Characteristics of Pipe-Type Cable Fluids

Environmental Data Protocol and Comprehensive Test Matrix for Fluid Evaluation

Technical Report

Characteristics of Pipe-Type Cable Fluids

Environmental Data Protocol and Comprehensive Test Matrix for Fluid Evaluation

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REPORT SUMMARY

Underground transmission cables transmit electricity in many urban areas. In high pressure fluid filled (HPFF) pipe-type cables, the interior of the cable is filled with insulating fluid. Occasionally cables can leak, and the fluid can contaminate the surrounding soil. This report presents a decision protocol for conducting a site investigation of cable fluid releases to soil and groundwater and a comprehensive testing and acceptance matrix for evaluation of new cable fluids. The report also summarizes earlier research from this project, which characterized the physical and chemical properties of HPFF cable fluids, evaluated their fate and transport in the environment, and developed risk-based cleanup levels.

Background

Not much is known about the chemical composition or environmental behavior of the three primary classes of cable fluids (mineral oils, alkylbenzenes and polybutenes). Regulators have typically considered cable fluids similar to diesel fuel or motor oil, and have required electrical utilities to clean up the spills to comparable concentration levels. To support a more reasonable regulatory approach, EPRI and Consolidated Edison of New York initiated a project to characterize cable fluids and to develop cleanup levels that are protective of human health and the environment.

Objectives

To identify data needed to evaluate the environmental risk of existing and newly developed fluids used as insulating liquid in underground transmission cables.

Approach

In the Interim Report for this project (1001932) EPRI developed a risk-based cleanup approach for soil and groundwater contaminated by cable fluids. To apply this approach, the site owner must identify the fluid’s chemical class, determine the approximate dimensions of the spill, and establish the proximity of the spill to sensitive receptors such as drinking water wells or surface water bodies. In this Final Report, EPRI identifies appropriate analytical methods for cable fluids in environmental media and presents a decision protocol for a site investigation that will provide data needed to support a risk-based cleanup. The cleanup approach applies only to those fluid classes that were characterized by EPRI. In the future, manufacturers may develop new fluids that are not addressed by this study. EPRI identified a suite of tests that can be used to evaluate the environmental acceptability, performance characteristics, and cost factors for a new fluid.

Results

To apply EPRI’s risk-based cleanup approach, the cable owner first must determine whether the spilled cable fluid is present only in soils above the water table or has also impacted groundwater. A sequence of decision points and data collection steps was developed for these

two spill scenarios. To gain the greatest benefit from the cleanup approach, the chemical class of the spilled fluid should be identified. Cable owners may also want to distinguish cable fluids from motor oil and other contaminants present in the environmental media. A suite of analytical methods was identified that will provide the required information.

The acceptability of a new cable fluid should be evaluated thoroughly prior to purchase, particularly if the fluid is of a new type. Factors that contribute to fluid acceptability include potential environmental impacts in the event of a fluid release, suitability of the fluid for its intended purpose, and the economics of fluid purchase, management, and disposal. A comprehensive suite of tests was developed that can be used to compare candidate fluids. Ranges of desirable values are identified for each test parameter, where applicable.

EPRI Perspective

Cable fluid leaks occur infrequently; however, when a leak does occur, the cable owner must negotiate a remedial response with regulators. Lacking data on cable oil characteristics, regulators have typically specified cleanup levels intended for diesel oil or similar petroleum products. Earlier work by EPRI characterized mineral oils used in transformers (1000141) and concluded that those fluids pose little risk to human health or the environment (TB-111083). The findings of these earlier studies were used by several state regulatory agencies as a basis for cleanup goals specific to transformer dielectric fluids. The results of this project may be used to support a similar approach to cleanup of pipe-type cable fluids containing mineral oil, polybutenes, or alkylbenzenes. The fluid characterization data and risk-based cleanup levels developed in the Interim Report and electronic database for this project (1001932/1001933) are applied here to guide underground transmission cable owners in site cleanup and fluid purchase decisions. The results of this research will reduce future costs of site remediation and fluid management for underground transmission cable owners.

Keywords

Transmission cables
Dielectric fluid
Site remediation
Mineral oil
Alkylbenzene
Polybutene

ABSTRACT

Underground transmission cables transmit electricity in many urban areas of the United States. In high pressure fluid filled (HPFF), pipe-type cables, the interior of the cable is filled with insulating fluid. Occasionally cables can leak, and the fluid can contaminate the surrounding soil. This Final Report presents a decision protocol for conducting a site investigation of cable fluid releases to soil and groundwater and a comprehensive testing and acceptance matrix for evaluation of new cable fluids. The report also summarizes earlier research from this project, which characterized the physical and chemical properties of HPFF cable fluids, evaluated their fate and transport in the environment, and developed risk-based cleanup levels.

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INTRODUCTION

There are approximately 3,000 miles (4,800 kilometers) of high-pressure fluid-filled (HPFF), underground transmission cable in service in the United States. The interior of an HPFF pipe-type cable is filled with a dielectric fluid that surrounds the three insulated conductors and provides electrical and thermal insulation. Occasionally cables can leak, and the fluid can contaminate the surrounding soil and may also impact groundwater, surface water and sediment. To address these spills, since not much is known about the chemical composition or environmental behavior of cable fluids, regulators have typically considered them similar to diesel fuel or motor oil, and have required electrical utilities to clean up the spills to comparable concentration levels.

To support a more reasonable regulatory approach, EPRI and Consolidated Edison of New York initiated a project to characterize cable fluids and to develop cleanup levels that are protective of human health and the environment. In February 2002, EPRI published a report: “Characteristics of Pipe-Type Cable Fluids and Development of Risk-Based Cleanup Goals; Interim Report (1001932)”. This report evaluated the chemical and physical characteristics, fate and transport, and toxicity of the cable fluids and developed risk-based cleanup goals for soils contaminated by releases of cable fluids. The data collected for this study were appended to the Interim Report as a Microsoft Excel database, in CD-ROM format (1001933).

To assist cable owners to apply the Interim Report findings to both current and future cable installations, EPRI completed two additional tasks:

1. Developed an environmental testing protocol for evaluating the environmental risk of cable fluid releases; and

2. Developed a comprehensive testing and acceptance matrix for new cable fluids.

This final report for the project presents the results of the last two tasks, as well as a brief summary of the Interim Report results (EPRI, 2002).

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SUMMARY OF CHARACTERIZATION STUDY

Three classes of chemical are used to fill HPFF pipe-type cables in the U.S.: mineral oil, alkylbenzenes, and polybutenes. In addition to these three classes, there is a commercially prepared blend of two fluid classes called an alkylbenzene polybutene blend (APB). Some cables contain mixtures of the fluid classes created when utilities added dissimilar fluids to a cable after a leak or cable failure. In the EPRI study, several cables were found to contain polybutene/alkylbenzene (PB/A) mixtures.

2.1 Data Collection

Data collection for the EPRI cable fluid project included two components: 1) review of existing information, and 2) sampling and analysis of in-service and virgin pipe-type cable fluids. Existing information was compiled from product specifications, Material Safety Data Sheets (MSDS), chemical analyses provided by participating utilities, and toxicological literature.

Fifteen in-service cable fluid samples were collected by six participating utilities, from underground transmission lines representing a wide range of fluid types, service ages, and cable voltages. In addition, six samples of unused (virgin) fluids were obtained from two vendors. The samples, described in Table 2-1, were analyzed for physical properties, volatile and extractable petroleum hydrocarbons (VPH and EPH), volatile and semi-volatile organic compounds (VOCs and SVOCs), and polychlorinated biphenyls (PCBs). Dissolution testing was also performed on selected samples to determine concentrations of chemicals that could dissolve into soil pore water.

Table 2-1
Description of Cable Fluid Samples

Sample ID	Type	Cable Age	Cable Voltage (kV)	Fluid Type
A-DF-001	In-service	1952	138	Mineral Oil
A-DF-002	In-service	1966	138	Mineral Oil
A-DF-003	In-service	1967-68	345	Polybutene/Alkylbenzene mixture
A-DF-004	In-service	1965	345	Polybutene/Alkylbenzene mixture
A-DF-005	In-service	1984	138	APB
A-DF-006	In-service	1973	345	Polybutene/Alkylbenzene mixture
A-DF-007	In-service	1991	345	Alkylbenzene
A-DF-008	In-service	1961	138	Mineral Oil
B-DF-001	In-service	Mid-1970s	345	Polybutene
C-DF-001	In-service	1979	345	Polybutene
KK-DF-001	In-service	1960	138	Mineral Oil
KK-DF-002	In-service	1977	138	Mineral Oil
KK-DF-003	In-service	1992	138	APB
D-DF-001	In-service	1996	115	Alkylbenzene
E-DF-001	In-service	1990	115	APB
M-DF-001	Virgin	--	--	Polybutene (higher viscosity)
M-DF-002	Virgin	--	--	Alkylbenzene
M-DF-003	Virgin	--	--	APB
M-DF-004	Virgin	--	--	Alkylbenzene
M-DF-005	Virgin	--	--	APB
M-DF-006	Virgin	--	--	Polybutene (lower viscosity)

2.2 Cable Fluid Characteristics

Physical Characteristics The physical parameters tested included surface and interfacial tension, viscosity (at 25°,10° and 5°C), and refractive index. In addition, specific gravity and flash point were measured for two in-service fluid samples to compare the results with manufacturer's information on virgin fluids. The results of the physical parameter testing are summarized on Table 2-2. The results of the specific gravity and flash point tests confirmed the existing data on these fluids. The fluids have specific gravities less than 1, indicating that these fluids will float on water. Vapor pressures were all less than 0.1 mm Hg at 20°C, indicating that cable fluids will not volatilize at any significant rate. Flash points ranged from 138°C to 200°C, indicating that cable fluids have a low risk of accidental combustion. The viscosities measured in this study at 25°C ranged from 33.95 centistokes (cSt) for alkylbenzenes to 505.84 cSt for mineral oils. The data confirmed that viscosity varies strongly with temperature. At a temperature characteristic of subsurface soils (5°C), alkylbenzene, the least viscous of the cable fluids, has a viscosity similar to that of light fuel oil, indicating it will act as a mobile liquid in the environment.

Interfacial tension can be used to evaluate the mobility of a fluid in the subsurface; lower values imply greater mobility. Based on the EPRI (2002) results, mineral oils will be more easily mobilized than alkylbenzenes and APB blends. The mobility of polybutene fluids varies according to the supplier.

Refractive index (RI) is an inexpensive laboratory test that can be used to distinguish between cable fluid classes. In this study, RI results were definitive for identification of mineral oils, but could not differentiate pure alkylbenzenes or polybutenes from alkylbenzene/polybutene mixtures.

Chemical Characteristics Cable fluids are complex mixtures containing hundreds of primarily semi-volatile, organic compounds. Since no methods have been developed specifically to measure bulk cable fluids, a Massachusetts Department of Environmental Protection (MADEP) gas chromatography (GC) method was used to quantify volatile petroleum hydrocarbons (VPH) in mineral oils and extractable petroleum hydrocarbons (EPH) in all fluid samples (Table 2-2). The MA VPH/EPH methods are used to evaluate the health risks associated with various fractions of a petroleum mixture. This risk evaluation process is only applicable to petroleum-derived fluids such as mineral oils.

The majority of the bulk cable fluids fall within the range of compounds measured by the EPH method, with the exception of the polybutenes. For the polybutene samples, the total EPH only accounted for about 50% of the total sample mass. It was concluded that a portion of the mass of the polybutene samples consists of high molecular weight compounds that cannot be analyzed by gas chromatography.

Table 2-2
Summary of Physical Properties, PCBs and EPH/VPH by Fluid Class

Parameter	**Units**	**Mineral Oil**		**Alkylbenzene**		**Polybutene**		**APB**		**Polybutene/Alkylbenzene Mixture**	
		Range	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**
Physical Parameters											
viscosity @25^{o}C	cSt	462.1 - 505.84		33.95 - 43.95		64.17 - 307.79		236.78 - 381.94		56.94 - 157.67	
viscosity @10^{o}C	cSt	NA		87.88 ^{1}		NA		1162.5 ^{2}		NA	
viscosity @5^{o}C	cSt	NA		121.08 ^{1}		NA		2009.53 ^{2}		NA	
refractive index		1.503 - 1.507		1.481 - 1.493		1.465 - 1.476		1.486 - 1.495		1.473 - 1.478	
surface tension	dynes/cm	31 - 33		28 - 29		27 - 28		29 - 30		27 - 28	
interfacial tension	dynes/cm	39 - 42		45 - 48		28 - 49		43 - 49		45	
specific gravity				0.876 ^{1}				0.872 ^{2}			
flash point	^{o}C	NA		192		NA		196		NA	
PCBs	mg/kg	<1		<1		<1		<1		<1	
EPH Total	mg/kg	702,000 - 868,000	5 of 5	767,000 - 980,600	4 of 4	405,500 - 590,000 ^{3}	4 of 4	679,000 - 931,000	5 of 5	427,000 - 819,000	3 of 3
C$_{9}$-C$_{18}$ Aliphatics	mg/kg	18,000 - 28,000	5 of 5	7,000 - 180,000 ^{3}	4 of 4	180,000 - 260,000 ^{3}	4 of 4	9,000 - 100,000	5 of 5	220,000 - 270,000	3 of 3
C$_{19}$-C$_{36}$ Aliphatics	mg/kg	450,000 - 620,000	5 of 5	560,000 - 700,000 ^{3}	4 of 4	220,000 - 260,000 ^{3}	4 of 4	443,000 - 760,000	5 of 5	170,000 - 510,000	3 of 3
unadjusted C$_{11}$-C$_{22}$ Aromatics	mg/kg	120,000 - 270,000	5 of 5	81,000 ^{3} - 327,000	4 of 4	5,500 - 93,600	4 of 4	36,000 - 276,000	5 of 5	37,000 - 71,000	3 of 3
VPH											
unadjusted C$_{5}$-C$_{8}$ Aliphatics	mg/kg	<[25] - 36 ^{4}	1 of 5	5.7 ^{6}	1 of 1	not measured		not measured		not measured	
unadjusted C$_{9}$-C$_{12}$ Aliphatics	mg/kg	88 ^{5} - 110 ^{4}	2 of 5	4.5 ^{6}	1 of 1	not measured		not measured		not measured	
C$_{9}$-C$_{10}$ Aromatics	mg/kg	<[25] - 40 ^{4}	1 of 5	2.8 ^{6}	1 of 1	not measured		not measured		not measured	

<1 = not detected at that detection limit
Freq. = Frequency of detection
NA = not analyzed for this parameter
APB = alkylbenzene polybutene blend
PCB = polychlorinated biphenyls
EPH = extractable petroleum hydrocarbons
VPH = volatile petroleum hydrocarbons
(1) - Results for D-DF-001
(2) - Results for E-DF-001
(3) - Includes analytical results for reanalysis of M-DF-006 (polybutene) and D-DF-001 (alkylbenzene), not available for Interim Report.
(4) - VPH for A-DF-008
(5) - VPH for A-DF-002
(6) - VPH for D-DF-001

The results of the volatile and semi-volatile chemical analyses are summarized on Table 2-3. The most frequently detected “target” volatile organic compounds (VOCs) were xylenes, toluene, benzene, ethylbenzene, isopropyl benzene, and acetone. Common semi-volatile organic compound (SVOC) detections included phthalates, noncarcinogenic polycyclic aromatic hydrocarbons (PAHs) and phenols. As shown in Table 2-2, PCBs were not detected in any of the cable fluid samples.

Cable fluids have very low solubility in water. The amount of bulk fluids that will partition into water is about 0.5 mg/l. As shown in Table 2-4, the concentrations of VOCs and SVOCs partitioning into water at equilibrium are in the low µg/L (ppb) range, with the exception of benzene and 1,1,1-trichloroethane.

Because polybutenes cannot be fully quantified by gas chromatography, fluids containing alkylbenzenes and polybutenes (APBs and PB/A mixtures) are difficult to distinguish from pure alkylbenzene fluids using GC fingerprinting techniques. In the EPRI study, the chromatograms for the alkylbenzene and APB samples from the same supplier were virtually identical. It was also impossible to distinguish between these fluid types using physical properties or VOC/SVOC target compounds. Inspection of the non-target chemical components of the mixture (tentatively identified compounds or TICs) is necessary to definitively identify these fluid types. Mineral oils, on the other hand, can easily be distinguished from other fluid types based on physical properties or chromatographic fingerprint.

Toxicological Characteristics Existing animal toxicity data indicate that naphthenic-based mineral oils exhibit low acute toxicity and fairly low subchronic toxicity, and are not mutagenic or carcinogenic. Compared to mineral oils, alkylbenzenes have higher acute and subchronic toxicity (particularly the smaller chain (C_{10}-C_{12}) molecules) and while not mutagenic or carcinogenic, have been shown to have some developmental toxicity. Of the three types of cable fluids, polybutenes appear to have the lowest acute and subchronic toxicity, were not found to be mutagenic or carcinogenic, and have shown no developmental toxicity.

Table 2-3
Summary of VOCs and SVOCs by Fluid Class

	Units	Mineral Oil		Alkylbenzene		Polybutene		APB		Polybutene/ Alkylbenzene Mixture	
		Range	Freq.	Range	Freq.	Range	Freq.	Range	Freq.	Range	Freq.
Volatile Organic Compounds											
Acetone	ug/kg	660 J	1/5	1,400 J	1/4	1,100 J - 7,800	2/4	710 J - 880 J	2/5	950 J - 1,300 J	3/3
Benzene	ug/kg		0/5	310 J - 8,800	2/4	270 J	1/4	340 J - 7,200	3/5	3,500 - 66,000	3/3
Bromomethane	ug/kg		0/5	360 J	1/4	240 J - 370 J^{3}	2/4		0/5		0/3
2-Butanone	ug/kg		0/5		0/4	3,000 J^{3}	1/4		0/5		0/3
n-Butylbenzene	ug/kg		0/5	360 J^{3} - 610	2/4		0/4	300 J - 470	2/5		0/3
sec-Butylbenzene	ug/kg		0/5	1,100	1/4		0/4		0/5	860 - 1900	2/3
tert-Butylbenzene	ug/kg		0/5	4,800	1/4		0/4	4,000 - 23,000	3/5	5,300 - 150,000	3/3
Chloromethane	ug/kg		0/5		0/4	210 J^{3} - 790	2/4	520 J	1/5	380 J	1/3
Ethylbenzene	ug/kg		0/5	970 J^{3} - 3,000	3/4	2,000	1/4	240 J - 1,200	3/5	570 J - 780 J	3/3
2-Hexanone	ug/kg		0/5		0/4	1700 J^{3}	1/4		0/5		0/3
Isopropylbenzene	ug/kg		0/5	500 J^{3} - 4,200	3/4		0/4	270 J - 1,100	4/5	2,400 - 5,700	2/3
Methyl isobutyl ketone (MIBK)	ug/kg		0/5	480 J	1/4	1,100 J^{3} - 2,300	2/4	470 J	1/5	610 J - 850	3/3
Naphthalene	ug/kg	550 J - 830 J	2/5	270 J - 410 J^{3}	2/4	450 J^{3} - 10,000	2/4	240 J	1/5		0/3
n-Propylbenzene	ug/kg		0/5	340 J^{3} - 630	3/4		0/4	430	1/5		0/3
Styrene	ug/kg		0/5	500 J	1/4	1,100	1/4		0/5		0/3
Toluene	ug/kg		0/5	250 J^{3} - 1,900	3/4	200 J^{3} - 1,100	2/4	240 J - 650 J	3/5	620 J - 1,200	3/3
1,1,1-Trichloroethane	ug/kg		0/5		0/4	13,000	1/4	4,000	1/5		0/3
1,2,4-Trimethylbenzene	ug/kg	440 - 1,100	3/5		0/4	510 - 1,100	2/4	220 J	1/5	430 J - 540 J	2/3
o-Xylene	ug/kg	700 J - 850	2/5	330 J^{3} - 4,600	2/4	400 J - 4,300	2/4	230 J - 2,300	2/5	600 J - 940	3/3
p/m-Xylene	ug/kg	1,200 J - 1,500 J	2/5	380 J^{3} - 9,200	2/4	410 - 7,400	3/4	350 J - 4,000	3/5	940 J - 2,400	3/3

Table 2-3, continued
Summary of VOCs and SVOCs by Fluid Class

	Units	Mineral Oil		Alkylbenzene		Polybutene		APB		Polybutene/ Alkylbenzene Mixture	
		Range	Freq.	Range	Freq.	Range	Freq.	Range	Freq.	Range	Freq.
Semi-Volatile Organic Compounds											
Acenaphthene	mg/kg	1.66	1/5	1.82 J^2 - 1.83 J^2	2/4	2.56 - 3.19	2/4		0/5	2.02 - 3.19	2/3
Acenaphthylene	mg/kg	1.43 J^2	1/5	1.78 J^2	1/4	1.87	1/4		0/5	0.62 - 0.95	2/3
Anthracene	mg/kg	0.91 - 11.9 J^2	3/5		0/4	1.27	1/4		0/5		0/3
bis(2-Ethylhexyl)phthalate	mg/kg	33.9	1/5	3.55 - 124 J^2	3/4	8.79 J^2 - 334	2/4	5.28 J^2- 15.3	3/5	8.95 - 15.4	3/3
Butylbenzylphthalate	mg/kg		0/5	2.23 J^2	1/4		0/4	2.39 J	1/5	1.63 J - 1.89 J	2/3
Dibenzofuran	mg/kg	0.9 - 1.03	2/5	0.99 J^2 - 1.04 J^2	2/4	4.6 - 6.32	2/4		0/5	1.77 - 3.53	3/3
Diethylphthalate	mg/kg	104 J^2	1/5	34.4 J^2	1/4	28.2 - 37.9 J^2	3/4	33 J^2	1/5	36.7	1/3
2,4-Dimethylphenol	mg/kg	1.52 J^2	1/5		0/4		0/4		0/5		0/3
Dimethylphthalate	mg/kg	8.27 J^2	1/5	3.3 J^2	1/4	1.38 J - 3.16	2/4	3.05	1/5	2.98 - 4.15	3/3
Di-n-butylphthalate	mg/kg	4.38 J^2 - 141	3/5	0.42 J^2 - 4.71	2/4	1.23 J^2 - 9.15	2/4	0.66 J^2 - 13.9	3/5	11.8 - 15	3/3
Di-n-octylphthalate	mg/kg		0/5	2.76 J^2	1/4		0/4		0/5		0/3
Fluoranthene	mg/kg		0/5		0/4	0.55 - 1.68	2/4		0/5		0/3
Fluorene	mg/kg		0/5	3.33 J^2	1/4	0.94 - 3.33	2/4		0/5	1.5 - 2.5	2/3
2-Methylnaphthalene	mg/kg	6.29 J^2 - 7.68	2/5	0.63 - 5.17 J^2	3/4	0.73 - 5.62	2/4	0.71 J^2 - 3.13	3/5	1.92 - 5.09	3/3
3,4-Methylphenol (o,p-cresol)	mg/kg	0.52 J^2 - 3.27 J^2	3/5		0/4		0/4		0/5	1.33	1/3
Naphthalene	mg/kg	2.18	1/5	0.61 J/J^2 - 7.5 J^2	3/4	0.84 J^2 - 10.2	3/4	0.94 J/J^2 - 3.31	3/5	2.29 - 5.16	3/3
2-Nitrophenol	mg/kg	2.18 - 12.5 J^2	2/5	0.66 J^2	1/4		0/4	1.00 J^2	1/5	3.83 - 5.33	2/3
N-nitrosodi-n-butylamine	mg/kg		0/5	4.59 J^2	1/4		0/4		0/5		0/3
Phenanthrene	mg/kg	6.27	1/5	0.25 J^2	0/4	1.76 - 9.21	3/4		0/5	12.9	1/3
Phenol	mg/kg		0/5	1.27	1/4		0/4		0/5		0/3
Pyrene	mg/kg		0/5		0/4	1.44	1/4		0/5		0/3

Freq. = frequency of detection
APB = alkylbenzene polybutene blend
J = laboratory flag denoting result below quantitation limit but above detection limit
J2 = estimated value due to surrogate recovery result(s) outside of acceptance limits
J3 = estimated value due to samples analyzed after holding time

Table 2-4
Summary of Aqueous Dissolution Test Results by Fluid Class

Parameter Name	**Units**	**Mineral Oil**		**Alkylbenzene**		**Polybutene**		**APB**		**Polybutene/ Alkylbenzene Mixture**	
		Range	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**	**Range**	**Freq.**
Volatile Organic Compounds											
Benzene	µg/L		0/2	27	1/2		0/1	42	1/1	85 - 150	2/2
2-Butanone	µg/L	5	1/2	4	1/2	14	1/1	6	1/1	6.6 - 11	2/2
tert-butylbenzene	µg/L		0/2		0/2		0/1	2	1/1	3 - 6.2	2/2
Chloromethane	µg/L		0/2		0/2		0/1	1 J	1/1		0/2
Ethylbenzene	µg/L		0/2	1 J	1/2		0/1		0/1		0/2
2-Hexanone	µg/L		0/2		0/2		0/1		0/1	2.7 - 4	2/2
Methyl isobutyl ketone (MIBK)	µg/L	3	1/2	3	1/2	3	1/1	6	1/1	4.7 - 5	2/2
Methylene chloride	µg/L		0/2	3700	1/2	1,200	1/1		0/1		0/2
Toluene	µg/L		0/2	2	1/2		0/1	1 J	1/1	1 J - 1.2 J	2/2
1,1,1-Trichloroethane	µg/L		0/2		0/2	58	1/1		0/1		0/2
o-Xylene	µg/L		0/2	2	1/2		0/1	2 J	1/1		0/2
p/m-Xylene	µg/L	1 J	1/2	4 J	1/2		0/1	3 J	1/1		0/2
Semi-Volatile Organic Compounds					0/2		0/1				
Butylbenzylphthalate	µg/L	0.17 J - 0.19 J	2/2		0/2		0/1		0/1		0/1
Dibenzofuran	µg/L	0.03 J	1/2		0/2		0/1		0/1	0.03 J	1/1
Diethylphthalate	µg/L	3.06	1/2		0/2		0/1		0/1		0/1
2,4-Dimethylphenol	µg/L	1.73	1/2		0/2		0/1		0/1		0/1
Dimethylphthalate	µg/L	0.14 J	1/2		0/2		0/1		0/1		0/1
Di-n-butylphthalate	µg/L	3.15	1/2		0/2		0/1		0/1		0/1
Fluoranthene	µg/L		0/2		0/2		0/1	0.06	1/1		0/1
Fluorene	µg/L	0.03 J - 0.08	2/2		0/2		0/1		0/1		0/1
2-Methylnaphthalene	µg/L	0.16 - 0.46	2/2		0/2		0/1		0/1		0/1
2-Methylphenol (m-cresol)	µg/L	0.04 J - 0.15	2/2	0.11	1/2		0/1	0.13	1/1	0.09	1/1
3,4-Methylphenol (o,p-cresol)	µg/L	0.13 - 4.82	2/2	0.20 - 0.21	2/2	0.03 J	1/1		0/1	0.05 J	1/1
N-nitrosodiphenylamine	µg/L	0.20	1/2		0/2		0/1		0/1		0/1
Phenol	µg/L		0/2	0.43 - 1.14	2/2	0.10	1/1	1.05	1/1	1.86	1/1
Pyrene	µg/L		0/2		0/2		0/1	0.09	1/1		0/1
TPH	mg/L	0.28	1/2	0.56	1/2	0.47	1/1	0.52	1/1		0/0

Freq. = frequency of detection
APB = alkylbenzene polybutene blend
TPH = total petroleum hydrocarbons
J = laboratory flag denoting result below quantitation limit but above detection limit

2.3 Risk-Based Cleanup Goals

Risk-based cleanup goals were evaluated for five classes of cable fluid: mineral oil, polybutene, alkylbenzene, APB and PB/A. The exposure pathways determined to represent the most realistic conservative scenario were: 1) direct contact by workers exposed to contaminated soils during construction or maintenance of subsurface utilities, and 2) residential ingestion of contaminated groundwater from a well located near the spill. Inhalation of chemical vapors in an outdoor setting was not judged to be a significant exposure. Potential risks from inhalation of vapors in confined spaces or that migrate into buildings were not evaluated, due to the difficulty of modeling this pathway for a non-site-specific exposure.

Risks were first evaluated based on the chemical constituents detected in the fluids. The fluids contain relatively few constituents of concern with respect to human health, and those constituents found were present at concentrations that would be below risk-based concentration limits when present in a fluid-saturated soil. These findings indicate that health risks to workers exposed to fluid-contaminated soils on a regular basis would be acceptable without remediation.

The risk associated with exposure to soils contaminated with the bulk fluid could be evaluated only for mineral oils. A risk-based corrective action (RBCA) scheme developed by the MADEP was used to estimate the risk associated with various petroleum hydrocarbon fractions in the fluid. By this protocol, it was determined that soils should contain less than 7.4 grams of mineral oil per kilogram of soil (7,400 mg/kg).

For all cable fluid classes, a maximum cleanup goal of 13 grams of fluid per kilogram of soil (13,000 mg/kg) is recommended to insure that any residual fluids will not migrate to groundwater under the influence of gravity or capillary suction. The 13 g/kg goal is based on the concept of residual saturation in soil and is not applicable to non-soil media.

In order to protect residents who may ingest groundwater migrating to a well from a cable fluid spill site, the following cleanup goals were developed, assuming a conservative, low biodegradation rate for the toxic constituents detected in the cable fluids:

- For sites where the cable fluid has only contaminated the vadose zone, no remediation is required to insure that drinking water standards are met at a receptor well 30 meters away from the source area. However, remediation may be required if the site is in close proximity to underground conduits such as sewers.
- At sites where the cable fluid is located at or below the water table and groundwater needs to be protected as a potable aquifer, remediation may be required for some spill sizes and fluid classes. For each release site, the owner needs to determine whether contamination dissolving from contaminated soils into groundwater will be diluted sufficiently so that the concentration at the receptor well is below applicable water quality standards. Using the results of the dissolution testing performed for this project, the dilution and attenuation factors needed (DAF_Ns) to protect groundwater were calculated for four cable fluid classes (alkylbenzenes, APBs, polybutene/alkylbenzene mixtures, and polybutenes) for the various EPA and New York State standards.

- For mineral oils, no target chemicals were detected at levels that would require remediation for groundwater protection. Minimal dilution (DAF_N = 1.4) would be required for the bulk fluid mineral oil to meet the Massachusetts GW-1 standard for Total Petroleum Hydrocarbons. Again, additional remediation may be necessary at spill sites in the saturated zone if the site is in close proximity to conduits such as sewers.
- For the other fluid classes, the maximum DAF_N was 470 for polybutene/alkylbenzene mixtures, 130 for APBs, 84 for alkylbenzenes, and 12 for polybutenes.
- Using a contaminant transport model, generic DAFs were developed for a range of fluid release sizes and distances from a receptor well. Users of the Interim Report may select a generic scenario that matches the conditions found at their site, or they may develop a site-specific DAF. If a site evaluation indicates the DAF will exceed DAF_N, then the risks associated with the ingestion-of-groundwater scenario are negligible. If the DAF for the site is lower than DAF_N, site remediation (typically source reduction or removal) will be required. As an alternative to a DAF calculation, an assessment was made of the minimum source-to-receptor distance (L_R) (i.e., distance from spill site to drinking water well) that would be needed given specified information on release size and local hydrogeology.

Risks to aquatic organisms from dissolved contaminants migrating from a cable fluid spill site are predicted to be negligible. To protect against aquatic impacts associated with direct contact between the fluid and a surface water, it is recommended that: (1) any soils in spill areas be remediated to the fluid immobilization standard listed above (13 g/kg); and (2) any free liquids (i.e., free/mobile cable fluids) be removed from areas where drainage to nearby surface areas might be facilitated, e.g., from around sewer lines and other similar conduits. The extent of removal around conduits should be based on the judgment of environmental professionals after evaluation of site-specific information, including logistical constraints.

Users of this data collection protocol should be aware of two assumptions that were made in developing the EPRI (2002) cleanup strategy:

1. Free product (as determined by visual or other field testing) will be removed from the spill site, to the extent possible, given logistical constraints on removal.

2. As noted above, the DAF_Ns that are used to evaluate the need for remediation to protect groundwater were obtained from a contaminant transport model, using conservative, non-zero values for the biodegradation rates of the risk-limiting chemicals. Some regulators may favor the assumption of zero biodegradation in transport modeling. The use of such an extreme assumption produces much higher DAF_Ns and can overestimate the risk to groundwater. In either approach – use of a reasonably conservative or extremely conservative (zero) biodegradation rate – EPRI would recommend further site-specific studies in any outcome where the screening indicated further remediation was required for groundwater protection.

3

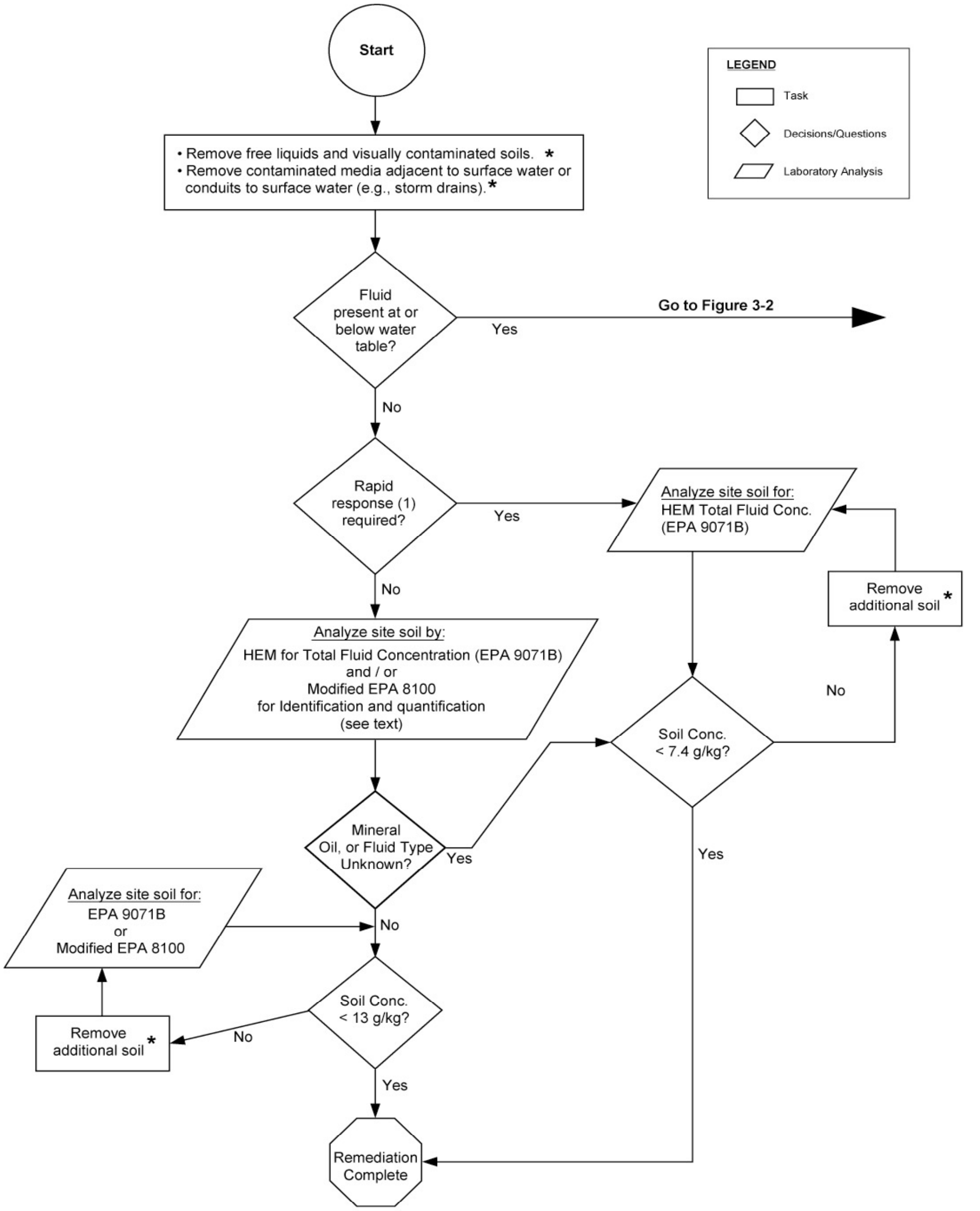
ENVIRONMENTAL TESTING PROTOCOL

An environmental testing protocol was developed to assist utilities in implementing the environmental cleanup goals presented in the Interim Report. The protocol consists of a sequence of actions (chemical tests) and decision points. The protocol can be used to respond to both historical and recent cable fluid releases. It is not the intent of this protocol to recommend sampling strategies such as the frequency and distribution of soil samples; cable owners, in coordination with local or state regulators, usually make these decisions.

The environmental testing protocol makes use of simplifying, conservative assumptions and minimal collection of data from the release site. The site investigator selects generic fluid spill scenarios that represent some, but not all, release situations. For releases that do not conform to the generic scenarios, or where a substantial remediation effort is indicated, additional data collection and transport modeling may be warranted. The Interim Report discusses data needs for a site-specific evaluation of cleanup goals.

The testing protocol for initial response to a cable fluid release is shown on Figure 3-1. This flowchart indicates the data requirements that apply when the test excavation must be closed quickly; for example, if the spill is located beneath a city street. This flowchart also applies to releases that are found to be isolated to the unsaturated zone (i.e., above the water table). Figure 3-2 illustrates the sequence of actions and decisions for releases that have occurred in or migrated to the saturated zone.

For cable fluid spills that are confined to the unsaturated zone, the risk-based cleanup strategy requires the site investigator to determine only the concentration of bulk fluid present in the soil and whether the fluid is a mineral oil. Even the fluid identification can be omitted, by making the conservative assumption that fluid is a mineral oil. However, in urban settings where contaminants such as motor oil may be present in the soil, it may also be desirable to distinguish between the spilled cable fluid and other oily materials that are not the responsibility of the cable owner.



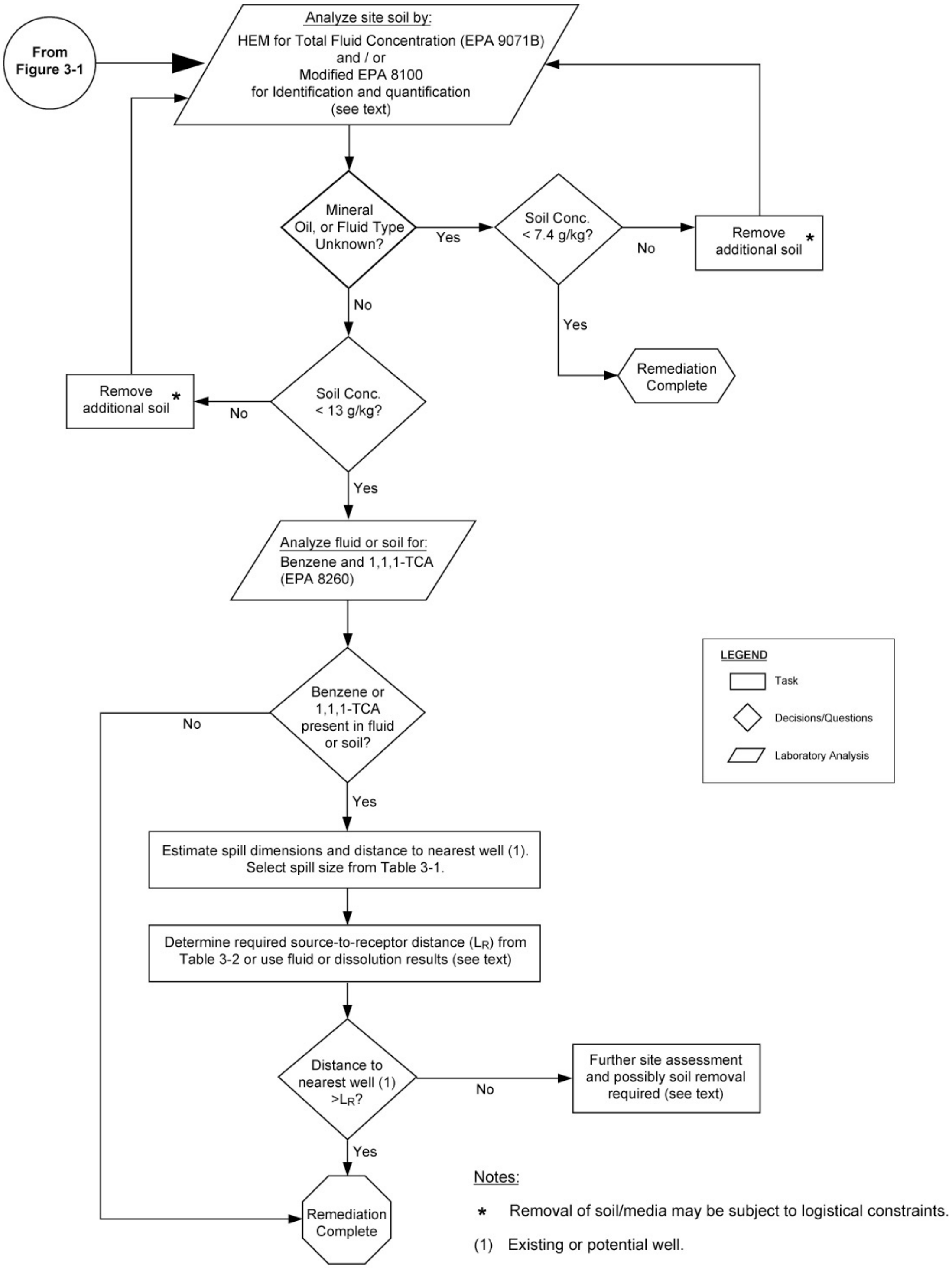
Notes:

* Removal of soil/media may be subject to logistical constraints.

(1) Rapid response is when the excavation can only be open very briefly (e.g., one day).

HEM Hexane Extractable Material

Figure 3-1
Decision Protocol for Initial Response to a Fluid Release



Notes:

* Removal of soil/media may be subject to logistical constraints.

(1) Existing or potential well.

HEM Hexane Extractable Material

Figure 3-2
Decision Protocol for Environmental Remediation: Saturated Zone Releases

For cable fluids that are released in or have migrated into the saturated zone, it is also necessary to know whether the fluid contains alkylbenzene or polybutene. This requirement exists because, of the two constituents posing a threat to groundwater, benzene is found only in alkylbenzene cable fluids, while 1,1,1-trichloroethane (1,1,1-TCA) was detected only in polybutene and APB fluids. Alternatively, the fluid can be tested for the presence of these two chemicals and the appropriate cleanup goal selected accordingly. One additional test that is optional, but that will provide a better estimate of site remediation needs, is an aquatic dissolution test of the cable fluid and subsequent analysis of the water for VOCs.

3.1 Analytical Methods

As discussed earlier, the Interim Report concluded that no single existing analytical method is ideally suited for both cable fluid identification and fluid quantification. Gas chromatography (GC) methods are not able to fully detect and quantify high molecular weight polymeric compounds such as polybutenes. For this reason, GC fingerprinting is not useful for distinguishing between alkylbenzene and APB fluids. However, to implement the vadose zone cleanup goals developed for this study, there is only a need to distinguish between mineral oils and the other cable fluids. This can easily be done by GC methods.

For cable fluid releases that are isolated to the unsaturated zone, two analytical methods will provide the data needed to implement a risk-based cleanup:

- Hexane Extractable Material (HEM) by EPA Method 9071B
- Gas Chromatography (GC) Fingerprint by modified EPA Method 8100

The HEM gravimetric method (EPA Method 9071B) is the U.S. EPA’s current version of the former “oil and grease” method and is designed to quantify high molecular weight compounds and mixtures. An optional silica gel cleanup step is used to eliminate interferences from naturally-occurring oils and waxes in soil. The advantage of the HEM method is that it is inexpensive and quick. There are a few problems with using this method to determine the amount of cable fluid in soils. First, this method does not distinguish between cable fluids and other hydrocarbons (e.g., motor oil). Second, since the applicability of the method to cable fluids has not been demonstrated, the laboratory would need to demonstrate acceptable hexane extraction efficiencies for cable fluids in soils. The lab would also need to determine the HEM total fluid concentration of “background” soil samples to establish a baseline for comparison with fluid-contaminated samples.

With additional method development, Method 9071B could potentially be used in a mobile laboratory in the field, producing results in a matter of hours. This would greatly enhance cleanup operations beneath streets, allowing the utility to close the excavation site with greater certainty that remedial goals have been reached. For this reason, this method is suggested for “rapid-response” cleanups.

To distinguish mineral oil from other cable fluids, and for locations where it is important to distinguish between cable fluids and other hydrocarbons, modified EPA Method 8100, a GC method, can be utilized to both identify and quantify the concentration of cable fluid. The modification from the standard EPA method involves quantifying the sample against a suite of cable fluid standards. To use this modified method, a cable owner must provide samples of their cable fluids to the laboratory so that it can add the fluids to the library of chromatograms used to identify unknowns. It is recommended that the laboratory prepare and analyze multiple calibration standard concentrations for each fluid, defining the working range of the analytical system. Additionally, a recent study (Con Edison, 2002) has indicated that the modified method gives accurate results when a heated sonication procedure is used for the extraction step.

Since GC fingerprints of the same cable fluid type differ among suppliers (particularly for alkylbenzenes), the greatest accuracy of identification and quantification will be obtained if the reference materials provided to the laboratory include all cable fluid types *and brands* that are present within the utility's transmission lines, including mixtures. This may not always be possible – for example, in a noncirculating cable that has been refilled after a leak, the fluid in the cables midpoint may be dissimilar from that at the fluid reservoir, the most convenient point to obtain fluid samples. In this case, the utility could provide a sample from the most contaminated area so that the laboratory can "fingerprint" the fluid and then the samples can then be quantified against the most appropriate standard within the library. However, it should be recognized that quantifying against a fluid different from that in the cable reduces the accuracy of the measurement.

Cable fluid analysis should be performed by an experienced chemist. The analyst must have the expertise to match the chromatogram of the sample with the standards in the lab's GC library and recognize and accommodate changes to the GC fingerprint that can occur with weathering. The GC library should include all possible cable fluids, plus the typical petroleum hydrocarbon standards required by the method. Following identification, the chemist can quantify the sample against the appropriate cable fluid standard. A diesel range organic (DRO) or extractable petroleum hydrocarbon (EPH) standard may also be used for quantification; however, EPRI's results indicate that this approach may underestimate the concentration of polybutene-containing fluids. Quantifying a polybutene fluid against a standard of like material should, at least theoretically, compensate for the low fraction of fluid detected by GC methods. Test results should cite the calibration standard source material used for quantification.

For chromatograms that indicate the sample is a mixture (of two different cable fluids or of a cable fluid and another hydrocarbon), the chemist can do one of following (listed from most conservative to least conservative):

1. Quantify the entire mixture using the HEM gravimetric method (EPA 9071B).

2. Quantify the entire mixture as the "best fit" cable fluid

3. Quantify the sample against a DRO or EPH standard

4. Attempt to assign the contribution of each fluid to the various fractions and quantify across the applicable ranges.

Because of the professional judgment involved in matching GC fingerprints using the modified 8100 method, the laboratory should provide copies of chromatograms for samples and standards upon request. It is recommended that the data user evaluate the chromatograms to resolve any data conflicts, or when performing data quality assessments for this technique. Also, laboratories should be aware that samples determined not to match standards within their library and labeled "unknown hydrocarbon" may be historical (weathered) cable fluids or mixtures that are not represented in their library of standards.

For saturated zone contamination, where it is necessary to distinguish between alkylbenzene and polybutene fluids to apply the correct L_R or DAF_N, the fluid or soil can be analyzed for the risk drivers (benzene and/or 1,1,1-TCA) by EPA Method 8260B, in lieu of a positive fluid identification. The Methods 8100 and 8260B analyses are to be performed on a fluid (preferred) or soil sample. The required detection limit for Method 8260B performed on a cable fluid sample is 500 µg/kg. The required detection limit for Method 8260B performed on a soil sample is 10 µg/kg and the analysis is only valid for determining the presence of benzene and/or 1,1,1-TCA if performed on a soil sample with a total fluid concentration of 15,000 mg/kg or higher.

3.2 Initial Response

The Interim Report concluded that when cable fluid releases have only contaminated the soils above the water table (the vadose zone), the risks from ingestion of contaminated groundwater are negligible, providing that any receptor well is at least 30 meters from the source area. Therefore, the goal of remediation for releases in the unsaturated zone is to protect workers who may contact the fluids, to protect any nearby surface water, and to eliminate fluid mobility. For releases where cable fluid extends to the water table or into the saturated zone, there may be some unacceptable risks from ingestion of contaminated groundwater, depending on several factors, including chemical concentrations in the fluid, release dimensions, local hydrology, and distance to the nearest drinking water well (actual or potential). Therefore, for saturated zone releases, the goal of remediation must be to protect workers and nearby aquatic resources, eliminate fluid mobility and protect potable aquifer.

As shown in Figure 3-1, the first step in any cable fluid release is to remove and properly dispose of all free liquids and visually-contaminated soils before determining whether contamination has extended to the saturated zone. If the release is located in an area where drainage to nearby surface waters is likely or may be facilitated by underground conduits (e.g., sewer or other utility lines), remove additional contaminated soils or media (e.g., pea gravel).

If a rapid response is necessary, meaning that the excavation may only remain open for a matter of hours, the remedial goal for soils left after excavation is a total fluid concentration of 7.4 g/kg, applying the more restrictive mineral oil cleanup goal to all fluid types. If it can be determined from utility records that the fluid is not a mineral oil, the remedial goal for rapid response would be 13 g/kg.

3.3 Saturated Zone Release Response

If the fluid type is known from utility records, the only testing required for the first step is HEM total fluid concentration (EPA Method 9071B) or modified EPA Method 8100.

As shown on Figure 3-2, for mineral oil releases, once soils are remediated to a total fluid concentration less than 7.4 g/kg, no further remediation is required to protect groundwater. For releases of other fluid types, soils in the saturated zone must be remediated to a total fluid concentration of less than 13 g/kg and additional evaluation is required to determine if further remediation is required to protect groundwater.

EPRI evaluated the need for groundwater cleanup for three spill scenarios, shown in Table 3-1. To select the scenario that best represents a particular release site, the dimensions of the spill should be estimated from soil borings and/or excavation data and the release area calculated. The source width (m) in Table 3-1 is the width perpendicular to groundwater flow or, to be conservative, the longest of the source's length/width dimensions. Equation 1 on Figure 3-3 can be used to estimate the release area when only spill volume is known.

Table 3-2 provides source-to-receptor distances (L_Rs) calculated using the maximum concentration of chemicals of concern found in the EPRI study, along with reasonable, conservative values for hydrogeological conditions and contaminant biodegradation. If distance to nearest existing or potential water supply well is less than the required L_R, then further site assessment and possibly soil remediation is required.

3.4 Beyond the Environmental Testing Protocol

If, after completion of the initial actions outlined in the flowchart, the site manager determines that soil contamination may pose a risk to groundwater (i.e., if the distance from the spill to the receptor well is less than the required distance shown in Table 3-2), it is recommended that the site manager collect additional site-specific data and reevaluate the need for remediation. Because conservative assumptions were made in developing the generic release scenarios relating to cable fluid composition, transport and fate of cable fluid contaminants, the actual risk may be significantly less than that indicated here. Site-specific data collection that could produce a more accurate estimate of risk include:

- Sample groundwater to determine if dissolved constituents from fluid are present above applicable standards.
- Determine - for the specific cable fluid involved in the release - the concentration of benzene or 1,1,1-TCA that would dissolve in groundwater, using the fluid dissolution test described in the Interim Report or an equivalent method. These data would be used to develop site-specific estimates of the Dilution and Attenuation Factors needed to protect site groundwater (DAF_Ns). Procedures for calculating DAF_Ns are detailed in Appendix D of the Interim Report.
- Obtain better estimates of release dimensions using borings or test pits.

Measure site-specific hydrogeological parameters (e.g., soil porosity, soil moisture content, infiltration rate, groundwater flow rate). Use the site-specific chemical and hydrogeologic information to calculate site-specific Dilution and Attenuation Factors (DAFs) using the transport model employed in the Interim Report. Procedures for calculating DAFs for a release site are detailed in Appendix D of the Interim Report.

Table 3-1
Default Parameter Values for Generic Release Scenarios

Release Dimensions (units)	Parameter Values Small Release	 Medium Release	 Large Release
Source area (m^2)	10	100	1,000
Source width (m)	3	30	300
Vertical source thickness (m)	1	5	10

$A = V_f/(\ S_r H)$ (Equation 1)

Where,

A = estimate of release area (m^2)

V_f = estimate of cable fluid volume remaining in site soils (m^3)

= total soil porosity (L/L)

S_r = residual saturation for fluid in soil (L/L)

H = vertical source thickness (m)

S_r typically ranges from 0.11 to 0.23 for cable fluids. A conservative value is 0.11.

typically ranges from 0.25 to 0.40 for soils. A conservative value is 0.25.

Figure 3-3
Estimating Release Area from Release Volume

Table 3-2
Required Source-to-Receptor Distances for a Source in the Saturated Zone

Cable Fluid	Required Source-to-Receptor Distance, L_R (m)					
	New York State Standards[3]			EPA Region III Standards and Guidance[3]		
	Small Release	Medium Release	Large Release	Small Release	Medium Release	Large Release
Alkylbenzene-containing fluid[1] OR benzene detected in cable fluid or contaminated soil	70	1,200	1,400	90	1,500	2,100
Polybutene fluid OR 1,1,1-TCA detected in cable fluid or contaminated soil[2]	< 30	200	700	0	0	0

[1] Alkylbenzene containing fluids: alkylbenzenes, alkylbenzene polybutene blend (APB), and mixtures.

[2] 1,1,1-TCA was detected in only two samples in the EPRI (2002) study: one pure polybutene and one APB. Cable owners with polybutene fluids should verify the presence of this chemical in their fluids. If not present, this cleanup goal does not apply. If both benzene and 1,1,1-TCA are present, use the most restrictive L_R value.

[3] Cable owners in regulatory jurisdictions other than New York State can calculate the required source-to-receptor distances for their sites using the procedures detailed in Appendix D of the Interim Report. As the USEPA has not developed nationwide cleanup guidance, EPA Region III standards and guidance are used in EPRI's study as the default nationwide standards.

4

COMPREHENSIVE EVALUATION AND ACCEPTANCE TEST MATRIX

4.1 Introduction

Cable fluids that may come on the market in the future will ideally have all the performance characteristics currently specified by the industry, and will also have minimal environmental impact in the case of a fluid spill. However, since it is unlikely that any single fluid will possess all desirable characteristics, this matrix will allow a comparison between candidate fluids.

The criteria and data used to evaluate environmental acceptability are based on the EPRI (2002) study results and conclusions. The test methods for engineering properties were developed by the Association of Edison Illuminating Companies (AEIC).

The comprehensive test matrix (Table 4-1) has three sections:

- Environmental Acceptability: parameters used to evaluate potential environmental impacts of cable fluids.
- Performance characteristics: parameters used to evaluate the suitability of a new cable fluid for its intended purpose.
- Cost Factors: economic factors that affect the purchase decision, including initial cost and life-cycle costs (fluid handling, site remediation and spent fluid disposal), which may differ for different fluids.

The second column of the matrix recommends test methods to be used for each environmental and engineering parameter. The third column presents, where possible, the desired range of values for each parameter. The three right-hand columns of the matrix are left blank and are intended to be used to enter a checkmark for each parameter in one of the columns: “In Range”, “Out of Range, or “No Data”. Candidate fluids may be ranked by comparing the number of parameters that are within the desirable range of test values. Because environmental acceptability concerns and engineering requirements will differ among regulatory jurisdictions and cable systems, EPRI has not attempted to assign weighting factors to the listed parameters.

Table 4-1
Comprehensive Test Matrix

Evaluation Criterion	Test Methods	Desirable Range of Values	In range	Out of range	No data
Environmental Acceptability					
Fluid VOC concentrations	EPA 8260B, 8270C	< 5.27 x EPA Region III's RBCs for industrial soil (see text)			
Fluid SVOC concentrations	EPA 8270C	< 6.85 x EPA Region IX's PRGs for industrial soil (see text)			
Aqueous dissolution test VOC and SVOC concentrations	EPRI (2002) EPA 8260B, 8270C	< 10 x applicable groundwater/drinking water standard or guidance and, for releases near surface water, < 10 x applicable surface water quality standard or guidance for protection of aquatic life (see text)			
EPH content of fluid(1)	MADEP (1999)	< 6.85 x MADEP std. for S2(GW-3) soils = Aliphatic C_9 - C_{18} < 17,000 mg/kg Aliphatic C_{19} - C_{36} < 34,000 mg/kg Aromatic C_{11} - C_{22} < 14,000 mg/kg			
Aqueous dissolution test TPH concentration(1)	EPRI (2002) EPA 8015M	< 2 mg/L			
Residual saturation in soil (S_r)	Wilkens et al.,1995	> 0.11			
Mammalian toxicity	Various (see text)	No significant acute or chronic mammalian toxicity (see text)			
Aquatic toxicity (where applicable)	Various (see text)	Non-toxic to representative freshwater or marine species (see text)			
Biodegradation rate in soil and/or water	ASTM D5864, OECD 302D (draft) [2]	High biodegradation rate compared to current fluid types (see text)			
Performance Characteristics		**Desirable Range of Values**			
Dielectric strength @ 25°C	ASTM D-877,1816	> 35 kV (>30 kV acceptable)			
Dissipation factor @ 100°C	ASTM D-924,1934	< 0.001 initially, < 0.002 after heating 96 hours @115°C (< 0.0025 initially, < 0.015 after heating 96 hours @115°C acceptable)			
Dielectric constant	ASTM D-924	< 3			
Volume resistivity	ASTM D 1169	> 1E+14 ohm-cm @ 100°C			

Table 4-1, Continued
Comprehensive Test Matrix

Evaluation Criterion	Test Methods	Desirable Range of Values	In range	Out of range	No data
Moisture content	ASTM D1533	< 30 ppm	☐	☐	☐
Viscosity @37.8°C	ASTM D445	Low viscosity: 18-32 cSt, 90-150 SUS High viscosity: 108-134 cSt; 500-620 SUS	☐	☐	☐
Viscosity@98.9°C	ASTM D445	Low viscosity: 2-5 cSt, 34-45 SUS High viscosity: 8-12 cSt; 55-65 SUS	☐	☐	☐
Flash point	ASTM D92	> 130°C	☐	☐	☐
Organic chlorides	ASTM D2522	Low viscosity <40 ppm; High viscosity <30 ppm	☐	☐	☐
Inorganic chlorides	ASTM D878	None	☐	☐	☐
Total sulphur	ASTM D3246	< 100 ppm	☐	☐	☐
Pour point	ASTM D97	Low viscosity: from -45 to -50°C; High viscosity: from -25 to -30°C	☐	☐	☐
Compatibility	Various(3)	No change in materials or in dielectric strength/dissipation factor of fluid	☐	☐	☐
Cost Factors		**Desirable Range of Values**			
Cost per gallon (installation)	NA	< $8/gallon (2002 U.S. dollars)	☐	☐	☐
Cost per gallon (retrofilling)	NA	< $9/gallon (2002 U.S. dollars)	☐	☐	☐
Worker protection cost	NA	MSDS lists no special worker respiratory or clothing requirements	☐	☐	☐
Fluid disposal cost	NA	Disposable as non-hazardous waste	☐	☐	☐
Spill cleanup costs	NA	Minimal soil removal required due to no hazardous constituents	☐	☐	☐

Notes

1. This parameter is only applicable to petroleum-derived oils such as mineral oil. It is not applicable to synthetic oils (e.g., polybutenes, alkylbenzenes, or silicones) or to vegetable oils.
2. Draft OECD Guideline 302D: "Inherent Biodegradability - CONCAWE Test" is available on the OECD website www.oecd.org/pdf/M00024000/M00024360.pdf. CONCAWE developed this draft methodology based on the existing ISO 14593 with modifications to address inherent biodegradability.
3. ASTM Methods D3455, D5642, D350 for all materials/fluids. ASTM Method D5282 for materials/silicone fluid.

ASTM - American Society for Testing and Materials
EPA - US Environmental Protection Agency
EPH - Extractable Petroleum Hydrocarbons
MSDS - Material Safety Data Sheet
MADEP - Massachusetts Dept. of Environmental Protection
NA - Not Available
OECD - Organisation for Economic Cooperation and Development
PRGs - Preliminary Remediation Goals
RBCs - Risk Based Concentrations
SVOC - Semivolatile Organic Compounds
TPH - Total Petroleum Hydrocarbons
VOC - Volatile Organic Compounds

The matrix specifies the data needed to evaluate any candidate fluid. However, some tests may not be necessary or appropriate for a particular cable installation. For example, aquatic toxicity is irrelevant if a cable is not situated near a surface water body. On the other hand, additional testing may be needed if the candidate fluid is a new class of chemical – i.e., not a standard mineral oil, polybutene, alkylbenzene, or blend of these fluids.

The matrix is not to be used to determine routine testing requirements for an in-use fluid. In general, environmental acceptability parameters would be determined in an initial evaluation, either by the manufacturer/supplier or the customer; repeat testing (i.e. per lot of fluid) would be at the discretion of the cable owner. The responsibility of the cable fluid supplier is to ensure that the fluid delivered to the site meets the specifications of the user. The specifications should be developed based on this matrix and AEIC standards.

Some performance properties may be impacted during transportation (dielectric strength, moisture content, contamination, etc.). For this reason, many users test the fluid upon receipt. Typically, the tests performed include dielectric strength (breakdown), moisture content and dissipation factor. These three tests will reveal if the performance properties have changed during transportation. Gassing of the fluid, which occurs in transit when the fluid is shipped under a dry nitrogen blanket or nitrogen pressure, can result in temporarily reduced dielectric strengths during field tests of incoming shipments. Environmental properties are not expected to change during transportation.

4.2 Description of Comprehensive Test Matrix Parameters

Environmental Acceptability

Table 4-1 lists a set of tests that will provide the data needed to evaluate the environmental acceptability of new cable fluids. Each test is discussed below.

Chemical Composition

Candidate fluids should be tested for chemical composition to evaluate risks to human health and the environment in the event of a fluid spill. Cable fluids of the same chemical type as current fluids – mineral oils, alkylbenzenes, and polybutenes – should be tested for the parameters listed in Table 4-1 and discussed below. Cable fluids derived from different chemical classes or chemical formulations may need to add additional analyses, e.g., Tentatively Identified Compounds (TICs) for VOCs and SVOCs, metals and other inorganic compounds. A qualified chemist should be consulted to determine the analytical requirements.

VOC Content of Fluid: Maximum VOC concentrations in a cable fluid that will be protective of workers contacting contaminated soils are obtained by multiplying EPA Region III's Risk-Based Concentrations (RBCs) (http://www.epa.gov/reg3hwmd/risk) for contaminated industrial soil by a factor of 5.27, as shown in Equation 2.

$C_f = C_{s,max}/0.146 = \text{EPA RBC}/(0.146 \times 1.3) = 5.27 \times \text{EPA RBC}$ (Equation 2)

where,

C_f = maximum VOC concentration in cable fluid (mg/kg),

$C_{s,max}$ = maximum VOC concentration in fluid-saturated soil (mg/kg), and

EPA RBC = EPA Region III Risk-Based Concentration (mg/kg).

The factor of 0.146 in Equation 2 is derived from the assumption of a fluid-saturated soil with a soil porosity of 30% and bulk densities for the soil and fluid of 1.85 and 0.9 kg/L, respectively. The factor of 1.3 is necessary to convert the ingestion-only RBCs to screening values that also consider particulate inhalation and dermal sorption uptake routes (EPRI, 2002; Appendix D, pages D-12 and D-14).

SVOC Content of Fluid: Maximum SVOC concentrations in a cable fluid that will be protective of workers contacting contaminated soils are obtained by multiplying EPA Region IX's Preliminary Remediation Goals (PRGs) for industrial soil (www.epa.gov/region9/waste/sfund/prg/index.htm) by a factor of 6.85, as shown below in Equation 3.

$C_f = \text{EPA PRG}/0.146 = 6.85 \times \text{EPA PRG}$ (Equation 3)

where,

C_f = maximum SVOC concentration in dielectric fluid (mg/kg), and

EPA PRG = EPA Region IX Preliminary Remediation Goal (mg/kg)

The factor of 0.146 in Equation 3 is derived as described above for Equation 2.

VOC and SVOC Content of Dissolution Test Water: Dissolution test data are used to evaluate the potential risk to humans or aquatic organisms exposed to contaminated groundwater migrating from a fluid spill. The screening value for protection of human health is obtained by multiplying the groundwater/drinking water standard or guidance for each detected chemical by 10. This assumes a dilution and attenuation factor (DAF) of at least 10 for any cable-fluid-contaminated leachate before the leachate reaches a drinking water well. An alternate method of screening for potential groundwater contamination problems – using data from fluid analyses – is described in EPRI (2002); however, the use of data from dissolution tests is more accurate.

These screening values may also be protective of aquatic life in nearby surface waters, as was found for eight fluid samples tested by EPRI (2002). Utilities should, however, compare the dissolution test results with applicable state and/or federal water quality standards and guidelines for protection of aquatic life (e.g., EPA [1999]; NYSDEC [1998]) if the cable will be located near a surface water body.

<u>EPH Content of Fluid</u>: The Extractable Petroleum Hydrocarbons (EPH) test is used to determine soil cleanup levels to protect workers contacting contaminated soil. The EPH parameter is only applicable to mineral oils or other cable fluids derived from petroleum via such processes as distillation, fractionation, and hydrogenation. It is not applicable to vegetable oils or to synthetic mixtures such as alkylbenzenes, polybutenes, or silicones. By definition (MADEP, 1999), the EPH content of a fluid consists of three fractions defined by the number of carbon atoms (C) in the compound and the compounds’ aliphatic/aromatic character. If the EPH analysis of a petroleum-derived fluid contains less of each fraction than the amounts shown in Table 4-1, then risks to workers exposed to contaminated soils may be considered negligible. The factor of 6.85 (= 1/0.146) was derived as described for Equation 3, above.

The application of this test to cable fluids involves significant uncertainty since the MADEP EPH risk-based screening values are based on the toxicities of representative chemicals in each of the three EPH fractions. Mineral oils studied by EPRI (2002) did not contain any of these representative chemicals.

<u>TPH in Dissolution Test Water</u>: The Total Petroleum Hydrocarbons (TPH) test is used to estimate risk from drinking water contaminated by cable fluids. This parameter is only applicable to mineral oils or other cable fluids that are derived from petroleum via such processes as distillation, fractionation, and hydrogenation. It is not applicable to synthetic chemicals such as alkylbenzenes, polybutenes, silicones, or vegetable oils. A screening value was derived by multiplying the MADEP (1999) GW-1 standard for TPH in potable groundwater (200 µg/L) by a DAF of 10.

Residual Saturation in Soil

A residual saturation test is used to determine the tendency of a fluid to be mobile in soil, and thus pose a risk to groundwater. A review of limited literature data on residual saturation (S_r) of mineral oils in soil indicated that S_r values were generally in the range of 0.11 to 0.23 (EPRI, 2002). Using the lower value and a conservative assumption on soil porosity (25%) produces a recommended soil cleanup goal of 13 g fluid/kg of soil to prevent fluid migration. If S_r for a new cable fluid is greater than 0.11, then the 13 g/kg cleanup goal should be adequately protective. If, however, the measured S_r value is less than 0.11, a proportionally lower cleanup standard would have to be used at any spill site to achieve equivalent protection against fluid mobility. S_r should be determined for any new class of cable fluid (i.e., one not studied by EPRI [2002]) or any new formulation of an existing fluid.

Mammalian Toxicity

Mammalian toxicity data are used to evaluate potential risks to humans and other mammals from exposure to cable fluids or fluid-contaminated environmental media. EPRI’s review of the toxicity of existing cable fluids (EPRI, 2002) indicated that the bulk constituents of the fluids were of relatively low toxicity to mammals. This cannot be assumed for future cable fluids.

Figure 4-1 lists toxicity tests that would provide an adequate basis for a toxicity assessment. Because of the large number of adverse effects that could potentially be of concern and the complexity of interpreting the resulting data, it is not possible to provide specific guidance on the range of toxicities considered acceptable.

For any new classes of synthetic fluids (i.e., other than those studied by EPRI [2002]), a toxicologist should review the available mammalian toxicity literature. In most cases, evaluation of mammalian toxicity will rely on published studies on the candidate material. If any additional studies are needed, it is likely that this would be the responsibility of the manufacturer/supplier rather than the customer.

Acute toxicity (LD_{50}, target organs, eye irritation) – Information critical for worker protection (OSHA)

Route-specific toxicokinetic data (ADME -- absorption, distribution, metabolism, excretion) – Absorption is particularly important for assessing possible exposures via both oral and dermal exposure routes. ADME data are also important for assessing target organs and possible sensitive subpopulations.

Subchronic toxicity– Toxicity data from a 90-day exposure study are often the best available for assessing possible long-term effects. Study should include at a minimum a full pathology evaluation to identify target organs, assessment of multiple endpoints including immunological effects, and a dose range that produces some untoward effects at the highest exposure.

Genotoxicity – Results from a battery of short-term tests for effects on DNA are often the only data available to assess possible carcinogenicity. Lifetime studies are relatively rare and are quite expensive. Tests should include both measures of point mutations and chromosomal damage, and preferably both *in vitro* and *in vivo* studies. The latter might include measurements of chromosome aberrations and/or sister chromatid exchanges in peripheral lymphocytes from laboratory animals.

Surrogate toxicity data – Toxicity data from tests with similar chemicals can be useful in supporting conclusions on a related but less well characterized chemical. A database of toxicity information for common classes of chemicals may be important in focusing needs for toxicity information.

Chronic (lifetime) toxicity – Information from a lifetime exposure study is generally considered most definitive in assessing possible long-term effects of exposure. Such exposure is of greatest concern for environmental releases. Chronic studies are relatively rare and are very expensive. Usually, if data exist, they come from a single study on only one member of chemical group.

Data from multiple studies – In all cases, data from more than one study adds considerable weight to findings.

Figure 4-1
Mammalian Toxicity Tests

Aquatic Toxicity

Aquatic toxicity data are used to evaluate risks to fish and other aquatic organisms from spills that reach surface water bodies. Relatively few data are available on the toxicity of cable fluids to aquatic life. No specific aquatic toxicity concerns (LC_{50}s greater than 1000 mg/L) were identified by EPRI (2002) for existing fluids. However, any fluid that forms a floating layer can cause deleterious effects such as gill fouling when released into surface waters. It is recommended that utilities review available data on aquatic toxicity if the cable is to be located in close proximity to surface water. The following tests would be acceptable for the assessment of aquatic toxicity:

- Acute (e.g., 96-hr LC_{50}) and chronic (7-day) tests on at least two species of fish (vertebrates). Common test fish include flathead minnow, bluegill, smallmouth bass, catfish, and suckers. Species selected should represent different trophic feeding levels.
- Acute (48-hr) and chronic (7-day) tests on the water flea (*Ceriodaphnia*), an invertebrate.
- Sediment toxicity tests (28-day) with an isopod (e.g., *Hyallella*) and black fly midge (*Chironomus*).

Because of the complexity of the conduct of toxicological tests and the interpretation of the resulting data, it is not possible to provide specific guidance on the range of toxicities that would be considered acceptable. A qualified individual should review the available aquatic toxicity data. In general, utilities would not be expected to conduct aquatic toxicity tests, but would request this information from the manufacturer/supplier.

Biodegradation Rate in Soil and/or Water

Biodegradation tests can be used to estimate the persistence of a cable fluid in the environment after a spill. Fluids that degrade rapidly are less likely to migrate offsite and may offer an advantage in negotiating cleanup levels with regulators. EPRI (2002) did not evaluate biodegradability as no data were available, and no claims of biodegradability were being made for the fluids under investigation. Furthermore, EPRI found that it was not necessary to consider biodegradation in deriving risk-based soil cleanup guidance for the existing fluids, as the chemicals making up the bulk of these fluids were found to be relatively non-toxic.

Biodegradation rates are typically obtained from laboratory studies under optimal conditions of soil homogeneity, temperature, nutrient availability, and microbial population density. These studies do not reflect the actual rate of biodegradation that will occur in a spill situation. To determine whether a new cable fluid will degrade faster than an existing product, both fluids should be tested under the same laboratory conditions.

No test method has been developed specifically for cable fluids. A now-withdrawn method from the Coordinating European Council, CEC L-33-A-93, is often used to measure the biodegradation of petroleum products (including transformer oils) and is the method most familiar to laboratories. This method measures “primary” biodegradation – (the loss of the parent material) in water, but the method also has been adapted to a soil medium. This method has been widely used because it is very simple, requiring only standard laboratory glassware and an infrared (IR) spectrophotometer. The test substance is introduced to an inoculum, incubated, and the extractable hydrocarbon remaining is measured at several time periods. However, since this method measures primary biodegradation rather than "ultimate" biodegradation (complete breakdown to carbon dioxide (CO_2), water, inorganic salts and new microbial cells) it cannot detect the potential buildup of byproducts, and thus may overestimate the actual removal of a material. For this reason, it is preferable to use methods that measure the potential for ultimate biodegradation.

Since the intent is to determine the potential for cable fluids to be degraded in the environment under typical spill scenarios over months and years, rather than days, methods that measure 'inherent' biodegradability (rather than "ready" biodegradability) are recommended. "Ready" biodegradability tests measure the potential for a substance to rapidly and extensively biodegrade in an aquatic environment (such as a waste water treatment plant) and they are so stringent that the true biodegradability could be underestimated. Inherent biodegradability tests evaluate whether the test substance will biodegrade under more favorable conditions than those used in the ready biodegradability test. Inherent biodegradability tests include procedures such as pre-exposure of the inoculum (to produce an acclimated population of bacteria), increased test duration and/or a higher microorganism-to-test-substance ratio. A positive inherent biodegradability test result indicates that the test substance will not persist indefinitely in an aerobic environment; however, rapid and complete biodegradation cannot be assumed. A negative result indicates the substance is not biodegradable and would be persistent in the environment.

The two methods listed on Table 4-1 are the only currently supported inherent biodegradability methods that are specifically designed for use with non-aqueous phase liquids (NAPLs), in both cases, lubricants. Method modifications may be necessary to apply these methods to cable fluids.

ASTM D5864 measures aerobic biodegradation of lubricants in water in the presence of a pre-adapted inoculum under controlled laboratory conditions. The method includes procedures to test water-insoluble materials and complex mixtures. The extent of biodegradation is measured as the CO_2 produced compared to the theoretical amount of CO_2 that would be generated if all of the carbon in the test material were converted to CO_2. The inoculum may be derived from sludge, soil or surface water. The test is run for at least 28 days or until a plateau of CO_2 evolution has been reached.

Draft OECD Method 302D is similar to the ASTM method, in that it determines aerobic biodegradation in water in the presence of a pre-exposed inoculum. However, this method measures the inorganic carbon (IC) accumulated in sealed test bottles, and compares the IC to the theoretical IC that would be generated from complete conversion of the material to CO_2. The inoculum is derived from soil and wastewater sludge. The test is run until biodegradation reaches a plateau, which may take from eight weeks to more than 3 months. Unlike the ASTM method, the draft OECD method stipulates a threshold for acceptable biodegradability of greater than 60% of theoretical IC. Less than 20% of theoretical IC indicates that the test substance is not inherently biodegradable under the conditions of this test. Results between 20% and 60% indicated that the test substance has inherent, primary biodegradability. While this range of values strictly applies only to pure substances and cable oils are a mixture of different organic compounds, the range was developed using white mineral oil, which is similar to cable fluids.

Therefore, the ranges of values cited appear appropriate for evaluating the potential fate of cable fluids in the environment.

Either the ASTM or OECD methods may be selected: the OECD method has the advantage of stipulating a range of acceptable results, but is not a final, approved method. When using either of the above two methods, it is recommended that primary biodegradability be measured as well as ultimate, using some measure of bulk fluid disappearance such as modified Method 8100. The addition of a sterilized sand or sandy soil to the test container may make the tests more realistic. Many other standard biodegradation tests are available, but all would require more substantial modifications as they were not designed for NAPLs, require the use of 14C-labeled compounds, or have other limitations. Examples include EPA's Soil Biodegradation Test [Office of Prevention, Pesticides, and Toxic Substances (OPPTS) 835.3300] and Shake Flask Die-Away Test (OPPTS 835. 3170).

Because the laboratory tests do not replicate field conditions, the resulting biodegradation rates cannot be extrapolated to actual spill sites. However, the relative rates of fluid breakdown can be informative. Because of the difficulty of predicting biodegradation in the environment, there is no absolute range of laboratory-measured biodegradation rates that would be acceptable. However, biodegradation half-lives on the order of days to weeks would clearly be positive. Biodegradation half-lives on the order of years or longer would not provide a significant benefit.

Performance Characteristics

The engineering tests listed in the matrix are used to evaluate the performance characteristics of new cable fluids. Each test is discussed below.

Dielectric Strength

Dielectric strength or breakdown strength of an insulating fluid is the voltage at which breakdown (sparking) occurs under prescribed conditions. The primary factors that influence dielectric strength are the presence of impurities and moisture in the fluid. While the AEIC currently specifies >35kV, mineral oils used in current cables do not meet this specification. Thus, >30kV may be acceptable; however, >35kV is desirable.

Dissipation Factor

The dissipation factor (also called the power factor) is a measure of energy dissipated in the fluid, which causes heating and eventual breakdown of the cable insulation. The dissipation factor should be as low as possible to prevent the unnecessary loss of energy and is negatively affected by ionic impurities such as colloidal particles. AEIC specifies a dissipation factor of <0.001 initially and <0.002 after heating. Current mineral oil cable fluids do not meet this specification, but still show acceptable performance. Thus, the higher factors shown in the matrix may be acceptable, but a lower factor is desirable and most synthetic cable fluids (e.g. alkylbenzenes, polybutenes) do have lower factors.

Dielectric Constant

The dielectric constant is a measure of the electrical energy stored in the material, expressed as a ratio of the capacitance of a capacitor filled with the dielectric to its capacitance in air. A low dielectric constant is required for cable fluids in order to minimize storage of energy in the insulation. The dielectric constant is about 2.2 for most hydrocarbon oils including the synthetic fluids (polybutenes and alkylbenzenes).

Volume Resistivity

The volume resistivity of an insulating material is a measure of the direct current resistance of the material. It should be as high as possible.

Moisture Content

The presence of moisture will impact drastically electrical properties such as dielectric strength and dissipation factor.

Viscosity

The optimum viscosity of a cable fluid depends on the particular cable system and whether the fluid is static or circulated (with or without cooling) in the system. Lower viscosity fluids are more desirable for circulated systems to reduce pressure drops and improve heat transfer. Viscosity must be low enough that pressure can be maintained throughout the length of a pipe cable system at all times, and high enough that the fluid is not unduly sensitive to contamination and can be frozen during system emergencies. The fluid must also have a high enough viscosity that it does not dilute the impregnating fluid of the paper insulation system.

Flash Point

Flash point measures the potential for fires and explosions due to ignition of the cable fluid. The temperature of HPFF cables has been known to reach 105°C or slightly above for short emergency periods, and higher during cable failures. The flash point must be sufficiently greater than the cable temperature to eliminate the potential for fire and explosion.

Chlorides, Total Sulfur

The presence of contaminants such as chlorides and sulfur compounds decreases dielectric strength and increases the dissipation factor of the fluid. Therefore, lower concentrations of contaminants are desirable. The values shown are the highest values acceptable for existing fluids, which should also be acceptable for new fluids.

Pour Point

Pour point should be sufficiently low that the fluid is able to lubricate the conductors at typical ground temperatures (when the conductors are being pulled through the pipe) but high enough that the fluid can be frozen solid during line repairs.

Compatibility

For new cable fluids derived from different oils, chemicals, or new chemical formulations, compatibility testing is required to assure that the new fluid is chemically and electrically compatible with:

- cable insulation (paper or laminated paper polypropylene), cable impregnant and all cable material components,
- internal pipe coating materials (epoxy or vinyl), and
- cable system accessory items (joints, terminators, valves, pumps).

The cable owner and fluid supplier, with input from the cable manufacturer, should mutually agree on methods of determining compatibility. Compatibility tests generally include accelerated aging at elevated temperatures (90 – 130°C), followed by a thorough examination of all materials and physical and chemical analyses performed on the oil and the equipment material. Tests on the oil after aging include dissipation factor, dielectric strength, interfacial tension, and color. The equipment material is physically examined for changes, particularly swelling and discoloration, and tests are performed to measure the test specimen’s hardness and dielectric strength.

Cost Factors

The relative cost of each fluid can be evaluated by considering the unit cost of the cable fluid under different purchasing situations. For example, the unit cost of the fluid in the large quantities used at installation (bulk shipment in rail tank cars or tank trucks) may be different from the unit cost of the fluid purchased in small quantities (under 55 gallons) for replenishment or retrofilling. Additionally, utilities should consider the total life-cycle cost of the cable fluid, which will be increased for fluids where issues of worker safety or environmental risks exist. For example, fluids found to be toxic or to contain toxic constituents may have higher labor costs for operation and maintenance (since workers need protective clothing) as well as higher spill cleanup costs (soil excavation, installation of monitoring wells, disposal costs, etc.). EPRI has not assigned ranges of values to life cycle costs, as these will be specific to the cable system and the regulatory setting. Nevertheless, it is recommended that these factors be included, at least in a qualitative manner, in the evaluation of candidate fluids.

4.3 Application of the Comprehensive Test Matrix

The user should review manufacturer or supplier data, and supplement these data with their own test results to determine if a candidate fluid shows acceptable or desirable values for each environmental, performance and cost parameter listed on Table 4-1. The matrix should be completed for each candidate fluid. Fluids with the most checks in the “In Range” column of the matrix are the most desirable. When evaluating cable fluids with low purchase costs but with few checks in the “In Range” column for performance, environmental or other cost parameters, the cable owner should understand that total life cycle costs of that fluid (in terms of utility costs for cable failure or environmental cleanup costs) may be higher than fluids with higher purchase costs but acceptable performance, environmental and other regulatory parameters.

5

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