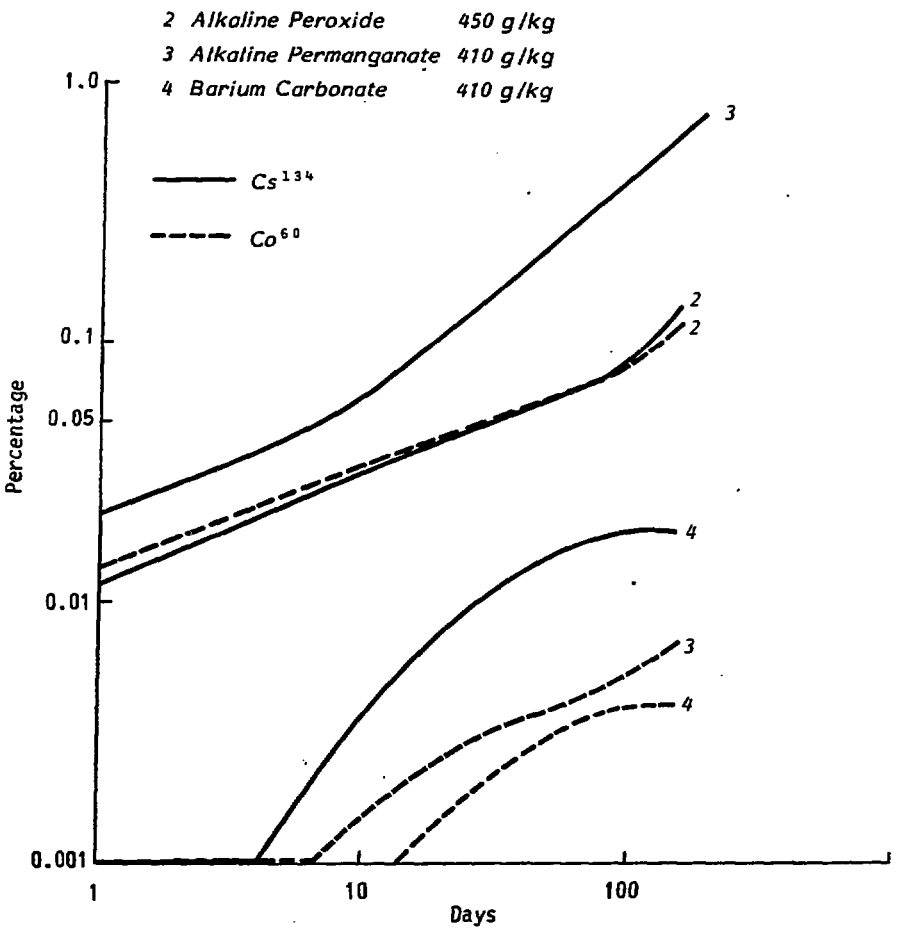
LEACH RESISTANCE
(d) TURCO 4521A. WASTE PRODUCTS
CUMULATIVE RADIONUCLIDE RELEASE

80-280
149811 RD



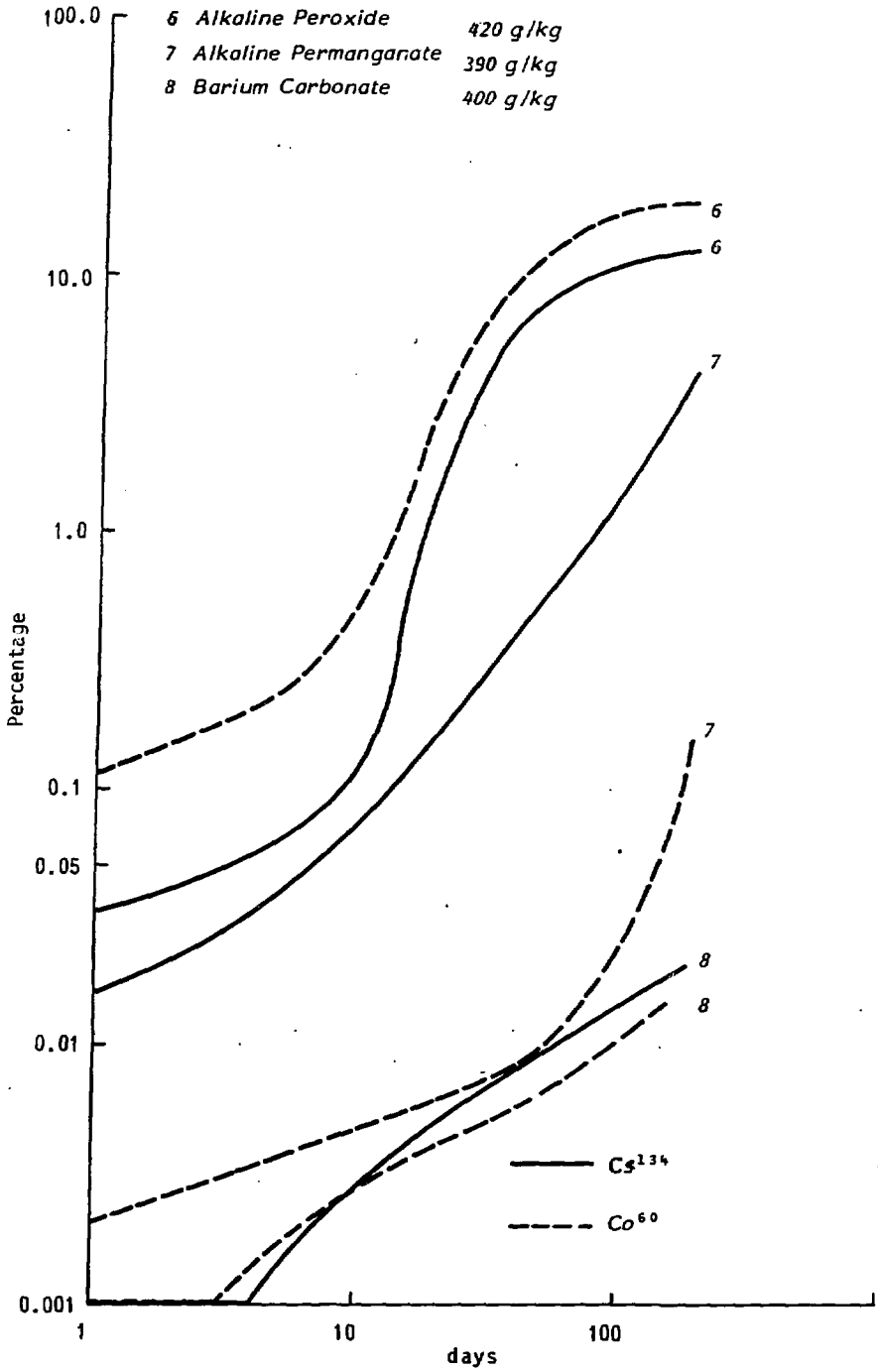
APPENDIX 4

LEACH RESISTANCE
(e) ASPHALT EMULSION TREATED WASTES
CUMULATIVE RADIONUCLIDE RELEASE



APPENDIX 4

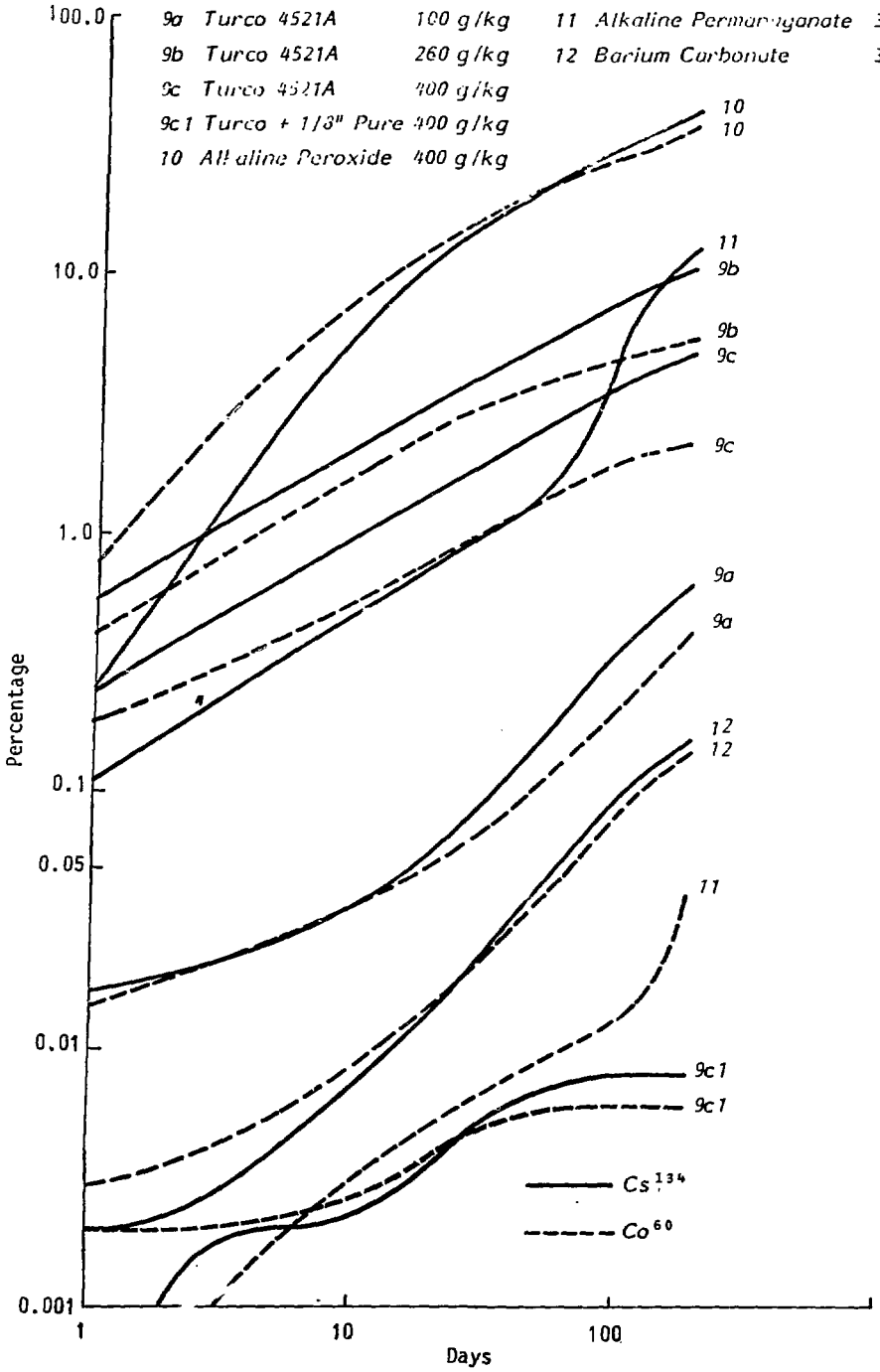
LEACH RESISTANCE
(f) 60/70 ASPHALT TREATED WASTES
CUMULATIVE RADIONUCLIDE RELEASE



APPENDIX 4

LEACH RESISTANCE
(g) BUR III ASPHALT TREATED WASTES
CUMMULATIVE RADIONUCLIDE RELEASE

80-280
149814-RD



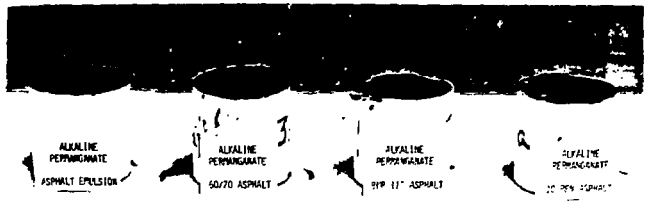
APPENDIX 4

LEACH RESISTANCE
(h) 10 PEN ASPHALT TREATED WASTES
CUMULATIVE RADIONUCLIDE RELEASE

APPENDIX 5

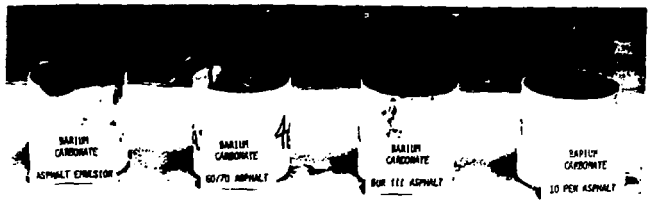
LEACHING RESISTANCE OF BITUMINIZED WASTES

Appearance after 28 days demineralized water immersion.



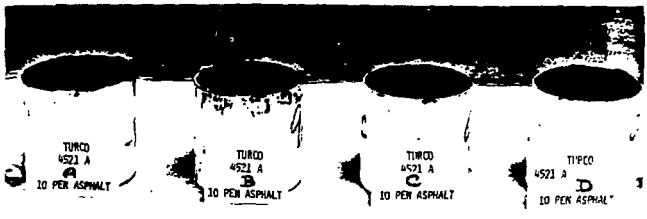
(R79-3047A)

(a) Alkaline permanganate products



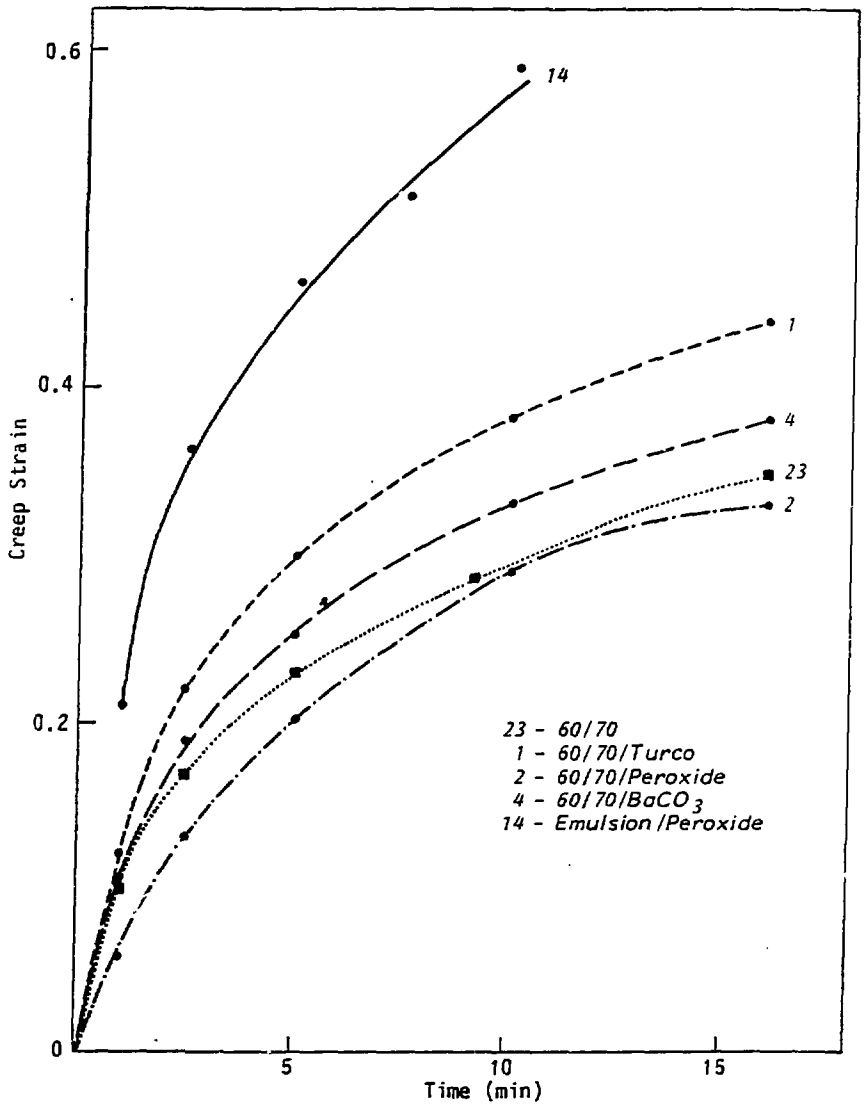
(R79-3048B)

(b) Barium carbonate products



(c) Turco 4521-A products

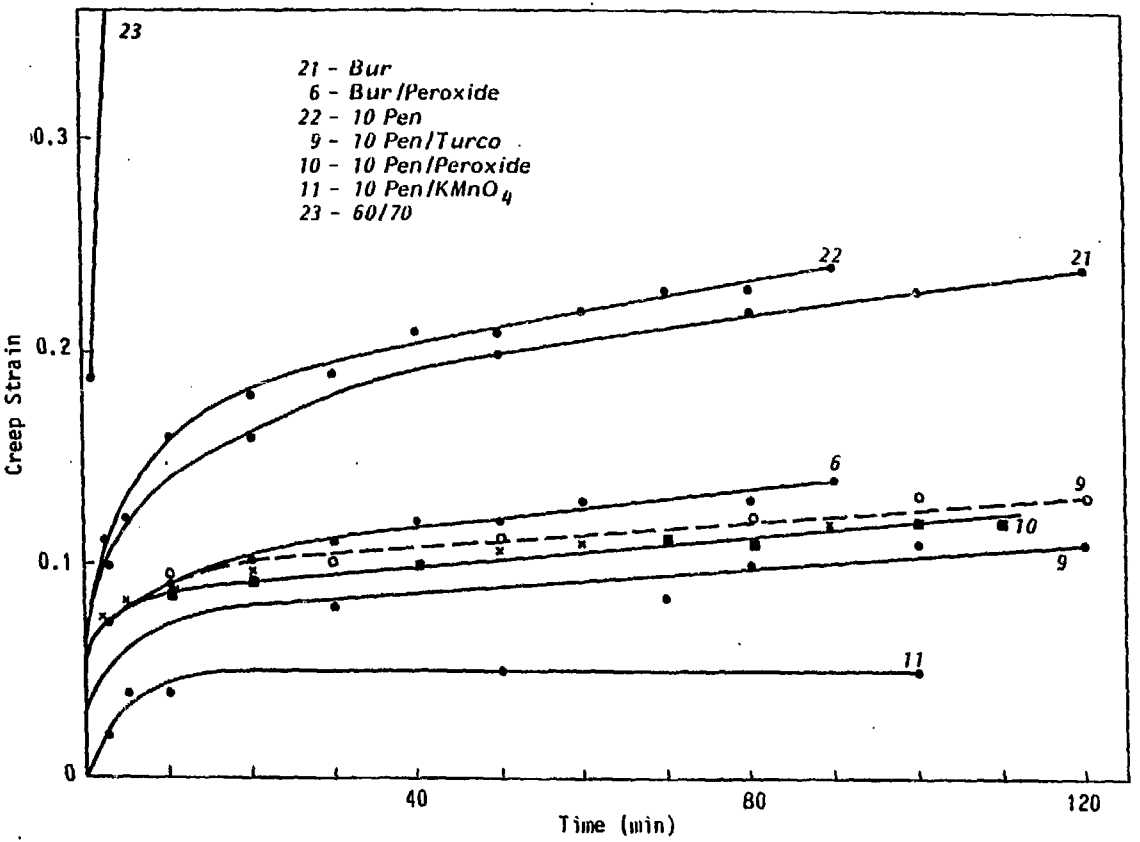
A - 100 g/kg
B - 260 g/kg
C - 400 g/kg
D - 400 g/kg + 5 mm asphalt cap



APPENDIX 6a

CREEP CURVES FOR SELECTED ASPHALTS UNDER 25 kPa COMPRESSIVE LOAD AT 25°C

80-280
148977 RD



APPENDIX 6b

CREEP CURVES FOR SELECTED ASPHALTS UNDER 120 kPa COMPRESSIVE LOAD AT 25°C