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Environmental Technology Verification Report

Cooper Power Systems
Envirotemp®FR3™
Vegetable Oil-Based
Insulating Dielectric Fluid

Prepared by

Department of Toxic Substances Control

Under a cooperative agreement with

U.S. Environmental Protection Agency

May 2002

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By

California Environmental Protection Agency
Department of Toxic Substances Control
Office of Pollution Prevention and Technology Development
Sacramento, California 95812-0806

Notice

The information in this document has been funded in part by the U.S. Environmental Protection Agency (EPA) under a Cooperative Agreement number CR 824433-01-0 with the California Environmental Protection Agency (CalEPA), Department of Toxic Substances Control (DTSC). The Pollution Prevention and Waste Treatment Technologies Center under the U.S. EPA Environmental Technology Verification (ETV) Program supported this verification effort. This document has been peer reviewed by the EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA or the Department of Toxic Substances Control (DTSC) for use.

This verification is limited to the use of the Cooper Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid for use in electrical apparatus such as distribution transformers as an alternative to mineral oil-based dielectric fluids. EPA and DTSC make no express or implied warranties as to the performance of the Cooper Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid technology. Nor does EPA and DTSC warrant that the Cooper Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid is free from any defects in workmanship or materials caused by negligence, misuse, accident or other causes.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's air, water, and land resources. Under a mandate of national environmental laws, the EPA strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technologies across all media, and to report this objective information to the permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification Organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. There are now six ETV technology centers, which include the original twelve ETV technology areas. Information about each of the environmental technology centers covered by ETV can be found on the Internet at http://www.epa.gov/etv.htm.

Effective verifications of pollution prevention and treatment technologies for hazardous waste are needed to improve environmental quality and to supply cost and performance data to select the most appropriate technology. Through a competitive cooperative agreement, the California Department of Toxic Substances Control (DTSC) was awarded EPA funding and support to plan, coordinate, and conduct such verification tests, for "Pollution Prevention and Waste Treatment Technologies" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/03/03_main.htm.

The following report reviews the performance of the Cooper Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid. Envirotemp®FR3™ fluid is used as an insulating dielectric fluid for electrical apparatus such as distribution transformers as an alternative to mineral oil-based dielectric fluids.

Acknowledgment

DTSC wishes to acknowledge the support of all those who helped plan and implement the verification activities, and prepare this report. In particular, a special thanks to Ms. Norma Lewis, Project Manager, and Ms. Lauren Drees, Quality Assurance Manager, of EPA's National Risk Management Research Laboratory in Cincinnati, Ohio.

DTSC would also like to thank Mr. Jay Wells and Mr. James Tolosano of Artwel Electric, Inc., Mr. Tony Borba of Western Utilities, and Mr. David Pais of Texas Instruments for their support and for providing the facility and necessary resources to conduct the verification field test. Additionally DTSC would like to thank Mr. John Luksich and Mr. Patrick McShane of Cooper Power Systems for their participation in this Environmental Technology Verification Pilot Project.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

EPA
U.S. Environmental Protection Agency

Cal/EPA
California Environmental Protection Agency

ETV JOINT VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**VEGETABLE OIL-BASED INSULATING DIELECTRIC FLUID**		
APPLICATION:	**VEGETABLE OIL-BASED INSULATING DIELECTRIC FLUID FOR USE IN ELECTRICAL APPARATUS REQUIRING A LIQUID DIELECTRIC COOLANT**		
TECHNOLOGY NAME:	**ENVIROTEMP®FR3™ INSULATING DIELECTRIC FLUID**		
COMPANY:	**COOPER POWER SYSTEMS, INC.**		
ADDRESS:	**1900 EAST NORTH STREET**	PHONE:	**(800) 643-4335**
	WAUKESHA, WISCONSIN 53188	FAX:	**(262) 524-4654**
WEB SITE	**http://www.cooperpower.com**		
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The U.S. Environmental Protection Agency has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and information dissemination. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved, and more cost-effective technologies. The ETV Program is intended to assist and inform those individuals in need of credible data for the design, distribution, permitting, and purchase of environmental technologies.

ETV works in partnership with recognized testing organizations to objectively and systematically document the performance of commercial ready environmental technologies. Together, with the full participation of the technology developer, they develop plans, conduct tests, collect and analyze data, and report findings. Verifications are conducted according to an established workplan with protocols for quality assurance. Where existing data are used, the data must have been collected by independent sources using similar quality assurance protocols.

EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with the California Department of Toxic Substances Control (DTSC) under an ETV Pilot

Project to verify pollution prevention, recycling, and waste treatment technologies. This verification statement provides a summary of performance results for the Cooper Power Systems **Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid**.

TECHNOLOGY DESCRIPTION

Cooper Power Systems (Cooper) has developed a vegetable oil-based dielectric fluid comprised of >98.5% vegetable oil and <1.5% additives. Envirotemp®FR3™ fluid is used in liquid-filled electrical apparatus such as transformers to act as an electrical insulating medium. Envirotemp®FR3™ fluid is currently used in pole, padmount, network, and small and medium power transformers with a voltage rating of 35 kV and a maximum rating of 10 MVA. Other electrical apparatus include loadbreak switches, cables, electromagnets, klystron modulators, power supplies, and bushings. To date, approximately 475 transformers currently use Envirotemp®FR3™ fluid.

EVALUATION DESCRIPTION

The evaluation consisted of:

- Developing a Technology Evaluation Workplan by DTSC to independently evaluate the technology with respect to the identified performance objectives for general performance, aquatic biodegradability, flammability, acute toxicity, chemical composition, and protection of worker health and safety;
- Implementing the Technology Evaluation Workplan by DTSC and Cooper at their manufacturing facility in Waukesha, Wisconsin. Field sampling has also been performed at transformers located at San Mateo High School in San Mateo, California, and Texas Instruments in Santa Cruz, California. The field sampling included collection of 12 samples from three different unused (virgin) product lots at Cooper's facility, and four samples from four different in-service transformers (one sample per in-service transformer).
- Analyzing virgin product samples for general performance parameters (fire and flash point, dielectric breakdown, dissipation factor, neutralization number, interfacial tension, viscosity, pour point, and water content), aquatic biodegradation, aquatic toxicity using the California sample preparation method, fatty acid content, phenolic antioxidants, SVOCs, and metals. In-service transformer sample analyses included general performance parameters (fire and flash point, dissipation factor, water content, conductivity, neutralization number, and interfacial tension,), fatty acid content, phenolic antioxidants, SVOCs, and metals;
- Reviewing supporting documentation on Envirotemp®FR3™ fluid including ASTM data, an acute toxicity report, aquatic biodegradability data, and material safety data sheets (MSDSs).

VERIFICATION OF PERFORMANCE

Performance results of Cooper Power Systems' Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid are as follows:

- General Performance. Envirotemp®FR3™ fluid met Cooper's performance specifications for dielectric breakdown (minimum and gap), pour point, viscosity at 40°C and 100°C, water content, interfacial tension, and neutralization number. Envirotemp®FR3™ fluid also met the ASTM, IEEE, and IEC specifications for dielectric breakdown (minimum, gap, and impulse) and met the ASTM D3487, IEEE, and IEC specifications for the neutralization number. However, all samples had higher dissipation factors at 100°C than past samples tested by Cooper. Envirotemp®FR3™ fluid also had an average dissipation factor at 25°C that did not meet the Cooper specification listed in Table 1. The high dissipation factors may be due to contaminants introduced during product storage, sample collection, sample preparation, or sample testing.

Table 1. Summary of Virgin Product Sampling Results

Performance Parameters	Specification Standards[1]					Sampling Results				
						Lot 01D1	Lot 01C6		Lot 01P2	
	Cooper	ASTM D3487	ASTM D5222	IEEE C57.121	IEC 1099	VFR3-01	VFR3-05	VFR3-07	VFR3-10	Average*
Dielectric Properties										
Dielectric Breakdown (kV)										
minimum	≥ 30	≥ 30	≥ 42	≥ 25-30	--	**45**	**45**	**45**	**46**	**45 ± 1**
gap	≥ 20	≥ 28	≥ 30	≥ 20-30	≥ 23	**36**	**37**	**34**	**39**	**37 ± 3**
impulse	--	≥ 145	NA	--	--	**170**	**168**	**164**	**168**	**168 ± 4**
Dissipation Factor (%)										
@ 25°C	≤ 0.15	N/A	N/A	N/A	--	*0.127*	0.159	0.157	*0.127*	*0.143 ± 0.029*
@ 100°C**	--	N/A	N/A	N/A	N/A	2.70	3.17	3.23	2.46	2.89 ± 0.59
Chemical Properties										
Interfacial Tension (dyne/cm)	≥ 18	N/A	N/A	N/A	--	*28*	*27*	*28*	*28*	*28 ± 1*
Neutralization Number (mgKOH/g)	≤ 0.07	≤ 0.03	≤ 0.01	≤ 0.03	≤ 0.03	0.03	0.03	0.02	0.03	0.03 ± 0.01
Water Content (ppm)	≤ 75	N/A	N/A	N/A	≤ 200	**53**	**59**	**57**	**52**	**55 ± 5**
Physical Properties										
Pour Point (°C)	≤ -18	N/A	N/A	N/A	N/A	*-18*	*-18*	*-18*	*-18*	*-18*
Viscosity (cSt) @ 100°C	≤ 8.5	N/A	N/A	N/A	--	*8*	*7.88*	*7.9*	*7.95*	*7.93 ± 0.09*
@ 40°C	≤ 35	N/A	N/A	N/A	N/A	*32.63*	*32.67*	*32.79*	*32.74*	*32.71 ± 0.11*
@ 0°C	--	N/A	N/A	N/A	--	188.01	187.14	187.53	187	187.42 ± 0.72

Note: Sampling results values in bold indicate these values met all the specification values listed for a given performance parameter. Italicized values met only the Cooper specification value. Underlined values meet all but one specification value.

*Data variability was calculated at 95% confidence using a two-tailed T-test assuming normal distribution.

**Cooper does not have specification value for the dissipation factor at 100°C. Cooper does not routinely test for the dissipation factor at 100°C but reported three past samples had values ranging 1.4% to 1.9%.

Acronyms and Abbreviations:

-- = No specification value available

ASTM D3487 = American Society for Testing and Materials (ASTM) standard specification for mineral insulating oil used in electrical apparatus

ASTM D5222 = ASTM standard specification for high fire-point electrical insulating oil (high molecular weight hydrocarbon specification)

cm = centimeter

Cooper = Virgin product specification for Envirotemp®FR3™ fluid developed by Cooper Power Systems

cSt = centistoke

IEC 1099 = International Electrochemical Commission (IEC) Specifications for Unused Synthetic Organic Esters for Electrical Purposes

IEEE C57.121 = Institute of Electrical and Electronic Engineers (IEEE) 1998 IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers (silicone oil specification)

kV = kilovolt

mgKOH/g = milligrams of potassium hydroxide per gram

N/A = Not applicable since these specification values were developed for fluids with different physical and chemical characteristics than Envirotemp®FR3™ fluid.

ppm = parts per million

For in-service transformer samples, the dissipation factor, neutralization number, interfacial tension, conductivity and water content met the Cooper and IEC 1203 specifications for in-service fluid (see

Table 2). Based on the historical data for the oldest in-service transformers, Envirotemp®FR3™ fluid appears to have degraded little over the service life of the unit.

Table 2. Summary of In-service Transformer Sampling Results

Performance Parameters	Specification Standards		Sampling Results			
	Cooper	IEC 1203	ISFR3-01	ISFR3-02	ISFR3-03	ISFR3-06
Dissipation Factor (%) @ 25°C	≤ 1.0	≤ 0.8	**0.139**	**0.196**	**0.120**	**0.146**
Water Content (ppm)	≤ 400	≤ 400	**98**	**56**	**33**	**41**
Interfacial Tension (dyne/cm)	≥ 18	---	**26**	**26**	**24**	**23**
Neutralization Number (mgKOH/g)	≤ 2.5	≤ 2.0	**0.03**	**0.02**	**0.01**	**0.08**
Conductivity @ 25°C (pS/m)	--	≥ 1.1	**10.6**	**17**	**12.75**	**13.6**

Note: Sample results in bold indicate these values met the both specifications listed in this table. Envirotemp®FR3™ was compared to the IEC 1203 specification since its in-use performance is similar to synthetic oil.

1. ISFR3-01 and ISFR3-02 were collected from two separate transformers owned by Cooper Power.
2. ISFR3-03 was collected from one transformer owned by Texas Instrument.
3. ISFR3-06 was collected from one transformer owned by San Mateo High School.

Acronyms and Abbreviations:

-- = No specification value available
cm = centimeter
Cooper = In-service fluid specification for Envirotemp®FR3™ developed by Cooper Power Systems
IEC 1203 = International Electrochemical Commission (IEC) Synthetic Organic Esters for Electrical Guide for Maintenance of Transformer Esters in Equipment
mgKOH/g = milligrams of potassium hydroxide per gram
ppm = parts per million
pS/m = picosiemen per meter

- Aquatic Biodegradability. The average biodegradability of Envirotemp®FR3™ fluid was 120% ± 33% after 28 days using OPPTS Method 835.3110. The higher than expected biodegradability is due to possible CO_2 leaks from the control samples. The average biodegradation rates for Envirotemp®FR3™ fluid and mineral oil based on literature data are presented in Table 3.

Table 3. Aquatic Biodegradation Rates

Compound	Biodegradation Rates				
	Cooper ETV[1]	Universite de Liege[2]	CONCAWE[3]	USACE[4,5]	TERC[6,7]
Envirotemp® FR3™	120% ± 33% after 28 days	---	---	---	98% after 28 days
Mineral oil	---	70% after 40 days	28% after 28 days	42-49% after 28 days	30.5% after 28 days
HMWH	---	---	---	---	21.3% after 28 days

[1]U.S. EPA, *Environmental Technology Verification Report ABB Inc. BIOTEMP® Vegetable Oil-Based Insulating Dielectric Fluid*, 2001.
[2]Cloesen,C. & Kabuya, A, *Research RW N° 2174 Physical and chemical properties of environment friendly lubricants*, no date.
[3]Conservation of Clean Air and Water-Europe (CONCAWE), *Lubricating Oil Basestocks*, pp. 20-22, June 1997.
[4]U.S. Army Corps of Engineers (USACE), *Engineering and Design Environmentally Acceptable Lubricating Oils, Greases, and Hydraulic Fluids*, April 1997.
[5]USACE, *Engineering and Design Environmentally Acceptable Lubricating Oils, Greases, and Hydraulic Fluids*, February 1999.
[6] Thomas Edison Research Center, *The Biodegradation of Envirotemp®FR3™, Univolt 60, and R-Temp Transformer Fluids*, April 1999.
[7]The mineral oil used in the TERC study was Univolt 60 while the high molecular weight hydrocarbon (HMWH) oil was R-Temp.

Based on the information above, the virgin Envirotemp®FR3™ fluid appears to biodegrade more readily than mineral oil. Although Envirotemp®FR3™ readily biodegrades per this test, releases to water should be prevented. The product's ability to degrade in the environment is dependent on site-specific factors such as climate, geology, moisture, pH, temperature, oxygen concentration, dispersal of oil, the presence of other chemicals, soil characteristics, nutrient quantities, and populations of various microorganisms at the location.

- Flammability. The flash and fire point for the virgin and in-service fluid were consistently above the minimum values listed in the ASTM D3487, D5222, and Cooper performance specifications presented in Table 4. The fire point results obtained also agreed with values reported by Underwriters Laboratories.

Table 4. Flash and Fire Point Results for Virgin and In-Service Samples

Product Lot No./ Transformer SN	Flash Point (°C)			Fire Point (°C)		
	Specification Criteria		ETV Result	Specification Criteria		ETV Result
	Cooper	ASTM D3487		Cooper	ASTM D5222	
Virgin Product						
01D1	≥ 320	>145	328	≥ 350	304-310	362
01C6	≥ 320	>145	333	≥ 350	304-310	363
01P2	≥ 320	>145	318	≥ 350	304-310	362
Average	≥ 320	>145	328 ± 11	≥ 350	304-310	363 ± 2
In-service Transformer Fluid						
ISFR3-01	≥ 320	>145	338	≥ 350	304-310	362
ISFR3-02	≥ 320	>145	328	≥ 350	304-310	364
ISFR3-03	≥ 320	>145	330	≥ 350	304-310	364
ISFR3-06	≥ 320	>145	340	≥ 350	304-310	364

Note: Data variability was calculated at 95% confidence using a two-tailed T-test assuming a normal distribution.
SN = Sample Number

- Acute Toxicity. The average LC_{50} for virgin Envirotemp®FR3™ fluid was less than 250 mg/L. This low LC_{50} value is thought to reflect the physical impacts on fish due to oil coating the gills and preventing oxygen exchange. The average LC_{50} indicates the spent (or waste) Envirotemp®FR3™ fluid may exhibit a hazardous characteristic when tested under California regulations (California Code of Regulations, Title 22, Section 66261.24(a)(6)). This determination is based on a limited set of data for the virgin product and may not apply in states other than California where hazardous waste criteria and test methods may differ. End-users should characterize their spent Envirotemp®FR3™ fluid at the time of disposal since changes to the oil may occur due to use, storage, or age. End-users should also consult their appropriate local, state, or federal regulatory authority on applicable waste characteristic definitions and available disposal options.

- Chemical Composition. The AOAC results for the virgin Envirotemp®FR3™ samples showed the virgin and in-service fluid agreed closely with Cooper's formulation. The virgin product consisted of 23.8% ± 0.1% monounsaturated fatty acids, 59.9% ± 0.1% polyunsaturated fatty acids, and 15.7% ± 0.1% saturated fatty acids. The in-service transformer fluid consisted of 22.0% to 23.8% monounsaturated fatty acids, 59.8% to 62.4% polyunsaturated fatty acids, and 15.2% to 16.3% saturated fatty acids.

Antioxidant concentrations in the virgin Envirotemp®FR3™ samples ranged from 2,787 ppm ± 834 ppm. Antioxidant concentrations in the in-service transformer samples ranged from 3,550 ppm to 4,595 ppm. The antioxidants detected agreed with ingredients list provided by Cooper.

For the 65 standard SVOC compounds analyzed by the DTSC Hazardous Material Laboratory, none were detected in the virgin product samples. Bis- (2-ethylhexyl) phthalate, butyl benzyl phthalate, and di-n-butyl phthalate were detected in the in-service transformer samples. These compounds were suspected to be contaminants introduced from the sampling equipment and deionized water used. Other tentatively identified compounds were various sterols normally found in vegetable oils.

All the virgin product samples and two in-service samples contained barium and zinc between 25 mg/kg and 36 mg/kg, and between 11 mg/kg and 24 mg/kg, respectively. Cadmium and molybdenum were also detected in one in-service transformer sample at 0.42 mg/kg and 2.6 mg/kg, respectively. The barium and zinc might have been introduced during the processing of the basestock oil, degassing of the oil, or storage in the finishing tank.

- Worker Health and Safety. Based on the MSDS information, Envirotemp®FR3™ fluid appears to have similar PPE requirements compared to select mineral oil-based transformer fluids. Envirotemp®FR3™fluid had less stringent PPE requirements when compared to select silicone oil-based transformer fluids. Envirotemp®FR3™ fluid has a slightly higher nuisance particulate OSHA PEL than mineral oil. Envirotemp®FR3™ fluid does not contain listed IARC confirmed carcinogens or teratogens. The select mineral oil-based transformer fluids listed a hydrotreated light naphthenic petroleum distillate, which is an IARC confirmed carcinogen. The silicone based transformer oils listed dimethyl polysiloxane as the primary ingredient, which is a teratogen in animals. Although the product appears to contain ingredients with less serious health effects, the end-user must comply with all applicable worker health and safety regulations when using this product.

- Estimated Cost of Using Envirotemp®FR3™fluid versus Mineral Oil. The initial purchase cost of a new transformer unit containing Envirotemp®FR3™ fluid is approximately 1.2 to 1.3 times more than that of a comparable mineral oil transformer. When comparing the price per gallon of Envirotemp®FR3™ fluid to mineral oil, the difference may be between $5 to $8 more per gallon depending on the volume purchased. Based on historical accelerated aging test results, the estimated life expectancy of an Envirotemp®FR3™ transformer is estimated to be 20 years, which is comparable to mineral oil-based transformers.

Results of the verification/certification show that the Cooper Power Systems Envirotemp®FR3™ Vegetable Oil-Based Insulating Dielectric Fluid is a readily biodegradable, vegetable oil-based dielectric fluid with a flash and fire point above 300°C. The product has dielectric breakdown voltages comparable to mineral oils, silicone oils, synthetic esters, and high molecular weight hydrocarbons. Envirotemp®FR3™ samples from in-service transformers had flash and fire points above 300°C, and showed no signs of oil degradation due to use for the oldest transformers, which were in-service for 4.8 years. The LC_{50} results for virgin Envirotemp®FR3™ fluid indicate the spent Envirotemp®FR3™ fluid may exhibit a hazardous characteristic per California's hazardous waste characteristic definition. This interpretation is based on a limited set of test data. The end-user should characterize the spent Envirotemp®FR3™ fluid at the time of disposal since changes may occur to the oil due to use, storage, or age.

Although Envirotemp®FR3™ fluid is a vegetable oil-based product, end-users are still subject to the federal oil pollution prevention regulations under 40CFR112. End-users should contact their appropriate local, state, or federal regulatory authority regarding the management of Envirotemp®FR3™ fluid and Envirotemp®FR3™ spills.

Original signed by: E. Timothy Oppelt	5/15/02	Original signed by: Kim F. Wilhelm	5/8/02
E. Timothy Oppelt Director National Risk Management Research Laboratory Office of Research and Development United States Environmental Protection Agency	Date	Kim F. Wilhelm, Acting Chief Office of Pollution Prevention and Technology Development Department of Toxic Substances Control California Environmental Protection Agency	Date

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and Cal/EPA make no expressed or implied warranties as to the performance of the technology. The end-user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of commercial product names does not imply endorsement.

Availability of Verification Statement and Report

Copies of the public Verification Statement and Verification Report are available from the following:

1. **U.S. EPA**

   Web site: http://www.epa.gov/etv/library.htm *(electronic copy)*

2. **Department of Toxic Substances Control**
   Office of Pollution Prevention and Technology Development
   P.O. Box 806
   Sacramento, California 95812-0806

   Web site: http://www.dtsc.ca.gov/sciencetechnology/etvpilot.html
   http://www.dtsc.ca.gov/sciencetechnology/techcert_index.html
   or http://www.epa.gov/etv *(click on partners)*

(Note: Appendices are not included in the Verification Report and are available from DTSC upon request.)

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Appendix A-3: Flammability ASTM Test Method: Objective 3
Appendix A-4: Acute Toxicity Test Method: Objective 4
Appendix A-5: Worker Health and Safety Assessment: Other Verification/Certification Objectives
Appendix A-6: AOAC Test Methods, EPA Test Method 8270 (SVOCs), and EPA Test

Appendix B: Cooper Field Test Plan

Technology Evaluation WorkPlan (Cooper), May 16, 2001; Department of Toxic Substances Control, Office of Pollution Prevention and Technology Development.

Note: Appendices are <u>not</u> included in the Verification Report and are available upon written request to DTSC at the following address:

Department of Toxic Substances Control
Office of Pollution Prevention and
Technology Development
P.O. Box 806
Sacramento, California 95812-0806

List of Abbreviations and Acronyms

Ωcm	ohm-centimeter
ANSI	American National Standards Institute
AOAC	Association of Analytical Chemists
ASTM	American Society of Testing and Materials
$Ba(OH)_2$	barium hydroxide
BHA	butylated hydroxy anisole
BHT	3,5-di-tert-butyl-4-hydroxytoluene
°C	degrees Celsius
CAA	Clean Air Act
CAS	Chemical Abstracts Service
CCR	California Code of Regulations
CFR	Code of Federal Regulations
cm	centimeters
CONCAWE	Conservation of Clean Air and Water-Europe
CO_2	carbon dioxide
Cooper	Cooper Power Systems
cSt	centistokes (millimeter squared per second or mm^2/s)
CWA	Clean Water Act
DEHA	bis-2-ehtylhexyl hexanedoic acid
DI	deionized
DL	detection limit
DO	dissolved oxygen
DTSC	California Department of Toxic Substances Control
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ETV	Environmental Technology Verification
FDA	Food and Drug Administration
FMRC	Factory Mutual Research Center
FRP	facility response plan
g	gram
HML	Hazardous Materials Laboratory
HMWH	high molecular weight hydrocarbons
HSC	Health and Safety Code
IARC	International Agency for Research on Cancer
IEC	International Electrochemical Commission
IEEE	Institute of Electrical and Electronic Engineers
KOH	potassium hydroxide
kPa	kilopascals
KV or kV	kilovolts
ka	kilovolt amperes
LC_{50}	lethal concentration for 50% of the test population
LD_{50}	lethal dose for 50% of the test population
mg/kg	milligrams per kilograms

mg KOH/g	milligram of potassium hydroxide per gram
mg/L	milligrams per liter
ml	milliliter
mmHg	millimeters of mercury
MSDS	material safety data sheet
MVA	megavolt amperes
NEC	National Electrical Code
NIOSH	National Institute for Occupational Safety and Health
NRMRL	National Risk Management Research Laboratory
OECD	Organization of Economic Cooperation and Development
OPPTD	Office of Pollution Prevention and Technology Development
OPPTS	Office of Prevention, Pesticides and Toxic Substances
ORD	EPA's Office of Research and Development
OSHA	Occupational Safety and Health Administration
QA/QC	quality assurance/quality control
PCBs	polychlorinated biphenyls
PEL	permissible exposure limit
PPE	personal protective equipment
ppm	parts per million
pS/m	picosiemens per meter
psi	pounds per square inch
psig	pounds per square inch gauge
RCRA	Resource Conservation and Recovery Act
SIRI	Safety Information Resources, Inc.
SOP	standard operating procedure
SMHS	San Mateo High School
SPCC	spill prevention, control, and countermeasures
SVOCs	semivolatile organic compounds
TBHQ	mono-di-tert-butyl hydroquinone
TCLP	toxicity characteristic leaching procedure
TERC	Thomas Edison Research Center
TI	Texas Instruments
TOCC	total organic carbon content
TSCA	Toxic Substances Control Act
TWA	time weighted average
UL	Underwriters Laboratory
USACE	U.S. Army Corps of Engineers
U.S. EPA	United States Environmental Protection Agency
WET	waste extraction test

Glossary of Terms

Dielectric breakdown (ASTM D1816; gap)	The dielectric breakdown voltage indicates the fluid's ability to resist electrical breakdown at a power frequency of 60 Hz and is measured as the minimum voltage required to cause arcing between two submerged convex electrodes, 0.04" or 0.08" apart, in the fluid. This test is recommended for virgin product acceptance testing and evaluation of in-service fluids. The method is considered more sensitive to the adverse effects of moisture in the oil in insulating systems.
Dielectric breakdown (ASTM D3300; impulse)	The impulse dielectric breakdown voltage indicates the fluid's ability to resist electrical breakdown under transient voltage stresses such as lightning and power surges and is measured as the voltage required to cause arcing between submerged electrodes under prescribed conditions.
Dielectric breakdown (ASTM D877; minimum)	The dielectric breakdown voltage at a 60 Hz test voltage indicates the fluid's ability to resist electrical breakdown under prescribed test conditions. It is measured as the minimum voltage required to cause arcing between two submerged planar electrodes, 0.1" apart, in the test fluid. This test is recommended for virgin product acceptance testing.
Dissipation Factor (maximum)	This factor is a measure of the dielectric losses in the fluid. A low dissipation factor indicates low dielectric losses and a low concentration of soluble, polar contaminants.
Diunsaturated fatty acids	Fatty acids consisting of several carbons with 2 carbon-carbon double bonds (e.g., C18:2).
Fire point	The lowest temperature at which the fluid will sustain burning for 5 seconds.
Flash point	The lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mmHg) where a test flame causes the test fluid's vapor to ignite.
Interfacial tension	The measure of force required to draw a planar ring of platinum wire, located below the water surface, across the oil/water interface.

Kinematic viscosity	The amount of the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.
Linoleic acid	A diunsaturated acid found as a triglyceride in high oleic oils. It has 18 carbons and 2 carbon-carbon double bonds (C18:2).
Linolenic acid	A triunsaturated acid found as a triglyceride in high oleic oils. It has 18 carbons and 3 carbon-carbon double bonds (C18:3).
Monounsaturated fatty acids	Fatty acids consisting of several carbons with 1 carbon-carbon double bond (e.g., C18:1).
Neutralization number	This number is a measure of the acidic or basic substances in the oil and is used as a quality control indicator. An increase in the value of the neutralization number may indicate degradation of the oil due to increased water content. This value is measured by dissolving the oil sample in a mixture of toluene, isopropyl alcohol, and a little water. A color indicator, *p*-naphtholbenzein, is added to this mixture and then titrated with potassium hydroxide until an orange (acid) or green-brown (base) color change occurs.
Oleic acid	A monounsaturated acid found as a triglyceride in many natural oils such as sunflower, olive, and safflower oil. This compound has 18 carbons with one carbon-carbon double bond (C18:1).
Polar contaminant	A polar contaminant in a dielectric fluid ionizes and imparts electrical conductivity to the solution. Examples of polar contaminants in dielectric fluids include water, dirt, and metals.
Polyunsaturated fatty acids	Fatty acids consisting of diunsaturated and triunsaturated fatty acids (i.e., several carbons with 2 or more carbon-carbon double bonds, respectively such as C18:2, C18:3)).
Pour Point	The lowest temperature at which the movement of the oil is observed. An average electrical power distribution application will require a dielectric fluid to have a pour point below -20°C.
Saturated fatty acids	Fatty acids consisting of several carbons and no carbon-carbon double bonds (e.g., C18:0).

Stearic acid	A saturated acid found as a triglyceride in high oleic oils. It has 18 carbons and no double carbon bonds (C18:0).
Triunsaturated fatty acids	A triunsaturated acid found as a triglyceride in high oleic oils. It has 18 carbons and 3 carbon-carbon double bonds (C18:3).
Water content	The concentration of water in the oil expressed in milligrams per kilogram (mg/kg) or parts per million (ppm). Water in a vegetable oil-based insulating oil will increase the breakdown rate of fatty acid esters and leads to the formation of polar contaminants. This breakdown rate is proportional to the amount of water present in the oil. A significant increase in the value of the neutralization number is an indicator this reaction is occurring due to the increased acidity of the fluid. Compared to conventional mineral oils, vegetable oils have a much higher water content saturation point, typically well over 1,000 ppm at room temperature. The recommended range for post-processed vegetable oil is 2 to 5% of the saturation level (25 to 50 ppm).

Section 1. Introduction

Background

Electric power utilities use electrical transformers for a variety of applications, including power distribution. The transformers generate significant amounts of heat, and must contain cooling/insulating (dielectric) mediums to prevent gas formation, electrical shorts, fire or explosion, and transformer damage. The media can be a solid, liquid such as mineral oil, high molecular weight hydrocarbons (HMWHs), synthetic oils such as silicone, or a gas such as sulfur hexafluoride. Most transformers currently use some type of mineral oil as the cooling fluid; however HMWHs and synthetics (less-flammable fluids) are used in transformers that must operate in safety-related applications (near or inside buildings). Recently, transformer fluid vendors have developed vegetable seed oil-based dielectric fluids. These fluids have been certified as meeting "less-flammable" safety-related requirements by organizations such as Underwriters Labs or Factory Mutual.

Typically, liquid-containing distribution class transformers store from 30 to 1,000 gallons of oil. Spills from transformers are potentially an environmental concern because even small amounts of oil can contaminate bodies of water, possibly deplete oxygen, coat plant and animal life, be toxic or form toxic products, affect breeding, produce rancid odors, or foul shorelines or other habitats. Effects on soils are not as well characterized.

Polychlorinated Biphenyls (PCBs) are still used but no longer produced because of their high toxicity - they are regulated under the federal Toxic Substances Control Act (TSCA). According to Title 40 Code of Federal Regulations Section 261.8 (40CFR261.8), dielectric fluids and electric equipment with dielectric fluids regulated under TSCA are not regulated under the federal Resource Conservation and Recovery Act (RCRA). Non-PCB transformer fluids generally do not meet the requirements for regulation as hazardous waste under RCRA; however, mineral oils that have been in service for approximately 10 years may have exceeded California's acute toxicity levels for copper due to leaching from the transformer coils.

Mineral oil transformer fluid spills to the soil are presumed to be hazardous until the contaminated soil has been tested. The clean-up levels for these spills vary depending on the responsible State and local regulatory authority overseeing the clean-up.

Facility owners and operators that handle, store, or transport oils (e.g., petroleum oils, vegetable oils, animal fats, etc.) are required to report an oil spill which "may be harmful to the public health or welfare, or environment". A reportable oil spill is defined as one that either (1) violates water quality standards, (2) causes a sheen or discoloration on the surface of a body of water, or (3) causes a sludge or emulsion to be deposited beneath the surface of the water or on adjoining shorelines. The oil spill must be contained, cleaned up, and reported to the National Response Center, the federal point of contact for all chemical and oil spills.

Table 1 illustrates the types and amounts of waste oil change-outs, spills, and associated clean-up costs that a small to medium-sized electrical utility transmission system monitoring and maintenance facility experienced in 1992. This facility, which is only one of several operated by the electrical utility, generated 155 tons of spilled oil and contaminated soil, most of which was caused by accidents involving utility poles and transformers.

Table 1. Summary of 1992 PCB Waste Generation - Electric Utility

Waste Generated	Annual Quantity Generated (tons)	Annual Costs ($)
Oil Spill and Leak Residue	155	46,000
Source of Waste: Primarily damage to transformers		
Waste Oil from Electrical Transformers	126	100,000
Source of Waste: Draining of oil prior to reconditioning or decommissioning transformers		
Wastes Containing PCB	28	50,000
Source of Waste: Primarily damage to transformers and PCB recovery		

Source: U.S. EPA, Risk Reduction Engineering Laboratory, EPA/600/S-92/063 - October 1992

Envirotemp®FR3™Dielectric Insulating Fluid

Cooper Power Systems (Cooper) has developed a vegetable oil-based dielectric fluid comprised of >98.5% vegetable oil and <1.5% additives. Envirotemp®FR3™ fluid is used in liquid-filled electrical apparatus such as transformers to act as an electrical insulating medium. This material is currently used in pole, padmount, network, and small and medium power transformers with a voltage rating of 35 kV and a maximum rating of 10 MVA. Cooper is preparing to retrofill two 69 kV transformers, one 35 MVA, and one 50 MVA, for a midwestern facility. Other electrical apparatus include loadbreak switches, cables, electromagnets, klystron modulators, power supplies, and bushings. To date, approximately 475 transformers currently use Envirotemp®FR3™ fluid. Customers that use this product include Universal Studios, Miller Park, US Gypsum, and the Jet Propulsion Laboratories.

Evaluation Approach

The Envirotemp®FR3™ fluid evaluation was designed to provide the data necessary to draw conclusions on the technology's performance, chemical composition, toxicity, and safety. The evaluation included a review of supporting documents, information, and laboratory data submitted by Cooper, and field sampling to provide independent data on the technology's performance, chemical composition, and toxicity.

The field sampling was conducted at Cooper's manufacturing facility in Waukesha, Wisconsin and at San Mateo High School in San Mateo, California and Texas Instruments in Santa Cruz, California. San Mateo High School and Texas Instruments are customers of Artwel Electric, Inc.

(Artwel), Cooper's distributor. Artwel and Cooper agreed to provide staff and access to these in-service transformers as part of the field sampling activities. Prior to the field sampling, the Department of Toxic Substances Control staff (DTSC) prepared a Technology Evaluation Workplan (Workplan) to identify specific field objectives, data quality objectives, testing procedures, and roles and responsibilities. Cooper assumed overall responsibility for providing staff for sampling and obtaining access to all locations where field sampling was conducted. DTSC staff provided independent oversight and was present to observe all field sampling activities. The agreed-upon Workplan specified that DTSC would maintain a record of all samples collected, and record all measurements and observations made during sampling.

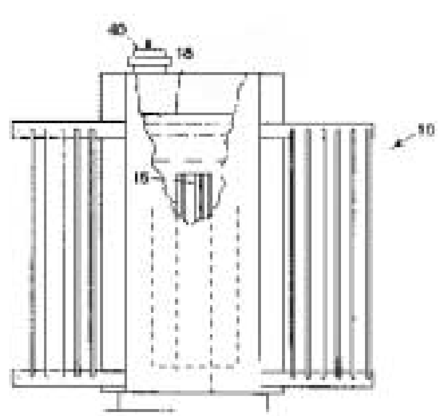
The oldest transformer in service with Envirotemp®FR3™ fluid as the dielectric insulating fluid is 4.8 years old. Since the technology is still new, no data was available to assess the performance of Envirotemp®FR3™ fluid over a transformer's service life or the fluid's waste characteristics at the end of the transformer's service life. Based on accelerated life tests, Cooper expects the normal service life of an Envirotemp®FR3™ transformer to be about 20 years.

Section 2. Description of Technology

Cooper has developed a vegetable oil-based dielectric fluid comprised of >98.5% vegetable oil and <1.5% additives. Antioxidants are added to prevent the unsaturated bonds in the oil from polymerizing with oxygen from the air. Color is added to visually differentiate it from mineral oil. Envirotemp®FR3™ fluid is manufactured using a food-grade vegetable oil purchased from an off-site processor. Each vegetable oil shipment is tested and compared to Cooper's quality control specifications before it is accepted. At Cooper's facility, the oil is degassed and then blended with antioxidant and color additives. During and after the blending process, the product is tested and compared to Cooper's product specifications.

Envirotemp®FR3™ fluid is used in electrical apparatus such as liquid-filled transformers as an electrical insulating medium. In addition to providing electrical insulation, the oil transports heat generated around the transformer's windings, core and connected circuits to cooling surfaces where the heat is dissipated by radiation and convection to the outside air. For this verification/certification, 3-phase transformers were the only electrical apparatus sampled. An example of a 3-phase transformer is presented in Figure 1. The main parts of a transformer are the core, the windings, the tank containing the core and windings, and the cooling system. The core is made of thin steel sheets laminated with varnish or an oxide film to insulate the sheets from each other. Two distinct sets of coils called windings are wound upon the core at a suitable distance from each other. These windings consist of wire insulated with a kraft paper covering. When the transformer is in-service, the oil and core expands and contracts as the heat generated by the transformer windings varies with the load. As the oil becomes heated, the hot oil rises to the top of the transformer where heat is dissipated to the outside, and then moves along the case to the bottom. Fins are sometimes attached to deflect moving air against the case and to increase the cooling area. Overheating the core can lead to damage, and overheating the windings can cause the paper insulation to deteriorate, which reduces the life of the transformer. Nearly all distribution transformers in the United States are sealed to prevent the oil from oxidizing with the air.

Figure 1. Transformer Cross Section



Some of the more expensive transformers or transformers servicing critical electrical loads are designed to have a nitrogen gas seal to prevent the oil from oxidizing with the air. The expansion of the oil reduces the volume of the nitrogen gas causing the gas pressure to be greater during power load periods. Large transformers may also use radiators, fans, circulating pumps or cooling water to increase heat exchange.

According to Cooper, the Institute of Electrical and Electronic Engineers (IEEE) accelerated life tests performed on transformers using Envirotemp®FR3™ fluid passed with an operational equivalence of 100 years. This operational equivalence is five times the normal transformer. According to Cooper, the insulation in the Envirotemp®FR3™ transformers showed less degradation than the insulation in identical transformers using mineral oil per this test. Based on this information, the normal service life is expected to be in the range of 20 years.

Because this fluid exhibits a high fire point (>300°C), Envirotemp®FR3™ fluid is classified by Underwriter Laboratories (UL) and approved by Factory Mutual Research Center (FMRC) as a less flammable transformer fluid. Typically, the less-flammable fluids are used in transformers where additional fire safety is required, such as inside buildings, rooftops, vaults, and adjacent to buildings.

Figure 1 shows a side view cutaway of the transformer tank and housing. Referring to Figure 1, the transformer coils and windings (labeled 15), are housed in a tank (labeled 10), which is filled with Envirotemp®FR3™ fluid. The fluid level is labeled 18. The transformer is also equipped with an automatic pressure release valve (labeled 40).

Section 450-23 of the National Electrical Code (NEC) contains the installation requirements for less-flammable liquid insulated transformers housed inside or near buildings. This section outlines simpler requirements for installing transformers in fire-sensitive areas when the transformers are filled with a less-flammable insulating fluid compared to mineral oil. This section requires that transformers using less flammable fluids such as Envirotemp®FR3™ fluid must meet specific requirements of the UL or FMRC Approval.

The UL requirements specify that a classified less-flammable fluid such as Envirotemp®FR3™ fluid used in 3-phase transformer installations with a rating of 45 to 10,000 kVA meet three "use restrictions". These "use restrictions" are as follows: (1) only 3-phase transformers with tanks capable of withstanding an internal pressure of 12 psig without rupture be used, (2) transformer tanks are equipped with pressure release valves to limit the internal pressure buildup and prevent tank rupture due to gas generation under low current arcing faults, and (3) transformers are equipped with either current limiting fuses or other overcurrent protection.

For the FMRC requirements, an approved less-flammable liquid insulated transformer is used in the 35kV Class or lower transformer installations rated at 5 kVA to 10,000 kVa for naturally cooled class transformer. The transformers are equipped with electrical protection for clearing high and low current faults. The transformer tank must also withstand an internal pressure of 20 psi for a cylindrical shaped tank and 15 psi for a rectangular shaped tank without rupture. All transformer tanks are required to be equipped with a pressure relief device.

Section 3. Verification Objectives

The field sampling objectives were to verify the applicant's technology performance claims for the Envirotemp®FR3™ dielectric insulating fluid listed below.

Verification/Certification Claim #1 - General Performance

- In the following composition ratio (>98.5% vegetable oil, <1.5% additives), Envirotemp®FR3™ fluid meets the dielectric breakdown specifications listed in ASTM D3487, *Standard Specification for Mineral Insulating Oil*, ASTM D5222, *Standard Guide for High Fire Point Fluids of Petroleum Origin*, IEEE C57.121, *1998 IEEE Guide For Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers*, IEC 1099, *Specifications for Unused Synthetic Organic Esters for Electrical Purposes*, and IEC 1203, *Synthetic Organic Esters for Electrical Purposes-Guide for Maintenance of Transformer Esters in Equipment*.

Verification/Certification Claim #2 - Aquatic Biodegradability

- Envirotemp®FR3™ fluid biodegrades 99% based on the average of several biodegradation tests, as measured by OPPTS 835.3110, *Ready Biodegradability*

Verification/Certification Claim #3 - Flammability

- Envirotemp®FR3™ fluid has a Flash Point of at least 320°C, and Fire Point of 350°C, based on the average of several performance tests by independent labs performing ASTM D92 (Cleveland Open Cup).

Verification/Certification Claim #4 - Acute Toxicity

- Results for virgin product tested by U.S. EPA/600/4-90/027F Test for *Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms* passes the aquatic toxicity characteristic criterion specified in the Code of California Regulations, Title 22, Section 66261.24(a)(6).

Other Verification/Certification Tests:

- To verify that Envirotemp®FR3™ fluid consists of >98.5 % vegetable oil and <1.5% additives, and that the formulation meets selected Cooper product specifications.

- To establish a baseline for measuring potential metals leaching and oil degradation of Envirotemp®FR3™ fluid under electrical loading over time.

- To evaluate the worker health and safety aspects of Envirotemp®FR3™ fluid.

- Estimate costs of Envirotemp®FR3™ fluid as compared to those of mineral oil.

Section 4. Verification Activities and Results

4.1 Verification Activities

4.1.1 Field Sampling

Prior to sampling, DTSC developed a technology evaluation workplan, which described the sample collection procedures and analyses to be performed. A copy of the technology evaluation plan is included in Appendix B. To ensure independent and representative samples were collected, DTSC personnel oversaw the sample collection in the field for virgin product and in-service transformers. Samples were assigned a field sample identification number, which was determined prior to sampling. Table 2 lists the samples collected and the analysis performed as part of this verification /certification. Proper chain of custody and storage procedures were followed. Laboratories sent data directly to DTSC. For more information on the sample collection procedures, refer to Appendix B.

<u>Virgin Product</u>

Samples of virgin fluid were collected at Cooper's dielectric fluid formulating facility in Waukesha, Wisconsin. Three different lots were sampled by a Cooper representative with DTSC oversight. A total of 12 samples (four samples per lot) were collected. One sample from each of the three lots was analyzed for SVOCs, metals, acute toxicity, aquatic biodegradation, and select AOAC and ASTM methods. One duplicate was analyzed for SVOCs, metals, and select AOAC and ASTM methods. Two matrix spikes and an equipment blank were analyzed for SVOCs and metals. A field blank was analyzed for metals only. Table 2 lists the analyses performed on each sample collected. Duplicate samples collected from each lot were held for future analyses if questionable data were produced.

Cooper also collected split samples from each lot sampled by DTSC for future quality control analyses. These split samples were analyzed for the following properties: dielectric breakdown voltage by ASTM D877 and D1816, dissipation factor at 25°C by ASTM D924, water content by ASTM Method D1533, interfacial tension by ASTM D971, neutralization number by ASTM D974, pour point by ASTM D97, flash and fire point by ASTM D92, and viscosity at 40°C and 100°C by ASTM D445. These samples were initially analyzed by Cooper to verify the dissipation values reported by Doble Engineering.

DTSC sampled two lots from 55-gallon drums (Lots 01D1 and 01C6) while the third lot (Lot 01P2) was sampled from a 2,500-gallon finishing tank. Drum samples were collected using a glass Coliwasa. A new glass Coliwasa was used at each new drum sampled to reduce the potential of cross contamination between samples. The finishing tank samples were collected at a sampling spigot located beneath the tank. Approximately one pint of oil was drained from the tank via the spigot prior to sampling. Sampling activities are presented in Figures 2 and 3.

Table 2. Envirotemp®FR3™ Samples and Analyses

Sample ID	Lot No.	SVOCs	Metals	Acute Toxicity	Aquatic Biodegradation	AOAC Methods	ASTM Methods	Comments
VFR3-01	01D1	a	b	e	d	f	g,h,i,k,l,m,n, p,q,r	
VFR3-02	01D1							Duplicate not analyzed. Sampled from same drum as VFR3-01.
VFR3-03	01D1	a	b					Matrix spike
VFR3-04	01D1							Duplicate not analyzed. Sampled from same drum as VFR3-03.
VFR3-05	01C6	a	b	e	d	f	g,h,i,k,l,m,n, p,q,r	
VFR3-06	01C6	a	b			f		Analyzed duplicate. Sampled from same drum as VFR3-05.
VFR3-07	01C6						g,h,i,k,l,m,n, p,q,r	Analyzed duplicate
VFR3-08	01C6							Duplicate not analyzed. Sampled from same drum as VFR3-07.
VFR3-09	01P2	a	b					Matrix spike
VFR3-10	01P2	a	b	e	d	f	g,h,i,k,l,m,n, p,q,r	
VFR3-11	01P2							Duplicate not analyzed
VFR3-12	01P2							Duplicate not analyzed
VFR3-15	N/A	c	b					Equipment blank
VFR3-16	N/A	c						Field blank
ISFR3-01	N/A	a	b			f	g,o,p,q,r,s	
ISFR3-02	N/A	a	b			f	g,o,p,q,r,s	
ISFR3-03	N/A	a	b			f	g,o,p,q,r,s	
ISFR3-04	N/A	c						Field blank
ISFR3-05	N/A	c	b					Equipment blank
ISFR3-06	N/A	a	b			f	g,o,p,q,r,s	
ISFR3-07	N/A	c						Field blank

The letter assigned to each sample corresponds to the analysis performed:
a - U.S. EPA Method, 8270 (SVOC screening) and prepared per U.S. EPA Method 3580
b - U.S. EPA Method 6010 (metals screening) and prepared per U.S. EPA Method 3051
c - U.S. EPA Method, 8270 (SVOC screening) and prepared per U.S. EPA Method 3510
d - U.S. EPA Method OPPTS 835.3110, *Ready Biodegradability*
e - U.S. EPA Method 600/4-90/027F, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms* and prepared per the requirements in California Regulations, Title 22, Section 66261.24(a)(6), *Static Acute Bioassay Procedures for Hazardous Waste Samples*.
f - AOAC Method 981.11, *Oils and Fats*, AOAC Method 972.28, *Total Fatty Acids in Oils and Fats*, AOAC Method 963.22, *Methyl Esters of Fatty Acids in Oils and Fats*, AOAC Method 983.15, *Phenolic Antioxidants in Oils, Fats, and Butter*, and AOAC Method 977.17, *Polymers and Oxidation Products of Vegetable Oil.*
g - ASTM Method D92, *flash and fire point*
h - ASTM Method D97, *pour point*
i - ASTM Method D445, *kinematic viscosity (0, 40, & 100 C)*
j - ASTM Method D445, *kinematic viscosity (40 C)*
k - ASTM Method D877, *dielectric breakdown (minimum)*
l - ASTM Method D1816, *dielectric breakdown (gap)*
m - ASTM Method D3300, *dielectric breakdown (impulse)*
n - ASTM Method D924, *dissipation factor (25°C & 100°C)*
o - ASTM Method D924, *dissipation factor (25°C)*
p - ASTM Method D971, *interfacial tension*
q - ASTM Method D974, *neutralization number*
r - ASTM Method D1533, *water content*
s - ASTM Method D4308, *conductivity*

Figure 2. Tank Sampling

Figure 3. Sampling Spigot

In-Service Transformer

In-service fluid samples were taken from four transformers that have been in use for at **least one year** and part of a regular sampling/testing program. In-service fluid samples were collected by Cooper and Artwel Electric, Inc. representatives under DTSC oversight and in conjunction with the normal on-going sampling program. Only one sample per transformer was collected to minimize the amount of fluid removed from each transformer and the impact to the ongoing test program. New Tygon tubing connectors were used at each transformer fluid sampling port to reduce the potential of cross contamination.

The transformer pressure valve is checked to confirm the unit is under positive pressure prior to sampling. A stainless steel sampling cylinder with Tygon tubing is attached to the sampling port. Oil is purged from the transformer into the sampling cylinder to ensure ambient air is not introduced into the transformer. After a few pints of oil have been purged through the sampling cylinder, the sample bottles are filled using Tygon tubing attached to the sampling cylinder.

Four transformers were sampled as part of this verification/certification: two owned by Cooper located in Waukesha, Wisconsin, one owned by San Mateo High School (SMHS) in San Mateo, California and one owned by Texas Instruments (TI) in Santa Cruz, California. Weather conditions during sampling at the Cooper transformers consisted of intermittent snow showers. Weather conditions during sampling at SMHS and TI were dry and sunny. Equipment information such as the transformer type, size, and service date is listed in Table 3. Transformer sampling activities are shown in Figures 4 and 5.

Table 3. Equipment Information on Sampled Transformers

Owner	Transformer Information						
	Type	Serial Number	kVA Rating (kVA)	Primary Voltage (kV)	Secondary Voltage (kV)	Temp. Rise (°C)	Initial In-Service Date
Cooper	3-phase pad mounted transformer	966001430	225	5	480	65	July 1996
Cooper	3-phase pad mounted transformer	966001429	225	5	480	65	July 1996
San Mateo High	3-phase pad mounted transformer	0037017339	225	21	480	65	March 2000
Texas Instruments	3-phase pad mounted transformer	0026000482	2500	21	480	65	May 2000

Figure 4. Transformer Sampling performed at SMHS and TI

Figure 5. Transformer Sampling at Cooper

4.1.2 Historical Data

In addition to field sampling conducted under DTSC oversight, DTSC staff reviewed internal product development testing data provided by Cooper. These data were collected as part of ongoing testing for internal use by Cooper. This data collection happened prior to entry into the verification/certification agreement. These data provided background information on the technology performance for past virgin lots and to develop trends on the fluid's performance in tested transformers for select ASTM parameters. Historical data collected by independent testing facilities under contract with Cooper were also used.

4.2 Results: Objective 1, General Performance

For this verification/certification, Envirotemp®FR3™ fluid was tested for select physical (e.g., pour point, viscosity), chemical (e.g., neutralization number, interfacial tension, water content), thermal (e.g., flash and fire point) and dielectric (e.g., dielectric breakdown, dissipation factor) properties to verify general performance claims listed in Cooper's product specifications. The results for the thermal properties are discussed in **Section 4.4**. Since no standard specifications exist for vegetable oil-based dielectric fluids, two ASTM specifications, two International Electrochemical Commission (IEC) specifications, and one Institute of Electronic and Electrical Engineers (IEEE) specification were used to evaluate Envirotemp®FR3™ fluid performance. ASTM D3487 and ASTM D5222 were developed to evaluate the performance of virgin mineral oil-based dielectric fluids and virgin high molecular weight hydrocarbons (HMWH), respectively. IEEE C57.121 was developed to evaluate the performance of virgin silicone fluids. IEC 1099 and IEC 1203 were developed to evaluate the performance of virgin synthetic organic esters and in-service synthetic organic esters, respectively. These specifications were selected since Cooper claimed the dielectric breakdown voltages for Envirotemp®FR3™ fluid were similar to those of mineral oil, HMWH, silicone and synthetic esters. The physical and chemical properties of virgin Envirotemp®FR3™ fluid were only compared to Cooper specifications since these properties differ due to the nature of the fluid. Samples were sent to Doble Engineering (Doble), an independent testing laboratory, to perform testing for select dielectric, physical, and chemical properties using the ASTM methods listed in Table 2. The ASTM, IEEE, IEC, and Cooper specifications and virgin sample results are presented in Table 4.

4.2.1 Virgin Product Performance Results

Dielectric Properties (or Dielectric Strength)

Dielectric breakdown is the common property used to evaluate a dielectric fluid's performance. Table 4 lists the minimum dielectric breakdown values specified by ASTM D3487, ASTM D5222, IEEE C57.121, IEC 1099 and Cooper that were used to evaluate Envirotemp®FR3™ electrical performance. The dissipation factor is compared to the Cooper specification since chemical properties vary between the various types of dielectric fluids.

<u>Dielectric Breakdown</u>

Both the minimum and gap dielectric breakdowns indicate the minimum voltage required to cause arcing between two submerged electrodes in a dielectric fluid. A low dielectric breakdown value may indicate the presence of water, dirt, or other electrically conductive particles in the oil, which may cause damage to the transformer core or windings due to arcing. The dielectric breakdown voltages for virgin Envirotemp®FR3™ samples were higher than the minimum dielectric breakdown voltage for four specifications. For the 0.04-inch (1.0 mm) gap dielectric breakdown, sample values were higher than the minimum voltage listed for all five specifications. No precision criteria were specified in ASTM Method D877 (minimum breakdown voltage)

Table 4. Performance Results for Virgin Envirotemp® FR3™ Samples

Performance Parameters	Specification Standards					Sampling Results				
						Lot 01D1	Lot 01C6		Lot 01P2	Average
	Cooper	ASTM D3487	ASTM D5222	IEEE C57.121	IEC 1099	VFR3-01	VFR3-05	VFR3-07	VFR3-10	
Physical Properties										
Pour Point (°C)	≤ -18	-40	-24	≤ -21	≤ -45	-18	-18	-18	-18	-18
Viscosity (cSt)										
@100°C	≤ 8.5	≤ 3	11.5-14.5	--	--	8	7.88	7.9	7.95	7.93 ± 0.09
@ 40°C	≤ 35	≤ 12	100-140	100-130	≤ 35	32.63	32.67	32.79	32.74	32.71 ± 0.11
@ 0°C	NA	76	1800-2200	--	--	188.01	187.14	187.53	187	187.42 ± 0.72
Dielectric Properties										
Dielectric breakdown (kV)										
minimum	≥ 30	≥ 30	≥ 42	≥ 25-30	--	45	45	45	46	45 ± 1
gap	≥ 20	≥ 28	≥ 30	≥ 20-30	23	36	37	34	39	37 ± 3
impulse	--	≥ 145	--	--	--	170	168	164	168	168 ± 4
Dissipation Factor (%)										
@ 25°C	≤ 0.15	≤ 0.05	≤ 0.01	≤ 0.05-0.1	--	0.127	0.159	0.157	0.127	0.143 ± 0.029
@ 100°C	--	≤ 0.3	≤ 0.3	≤ 0.30-1.0	2.5	2.70	3.17	3.23	2.46	2.89 ± 0.59
Chemical Properties										
Interfacial Tension (dyne/cm)	≥ 18	≥ 40	≥ 45	≥ 38-40	--	28	27	28	28	28 ± 1
Neutralization Number (mgKOH/g)	≤ 0.07	≤ 0.03	≤ 0.01	≤ 0.03	≤ 0.03	0.03	0.03	0.02	0.03	0.03 ± 0.01
Water Content (ppm)	≤ 75	≤ 35	≤ 25	≤ 25	≤ 200	53	59	57	52	55 ± 5

Note: The dielectric breakdown value listed in the five specifications is similar and is the basic property used to evaluate a dielectric fluid's performance. Since the specification values vary due to the chemical and physical nature of the dielectric fluid type, the following values are compared to the Cooper performance specification: viscosity, pour point, neutralization number, dissipation factor, interfacial tension, and water content. Data variability was calculated at 95% confidence using a two-tailed T-test and assuming normal distribution.

Acronyms and Abbreviations:

-- = No specification value available
ASTM D3487 = American Society for Testing and Materials (ASTM) standard specification for mineral insulating oil used in electrical apparatus.
ASTM D5222 = ASTM standard specification for high fire-point electrical insulating oil.
cm = centimeter
Cooper = Virgin product specification for Envirotemp® FR3™ developed by Cooper Power Systems
cSt = centistoke
IEC 1099 = International Electrochemical Commission (IEC) Specifications for Unused Synthetic Organic Esters for Electrical Purposes
IEEE C57.121 = Institute of Electrical and Electronic Engineers (IEEE) 1998 IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers
KV = kilovolt
mgKOH/g = milligrams of potassium hydroxide per gram
ppm = parts per million

and ASTM Method D1816 (gap breakdown voltage). Since Envirotemp®FR3™ fluid's dielectric breakdown values were higher than the values for each specification in Table 4, the fluid met these performance criteria and would not likely cause damage to the transformer core or windings due to arcing.

The impulse dielectric breakdown value is designed to determine the minimum voltage to cause arcing in the fluid under lightning or power surge conditions. A high impulse voltage may indicate the oil has a low contaminant or water content, which will not adversely affect transformer performance. The impulse breakdown voltage for all samples is higher than the minimum voltage specification for mineral oils under ASTM D3487. Cooper does not have a specification value for the impulse breakdown voltage but has found this value typically ranges from 130 to 170 kV in virgin product. The 95% confidence interval for the data collected was ± 4.0 kV, which meets the precision criteria of ±13 kV at 95% confidence listed in ASTM D3300. Envirotemp®FR3™ fluid meets ASTM D3487's performance specification for the impulse dielectric breakdown voltage and has values within the range of typical values exhibited in past virgin product lots.

Dissipation Factor

The dissipation factor is used to measure the dielectric losses to an insulating dielectric fluid (such as oil) when it is exposed to an alternating electric field. For ASTM Method D924, the dissipation factor is determined by passing an alternating electric current through a test cell filled with dielectric fluid and measuring the capacitance with an electronic bridge circuit. This value is also used to control the product quality, and to determine changes in the fluid due to contamination or degradation during use. A low dissipation factor indicates a low dielectric loss and a low contaminant concentration (e.g., dirt, water, or metals).

For two samples, the dissipation factor at 25°C was measured below the maximum Cooper specification value while the other two samples were slightly above this value. The average dissipation factor for the samples (0.143%) was below the Cooper maximum specification value. All samples were above the maximum value specified at 25°C and at 100°C for the other four specifications listed in Table 4. Cooper tested their split samples from lots 01C6 and 01D1 to verify the dissipation factor at 25°C reported by Doble. Cooper reported a dissipation factor of 0.131% for Lot 01C6 and 0.097% for Lot 01D1. The precision criterion for results from two different laboratories, which is outlined in ASTM Method D924, was used to evaluate the results from Doble and Cooper. The difference between the results for Lot 01C6 was 0.039% and Lot 01D1 was 0.030%, which met the precision criteria of being less than 25% percent of the higher result plus 0.001 (±0.041% for Lot 01C6 and ±0.033% for Lot 01D1). Past performance testing by Doble measured the dissipation factor at 25°C of 0.0610%, which met the Cooper specification. Cooper does not routinely test for the dissipation factor at 100°C but reported three past samples had values ranging from 1.4% to 1.9%.

The average dissipation factor at 25°C did not meet the Cooper specification value of ≤ 0.15%. All samples had higher dissipation factors at 100°C than past sample results reported by Cooper, which may be due to contaminants introduced during product storage, sample collection, sample preparation, or sample testing. However, Envirotemp®FR3™ fluid did not meet the other four specifications for the dissipation factor since these specifications were developed for other types of fluids.

Chemical Properties

Neutralization Number

The neutralization number is used as a quality control guide for lubricating oil formulation. This number determines the relative amount of acidic substances contained in the oil by the amount of base titrated. The acidic substances may be additives or degradation products formed during service, such as oxidation products. When an in-service fluid is analyzed for this property, an increasing neutralization number over time may be an indicator of oil degradation due to oxidation. According to ASTM Method D974, this test cannot be used to predict the corrosiveness of an oil under service conditions. There is no general correlation known between the neutralization number and the corrosive tendency of oils toward metals.

The neutralization number was consistent between lots and met Cooper's, ASTM D3487, IEEE C57.121, and IEC 1099 specifications. The difference between the test results at the 95% confidence level was 0.01 mg KOH/g, which met the repeatability criteria of < 0.03 mg KOH/g listed in ASTM Method D974.

The split sample results tested by Cooper for Lots 01C6 and 01D1 were 0.027 mg KOH/g and 0.025 mg KOH/g, respectively. The difference between Cooper and Doble data was 0.010 mg KOH/g for Lot 01C6 and 0.003 mg KOH/g for Lot 01D1, which met the reproducibility criteria in ASTM Method D974 of less than 0.04 mg KOH/g. Envirotemp®FR3™ fluid met Cooper's specification for the neutralization number and also met the specifications for ASTM D3487, IEEE C57.121, and IEC 1099.

Water Content

Water content is used by industry to monitor a dielectric fluid's quality and as an indicator of possible oil deterioration, which could adversely affect the oil's electrical properties such as dielectric breakdown. This value is based on the relative saturation of the water in the dielectric fluid. The relative saturation is based on the amount of water dissolved in the oil divided by the total amount of water the oil could hold at that temperature. The dielectric strength of oil starts to fall when saturation reaches about 50%. For petroleum based dielectric oils, 50% saturation at room temperature is 30-35 mg/kg. Synthetic esters and vegetable oil contain about 500-600 mg/kg of water at room temperature and 50% saturation. A water content at or near 50% saturation may indicate the oil has deteriorated and may cause a lower dielectric breakdown voltage, which can damage the transformer core and windings.

Water content was tested by Doble using ASTM Method D1533, water in insulating liquids. Water content for all four samples varied between 52 and 59 ppm which was less than the maximum water content of 75 ppm specified by Cooper and 200 ppm specified by IEC 1099. The water content was consistent between lots with a difference of 5.2 ppm, which was greater than ASTM Method D1533 precision criteria of less than 3 ppm at the 95% confidence level.

Split sample results analyzed by Cooper reported the water content at 55 ppm for Lot 01C6 and 51 ppm for Lot 01D1. Comparing the results from Doble with the split sample results, the data met the reproducibility criteria with a difference of less than 10 ppm. Envirotemp®FR3™ fluid met the Cooper and IEC 1099 specifications for water content. Envirotemp®FR3™ fluid was not expected to meet the ASTM D3487, D5222, and IEEE specifications since these specifications are based on mineral and silicone oil properties.

<u>Interfacial Tension</u>

The interfacial tension was developed to gauge the presence of hydrophilic compounds in mineral oil. Interfacial tension is a measurement of the amount of force needed to detach a platinum ring from the water-oil interface. In practice, this value has been found to be a good indicator of oil degradation due to oxidation. A lower interfacial tension value indicates a higher hydrophilic or water content in the oil which may adversely affect the oil's dielectric properties.

The interfacial tension value measured for all samples was consistent and averaged 27.8 dynes/cm, which met Cooper's specification of $\leq$ 18 dyne/cm. The data also met the precision criteria in ASTM D971 where the results did not differ from the mean by more than 2%. Split samples analyzed by Cooper reported the interfacial tension at 28 dynes/cm for Lot 01C6 and 27.7 dynes/cm for Lot 01D1. The differences between the Cooper and Doble results met the reproducibility criteria in ASTM D971 by not differing by more than 5% of the mean. Envirotemp®FR3™ fluid met the Cooper specification for interfacial tension. It was not expected to meet the other four specifications since they were based on the chemical properties for mineral oils, HMWH, silicone oils, and synthetic esters.

Physical Properties

<u>Pour Point</u>

The pour point indicates the lowest temperature an oil can be used. The pour point was consistently measured at -18°C for all samples and met the Cooper specification. The data also met the precision criteria listed in ASTM D97. The split samples analyzed by Cooper had pour points at -22°C for Lots 01C6 and 01D1. The difference between Cooper's and Doble's results did not exceed 6°C per the reproducibility criteria in ASTM Method D97. Envirotemp®FR3™ fluid met the Cooper specification for pour point but did not meet the ASTM D3487, ASTM D5222, IEEE, and IEC 1099 specifications. Envirotemp®FR3™ fluid was not expected to meet these latter specifications since they were based on the physical properties for mineral oils, HMWH, silicone oils, and synthetic esters.

Viscosity

The dielectric fluid's viscosity is used by transformer designers to confirm that the fluid is appropriate for the unit under certain operating conditions. The viscosity of Envirotemp®FR3™ fluid was determined at 0°C, 40°C, and 100°C. The results at 40°C had a confidence coefficient of ± 0.11 cSt and met the precision criteria in ASTM Method 445 where the results did not differ by more than 0.35% of the mean (0.11 cSt) at the 95% confidence level. However, the viscosity results at 100°C differed by 0.09 cSt, which was greater than the precision criteria of < 0.03 cSt.

Split samples analyzed by Cooper reported the viscosity at 40°C and 100°C at 32.13 cSt and 7.47 cSt for Lot 01C6, and at 32.68 cSt and 7.49 cSt for Lot 01D1, respectively. The precision criteria for results from two separate laboratories should not differ more than 0.70% of the mean. The results for Lot 01C6 met the precision criteria for values measured at 40°C but not at 100°C. Results for Lot 01D1 did not meet the precision criteria. No precision criteria were listed in the method for viscosity at 0°C. Envirotemp®FR3™ fluid met Cooper specifications for viscosity at 40°C and 100°C. Cooper has no specification for viscosity at 0°C. Although Envirotemp®FR3™ fluid did not meet the other specifications for viscosity, it was not expected since those specifications were based on the physical properties of mineral oils, HMWH, silicone oils, and synthetic esters.

4.2.2 In-service Transformer Fluid Results

In-service transformer samples were tested for dissipation factor at 25°C, water content, interfacial tension, neutralization number, and conductivity. Past available monitoring results for each transformer over its service life have been plotted on graphs and are presented in Figure 6. Interfacial tension results are compared only to Cooper specifications to evaluate the fluid performance. The dissipation factor, water content, and neutralization number for Envirotemp®FR3™ fluid are compared to the IEC 1203 specification because Envirotemp®FR3™ fluid is reported to have similar fluid characteristics to synthetic esters when in use. Table 5 presents the sample results obtained as part of this verification/certification along with the ASTM and IEEE specifications to illustrate the difference in the fluid characteristics with mineral oil, HMWH, and silicone oil, respectively.

The sample results for the dissipation factor at 25°C ranged from 0.120% to 0.196% and met the Cooper and IEC 1203 specifications for in-service fluid. When the historical data for the oldest transformers (S/N 966001429 and 966001430) are plotted over time, the dissipation factor appears to gradually increase. The relatively small changes in the data over the service life for the oldest transformers indicate the fluid has not degraded with use.

Figure 6. Trends for In-Service Transformer Parameters

(Dissipation Factor, Neutralization Number, Water Content, Volume Resistivity, Interfacial Tension)

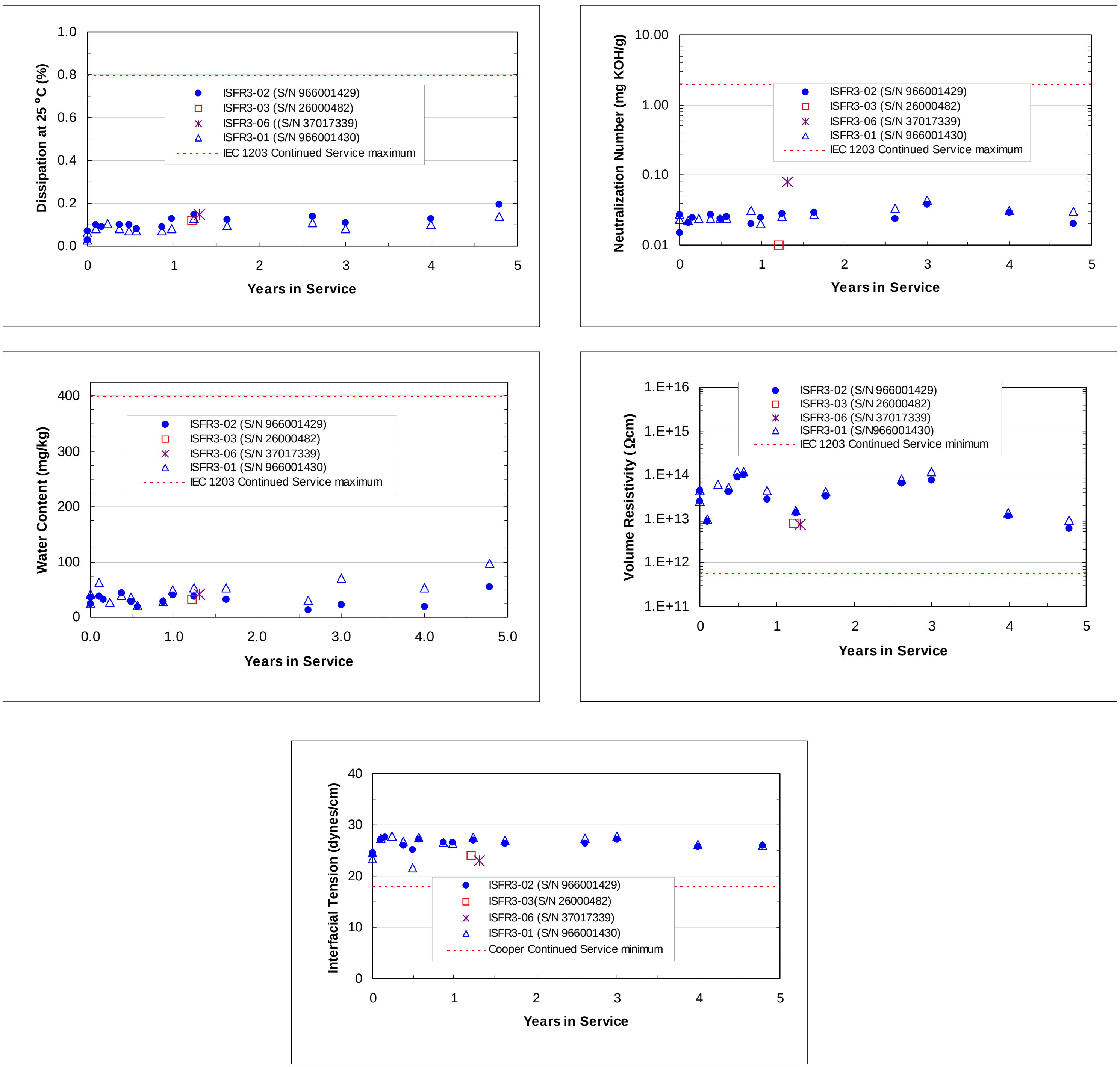


Table 5. Performance Results for In-Service Envirotemp®FR3™ Samples

Performance Parameters	Specification Standards					Sampling Results			
	Cooper	ASTM D3487	ASTM D5222	IEEE C57.121	IEC 1203	ISFR3-01	ISFR3-02	ISFR3-03	ISFR3-06
Dissipation Factor (%) @ 25°C	≤ 1.0	≤ 0.05	≤ 0.01	≤ 1.0	≤ 0.8	0.139	0.196	0.120	0.146
Water Content (ppm)	≤ 400	≤ 35	≤ 25	≤ 35	≤ 400	98	56	33	41
Interfacial Tension (dyne/cm)	≥ 18	≥ 40	≥ 45	≥ 24	---	26	26	24	23
Neutralization Number (mgKOH/g)	≤ 2.5	≤ 0.03	≤ 0.01	≤ 0.2	≤ 2.0	0.03	0.02	0.01	0.08
Conductivity @ 25°C (pS/m)	--	--	--	--	1.1	10.6	17	12.75	13.6

Note: Envirotemp®FR3™ performance while in use is similar to synthetic oil monitored by IEC 1203 and therefore the following parameters are compared to Cooper and IEC 1203 specifications: neutralization number, dissipation factor, and water content. The ASTM and IEEE specification values pertain to virgin product and are provided as a reference.

1. ISFR3-01 and ISFR3-02 were collected from transformers owned by Cooper Power.
2. ISFR3-03 was collected from the transformer owned by Texas Instrument.
3. ISFR3-06 was collected from the transformer owned by San Mateo High School.

Acronyms and Abbreviations:

-- = No specification value available
cm = centimeter
Cooper = In-service fluid specification for : Envirotemp®FR3™ developed by Cooper Power Systems
IEC 1203 = International Electrochemical Commission (IEC) Synthetic Organic Esters for Electrical Purposes - Guide for Maintenance of Transformer Esters in Equipment
mgKOH/g = milligrams of potassium hydroxide per gram
ppm = parts per million
pS/m = picosiemen per meter

The sample results for the water content met the Cooper and IEC 1203 specifications for in-service fluid. Referring to Figure 6, the water content after more than one year of service is similar for all four transformers. Again, the historical data for the oldest transformers appears to show a gradual increase over time. The small fluctuations in the data for the oldest transformers indicate the fluid has not degraded with use.

Interfacial tension results for the samples listed in Table 5 all met the Cooper specification. One of the four samples did not meet the IEEE C57.121 specification. Although the data for the fluid in the oldest transformers have fluctuated over time, the interfacial tension values have remained above the minimum value specified by Cooper. The current data trend, including the oldest transformers, indicates the fluid has not degraded with use.

The neutralization number for all four samples ranged from 0.01 mg KOH/g to 0.08 mg KOH/g and met the Cooper and IEC 1203 specifications for in-service fluid. Samples ISFR3-01, ISFR3-02, and ISFR3-03 also met the ASTM D3487 specification. Comparing the values for all four transformers after one year of service, sample ISFR3-06 collected from the SMHS transformer had the highest neutralization number. ISFR3-03 collected from the TI transformer had a value comparable to virgin product. Data collected over the oldest transformers' service lives were well below the maximum value specified by IEC 1203 of 2.0 mg KOH/g. The small fluctuations in the data for the oldest transformers indicate the fluid has not degraded with use.

The conductivity values were converted to volume resistivity units (1 pS/m = 1.0 x 10^{14} Ωcm) for comparison to IEC 1203 criteria. The converted conductivity values for samples ISFR3-01, ISFR3-02, ISFR3-03, and ISFR3-06 were 9.4 x 10^{12} Ωcm, 5.9 x 10^{12} Ωcm, 7.8 x 10^{12} Ωcm, and 7.4 x 10^{12} Ωcm, respectively. All values were above the minimum volume resistivity of 6.00 x 10^{11} Ωcm.

The historical results for the two oldest transformers indicate the oil has degraded little over the service period of 4.8 years. As the service life of the transformer increases, the interfacial tension will drop as the water content, dissipation factor and neutralization factor rise. Changes in these parameters for Envirotemp®FR3™ fluid would also expected to be observed in mineral oil transformers.

4.3 Results: Objective 2, Aquatic Biodegradability

Three virgin Envirotemp®FR3™ samples, one from each lot, were analyzed by U.S. EPA Method OPPTS 835.3110, *Ready Biodegradability*, using the carbon dioxide (CO_2) evolution method. Three test solutions were prepared: one consisting of a stock solution (bacteria in a mineral nutrient medium), one of a stock solution with Envirotemp®FR3™ fluid, and one of a stock solution with a known biodegradable material (phthalic acid) as a reference. The biodegradability result for the phthalic acid solution is used as a control check on the selected stock solution and test apparatus. Each solution was tested in parallel in an apparatus consisting of a stoppered flask connected to a series of barium hydroxide ($Ba(OH)_2$) absorbers with flexible tubing. Each flask was aerated with a low flow of carbon-dioxide free air under continual darkness. After the second or third day of the test, the first $Ba(OH)_2$ absorber in the series for each solution was removed and titrated with hydrochloric acid to determine the CO_2 content. A new absorber was connected to the end of the absorber series for each testing set-up. This process was repeated every two (2) or three (3) days during the first ten (10) days of the test and then every fifth (5) day until the twenty-eighth (28) day. The amount of CO_2 produced by the degrading Envirotemp®FR3™ fluid was calculated by subtracting the amount of CO_2 produced by the stock solution from the amount of CO_2 produced by the stock solution and Envirotemp®FR3™ fluid. The degree of biodegradation was calculated by dividing the amount of CO_2 produced by Envirotemp®FR3™ fluid by the theoretical CO_2 content ($ThCO_2$). The $ThCO_2$ amount for each sample is listed in Table 6 below.

An inhibition test where the stock solution, phthalic acid, and Envirotemp®FR3™ fluid are combined in the same flask was performed to determine if the Envirotemp®FR3™ fluid would inhibit the phthalic acid's ability to biodegrade. Global Tox International (Global Tox), an independent testing laboratory, performed this test for each lot. These tests were conducted in parallel with other biodegradation tests for this verification/certification.

In the past, Cooper performed aquatic biodegradability tests on three different types of transformer fluids by U.S. EPA Method OPPTS 835.3100, *Aerobic Aquatic Biodegradation*. The fluids were Univolt 60, a mineral oil-based transformer fluid; R-Temp, a HMWH transformer fluid; and Envirotemp®FR3™ fluid. Samples were analyzed by the Thomas Edison Research Center (TERC) who is owned by Cooper Power Systems. This method also estimated the amount of CO_2 produced by the test solution by calculating the difference in the CO_2 produced in the test flask and the control (inoculum) flask. Method OPPTS 835.3110, used for this verification/certification, has replaced OPPTS 835.3100 as U.S. EPA's current test method for ready biodegradability.

Table 6 lists the results by Global Tox by OPPTS 835.3110, *Ready Biodegradability*, and the TERC by OPPTS 835.3100, *Aerobic Aquatic Biodegradation*. The results from Global Tox meets the method's validity criteria of less than 20% difference between the replicate end results except for Sample VFR3-10 which had a percent difference of 35%. The higher percent difference for VFR3-10 was thought to be due to a leak in the second replicate testing apparatus, which had the lower reported CO_2 content.

Table 6. Aquatic Biodegradability Results

Sample ID	Lot Number	Average $ThCO_2$ (mg)	Inhibition Results (%)	Biodegradability (%)
VFR3-01[1]	01D1	75.23	83	132.7
VFR3-05[1]	01C6	67.44	91.6	121.4
VFR3-10[1]	01P2	74.00	21.4	105.9
Average	--	--	--	120 ± 33
Historical Data[2]	--	--	--	99 ± 19

[1]The higher than expected biodegradability percentages may be due to a loss of CO_2 from leaks in the stock solution test system.

[2]This value is the average of three test results listed in a report prepared for Cooper by TERC dated April 1999.

The average biodegradability of Envirotemp®FR3™ fluid was 120% ± 33% after 28 days. The higher than expected biodegradability value indicated the stock solution testing apparatus may have leaked CO_2 to the atmosphere. A lower CO_2 value for the stock solution would cause the amount of CO_2 for the test substance to be higher and therefore the biodegradability to be higher than 100%. The error propagation associated with the barium hydroxide traps has been cited to cause 125% CO2 production results (Gerike, P., 1984). A review of the stock solution data showed a CO2 production drop between day 10 and day 21, and again on day 28. If the CO_2 amounts are adjusted by using data from days 8 and 21, then the average biodegradation rate after 28 days for Envirotemp®FR3™ fluid would be 108% and for phthalic acid would be 67%. Both of these new rates would be greater than the 60% biodegradation criterion required after 28 days by this method. Based on this, Envirotemp®FR3™ fluid is considered to be readily biodegradable. However, the rates are considered to be a qualitative measurement.

To check the testing apparatus and stock solution selected, a reference flask containing the stock solution (bacteria in a mineral nutrient medium) and phthalic acid (a known biodegradable material) was tested in parallel with flasks containing only the stock solution, and the stock solution with Envirotemp®FR3™ fluid. The reference stock solution had a biodegradation rate of >60% after 14 days and after 28 days which verified that the appropriate test system and bacteria inoculum were used.

Inhibition tests were run for each lot to determine if the Envirotemp®FR3™ fluid would inhibit the bacteria ability to biodegrade phthalic acid. The inhibition tests indicated the Envirotemp®FR3™ fluid was not toxic to the bacteria except for Sample VFR3-10. Global Tox thought the low inhibition result for Sample VFR3-10 was likely a false result due to leaks of CO_2 to the atmosphere from the test apparatus since the sample did exhibit a biodegradability of > 60%. A large difference in the amount of CO_2 generated on days 8 and 28 are observed between the sample and its replicate for sample VFR3-05. Results from this test should be considered a qualitative measurement of Envirotemp®FR3™ fluid biodegradability.

While mineral oil was not tested as part of this study, literature data are available on biodegradability using U.S. EPA and the Organization of Economic Cooperation and Development (OECD) methods. These methods are equivalent to OPPTS 835.3110. Biodegradation rates for conventional mineral oil ranged from 42 to 49% after 28 days using U.S. EPA Method 560/6/-82-003, Aerobic Aquatic Biodegradability (USACE, 1997, 1999). Another study by CONCAWE reported a ready biodegradation rate for a light naphthenic distillate mineral oil of 28% after 28 days when analyzed by OECD 301B, Sturm Test (CONCAWE, 1997). These results agree with historical results obtained by TERC as part of their biodegradability testing for Envirotemp®FR3™ fluid. TERC reported average biodegradation rates after 28 days of 30.5% for Univolt 60, 21.3% for R-Temp, and 98% for Envirotemp®FR3™ fluid(TERC, 1999).

Based on these reported biodegradation rates for mineral oil, the Envirotemp®FR3™ fluid appears to biodegrade more readily. Although Envirotemp®FR3™ fluid readily biodegrades per this test, the product's ability to degrade in the environment is dependent on site-specific factors such as climate, geology, moisture, pH, temperature, oxygen concentration, dispersal of oil, the presence of other chemicals, soil characteristics, nutrient quantities, and populations of various microorganisms at the location (U.S.EPA 1997).

4.4 Results: Objective 3, Flammability

The flash point and fire point for virgin and in-service Envirotemp®FR3™ fluid were determined using ASTM Method D92, Cleveland Open Cup test. The flash point was measured to assess the overall flammability of the fluid and determine the presence of volatile or flammable material at elevated temperatures. The fire point was measured to determine the temperature at which the fluid would support combustion. These values were compared to the Cooper specifications, ASTM D3487 specification for flash point and ASTM D5222 specification for fire point, and are presented in Tables 7 and 8. The individual and average flash and fire point values for both the virgin and in-service fluid met the Cooper and ASTM specifications. The deviation in the fire point data is within the precision margin of ± 8°C at 95% confidence specified in ASTM Method D92. The flash point exceeded this criteria and the reported values should be considered an approximation. Historic flash and fire point data for the two transformers sampled at Cooper's facility are plotted and presented in Figures 7 and 8. The fluid in the oldest transformers after approximately 4.5 years of service have flash and fire points above 320°C and 350°C, respectively. These values are greater than the minimum values specified by the Cooper and ASTM specifications for virgin mineral oil and HMWH.

The fire point results also agreed with those obtained by Underwriters Laboratory (UL). UL evaluated this product using ASTM Method D92 (Cleveland Open Cup) and reported the fire point at 358°C. The flash point determined by UL was 255°C using ASTM Method D93 (Pensky-Martens Closed-Cup). The lower flash point was due to the different test method used by UL.

Table 7. Flash Points for Virgin and In-service Envirotemp®FR3™Samples

Sample Numbers	Product Lot No./ Transformer SN	Specification Criteria (°C)			Flash Point (°C)
		Cooper	ASTM D3487	ASTM D5222	
Virgin Product					
VFR3-01	01D1	≥ 320	>300	NA	328
VFR3-05	01C6	≥ 320	>300	NA	332
VFR3-07	01C6	≥ 320	>300	NA	334
VFR3-10	01P2	≥ 320	>300	NA	318
Average		≥ 320	>300	NA	328 ± 11
In-service Transformer Fluid					
ISFR3-01	966001430	≥ 320	>300	NA	338
ISFR3-02	966001429	≥ 320	>300	NA	328
ISFR3-03	26000482	≥ 320	>300	NA	330
ISFR3-06	37017339	≥ 320	>300	NA	340

Note: Data variability was calculated at 95% confidence using a two-tailed T-test assuming a normal distribution.

NA = Not applicable SN = Serial Number

Table 8. Fire Points for Virgin and In-service Envirotemp®FR3™ Samples

Sample Numbers	Product Lot No./ Transformer SN	Specification Criteria (°C)			Fire Point (°C)
		Cooper	ASTM D3487	ASTM D5222	
Virgin Product					
VFR3-01	01D1	≥ 350	NA	304-310	362
VFR3-05	01C6	≥ 350	NA	304-310	364
VFR3-07	01C6	≥ 350	NA	304-310	362
VFR3-10	01P2	≥ 350	NA	304-310	362
Average		≥ 350	NA	304-310	363 ± 2
In-service Transformer Fluid					
ISFR3-01	966001430	≥ 350	NA	304-310	362
ISFR3-02	966001429	≥ 350	NA	304-310	364
ISFR3-03	26000482	≥ 350	NA	304-310	364
ISFR3-06	37017339	≥ 350	NA	304-310	364

Note: Data variability was calculated at 95% confidence using a two-tailed T-test assuming a normal distribution.
NA = Not applicable SN = Serial Number

UL classified Envirotemp®FR3™ fluid as a dielectric medium and transformer fluid with a fire hazard rating of 4 to 5 which is less hazardous than paraffin oil. The UL fire rating system uses the flash point determined by Pensky-Martens Closed-Cup to rate the material's flammability. The material's flammability is rated and classified using the following scale arranged from flammable to nonflammable: ether rated at 100, gasoline from 90 to 100, ethyl alcohol from 60 to 70, kerosene from 30 to 40, paraffin oil from 10 to 20, and water at 0. Envirotemp®FR3™ fluid is one of five products listed by UL as a Class 4 to 5 dielectric medium and one of three products listed as a Class 4 to 5 transformer fluid (UL, 2001). The other UL listed dielectric medium products are either silicone oil-based, HMWH, or vegetable oil-based fluids. The other UL classified transformer fluids are either a silicone oil-based or HMWH fluids.

Envirotemp®FR3™ fluid is also classified as a less flammable transformer fluid by Factory Mutual Research Center (FMRC). FMRC defines a less flammable transformer fluid as having a fire point greater than 300°C when tested per ASTM D92 (Cleveland Open Cup). Envirotemp®FR3™ fluid is one of ten products classified as a less flammable transformer fluid. The other products classified as less flammable consist of either silicone oil-based, HMWH, or vegetable oil-based transformer fluids (FMRC, 1999). FMRC also identified Envirotemp®FR3™ fluid as an alternative to high fire point hydrocarbons, silicone fluids, and synthetic esters or hydrocarbons where fire resistance, improved high temperature operation, and improved cooling are desired.

Figure 7. Flash Point Trend for Transformers Sampled

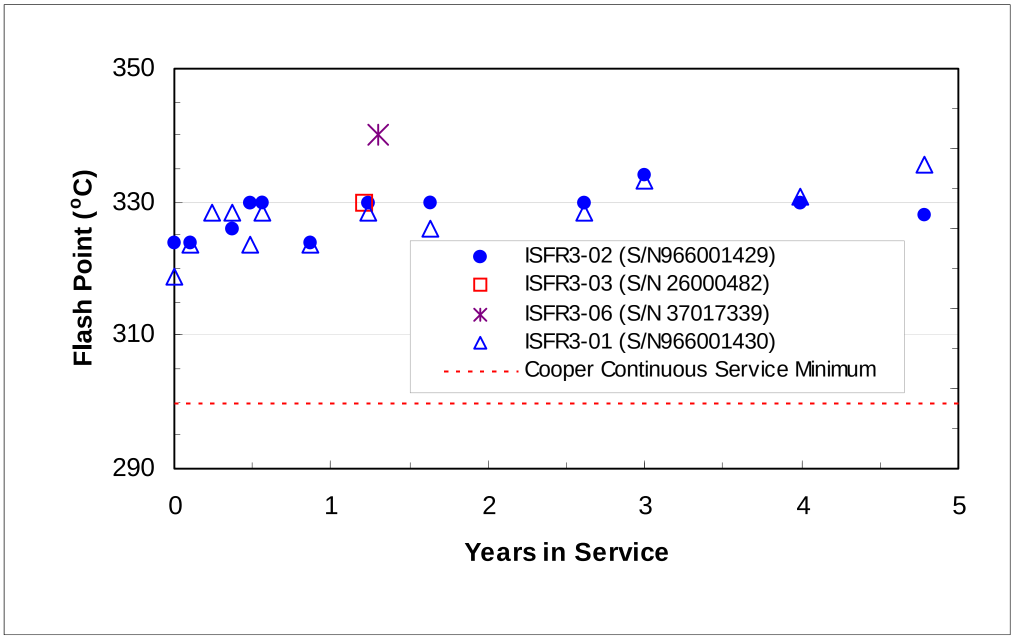
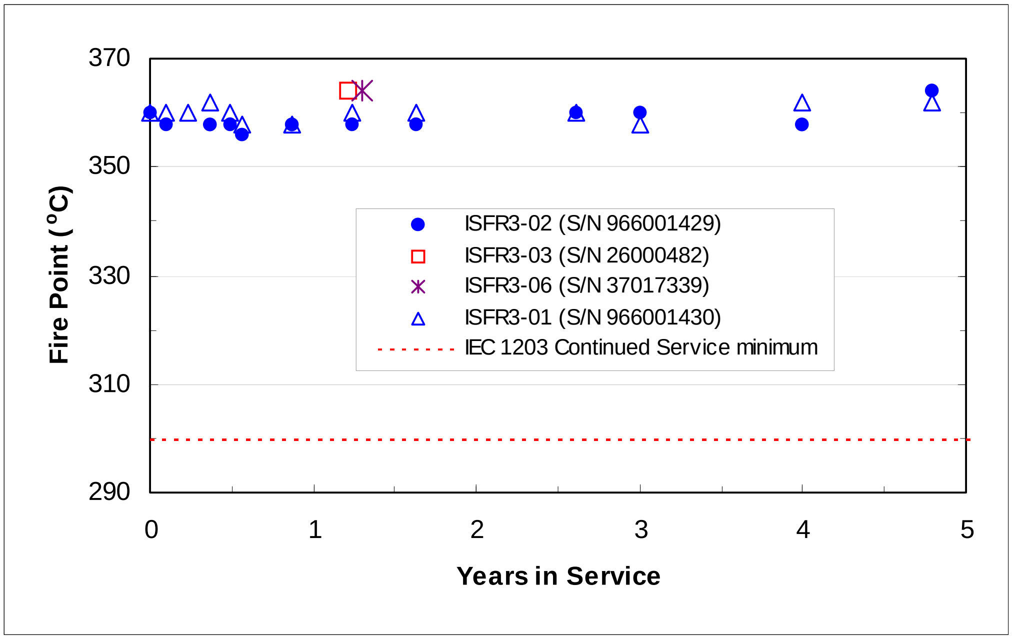


Figure 8. Fire Point Trend for Transformers Sampled



4.5 Results: Objective 4, Acute Toxicity

Three virgin Envirotemp®FR3™ samples, one from each lot, were analyzed using U.S. EPA method, *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*, EPA/600/4-90/027F, August 1993. Tests were performed by Associated Laboratories, a California independent laboratory, which performed the work under contract with DTSC. Based on earlier acute toxicity results provided by Cooper, the screening test was not conducted and instead three test chambers were prepared containing 750 mg/l, 500 mg/l, and 250 mg/l of Envirotemp®FR3™ fluid. Duplicate testing was performed in parallel with the test samples. The test method presented in the test plan was modified by using juvenile pimephales promelas (fathead minnow) instead of juvenile oncorhynchus mykiss (rainbow trout). Samples were prepared by the "Static Acute Bioassay Procedures for Hazardous Waste Samples" developed by the California Department of Fish and Game, Water Pollution Control Laboratory in the Code of California Regulations, Title 22, Section 66261.24(a)(6). This procedure requires shaking the sample for six hours using a wrist-action or similar type of shaker to dissolve the oil in 200 ml of water before the sample is added to the aquatic bioassay fish tank. Dissolved oxygen (DO) content, pH, and temperature were monitored and maintained at 6.0-7.0 mg/l, 7.0-7.5, and 20°C, respectively as required by the method. Associated Laboratories also performed a second set of tests using adult pimephales promelas (fathead minnow) at the same concentrations. The acute toxicity tests for the adult and juvenile pimephales promelas were conducted in parallel.

Earlier tests performed by Global Tox, an independent laboratory, under contract with Cooper analyzed the samples per the Organization of Economic Cooperation and Development (OECD) Procedure 203, *Fish Acute Toxicity Test* which used rainbow trout. Oil samples were prepared using an acetone carrier solvent to make the oil miscible in water. Dissolved oxygen (DO) content, pH, and temperature were monitored and maintained at between 8.0 and 9.0 mg/l, 7.8, and 15°C ± 1°C, respectively, as outlined in the method.

Table 9. Fish Bioassay Results for Virgin Envirotemp®FR3™ Samples

Sample Numbers	California Toxicity Criteria[1] (mg/L)	Sample Results (mg/L)	
		Juvenile	Adult
VFR3-01	<500	<250	314
VFR3-05	<500	<250	386
VFR3-10	<500	<250	250
Average[2]	<500	<250	317 ± 169
Historic Data[3]	<500	>1,000	---

[1]The virgin oil is considered to exhibit a toxic characteristic if the LC_{50} is less than 500 mg/l when measured in soft water.

[2]Data variability was calculated at 95% confidence.

[3]The result is for a single sample collected by the Cooper in December 1998.

Results are compared to the toxicity characteristic listed in the Code of California Regulations, Title 22, Section 66261.24(a)(6) in Table 9. A waste is considered to exhibit a toxic characteristic if the LC_{50} is less than 500 milligrams per liter when measured in soft water (total hardness 40 to 48 milligrams per liter of calcium carbonate).

A DTSC aquatic toxicologist reviewed the reports prepared by both Associated Laboratories and Global Tox to identify the differences, which could lead to such conflicting results. As part of the review, the toxicologist also reviewed the test methods, and material safety data sheets for Envirotemp®FR3™ fluid and its additives. The tank water was not analyzed for breakdown products associated with degraded vegetable oil by either the Global Tox or Associated Laboratories. The main difference between the two sets of test was the sample preparation method used. Associated Laboratories used a shaker table per the method cited in the test plan. Global Tox prepared their samples per OECD Procedure 203, *Fish Acute Toxicity Test*, where an acetone carrier solvent was used to make the oil miscible in water. Oil samples prepared using the wrist action method stratify the oil at the top of the tank. Fish swimming through this upper layer of the tank are thought to become coated with the product, which would impair gill exchange. Oil samples prepared using the wrist shaker method are thought to provide a more realistic result for conditions, which may occur during an environmental release. Samples prepared using the OECD method provided results that reflect systemic or chemical impacts on fish.

In California, insoluble, viscous waste samples are prepared using the wrist-shaker method and ultrasonic method, and sometimes the solvent carrier method as part of the fish bioassay screening tests for hazardous waste characterization. The preparation method yielding the most conservative LC_{50} result is then used to perform the definitive tests. This methodology is required by DTSC Waste Evaluation Unit and overseen by the Department of Health Services Environmental Laboratory Accreditation Program's Aquatic Toxicity Bioassay Section who certifies laboratories performing aquatic toxicity tests for DTSC. Cooper disagrees with DTSC's methodology (see vendor's comment section for Cooper's opinion). The reader should note that this methodology is used to characterize the hazardous characteristics for **waste**. Any statement concerning the hazardous characteristic of the Envirotemp®FR3™ fluid applies to the **spent (waste)** fluid only and is not intended to classify the virgin product.

The lower LC_{50} results and physical effects described above are similar to those presented by the U.S. EPA in their responses to comments on the rule for Oil Pollution Prevention at Non-Transportation Related Onshore Facilities (40 CFR Part 112). The physical effects observed in the toxicity tests performed by Associated Laboratories have been observed in vegetable oils, and oils in general, and were therefore expected (Polisini, personal communication). Based on these limited results which were performed on virgin product, the spent Envirotemp®FR3™ fluid may be classified in California as hazardous waste and need to be managed accordingly. The end-user should characterize the spent Envirotemp®FR3™ fluid at the time of disposal since changes may occur to the oil due to use, storage, or age. The end-user should also consult the appropriate regulatory authority about applicable waste characterization regulations and the appropriate disposal method for their area.

4.6 Results: Other Verification/Certification Objectives

Chemical Composition

The chemical composition of the virgin and in-service fluids was analyzed by selected Association of Analytical Chemist (AOAC) methods, semivolatile organics (SVOCs) by EPA Method 8270, and metals analysis by EPA Method 6010. The AOAC methods were selected to provide a chemical "fingerprint" for Envirotemp®FR3™ fluid. Samples were also analyzed for SVOCs and metals to identify any contaminants of concern. Silliker, an independent laboratory, analyzed samples per the AOAC methods while the Hazardous Materials Laboratory (HML) analyzed the SVOC and metals samples.

Cooper has reported the composition of Envirotemp®FR3™ as follows. The product is composed >98.5% vegetable oil and <1.5% additives (e.g., antioxidants and color). The vegetable oil is comprised of at least 23.5% monounsaturated, 61% polyunsaturated fatty acids, and 15.5% saturated fatty acids. According to the Cooper, the antioxidants may consist of combination of antioxidants, which include butylated hydroxyl anisole (BHA), mono-tertiary butylhydroquinone (TBHQ), 3,5-di-tert-butyl-4-hydroxytoluene (BHT or DBPC), and Vitamin E.

Tables 10 and 11 present the sample results for virgin and in-service Envirotemp®FR3™ fluid. Analytes detected at percentages greater than 5% in virgin samples met the repeatability criteria listed in AOAC Method 963.22 with a relative percent difference between results of < 3% and an absolute percent difference of < 1%. Results for the in-service samples were not compared to the precision criteria since no duplicate was collected to minimize impacts on the transformer and the on-going sampling program.

Table 10. AOAC Results for Virgin Envirotemp®FR3™ Samples

Analyte		**Sample Number**				
		VFR3-01	**VFR3-05**	**VFR3-06**	**VFR3-10**	**Average**
Total Fatty Acids						
Hexadecanoic (Palmitic)	16:0	10.60%	10.60%	10.60%	10.60%	10.60%
Octadecanoic (Stearic)	18:0	4.35%	4.18%	4.20%	4.29%	4.26% ± 0.13%
Octadecenoic (Oleic)	18:1	23.40%	23.60%	23.60%	23.50%	23.53% ± 0.15%
Octadecadienoic (Linoleic)	18:2	52.40%	52.30%	52.30%	52.30%	52.33% ± 0.08%
Octadecatrienoic (Linolenic)	18:3	7.58%	7.55%	7.56%	7.56%	7.56% ± 0.02%
Eicosanoic (Arachidic)	20:0	0.33%	0.34%	0.34%	0.34%	0.34% ± 0.01%
Eicosenoic (Gadolelc)	20:1	0.24%	0.25%	0.25%	0.25%	0.25% ± 0.01%
Docosanoic (Behenic)	22:0	0.35%	0.36%	0.36%	0.35%	0.36% ± 0.01%
Tetracosanoic (Lignoceric)	24:0	0.11%	0.11%	0.11%	0.11%	0.11%
Unknown components		0.40%	0.43%	0.43%	0.44%	0.43% ± 0.03%
Phenolic Antioxidants (AOAC Method 983.15)	**(ppm)**	2,001	3,047	3,074	3,025	2787 ± 834
Polymers and Oxidation Products (%)		1.3	<1.0	1.3	<1.0	1.2 ± 0.3

Results are presented for the individual fatty acids along with their number of carbons and the number of double bonds (i.e., 18:1 represents 18 carbons and one double carbon bond). The percentage of monounsaturated and polyunsaturated fatty acids are determined by adding the fatty acids with one, two or three double carbon bonds together, respectively. The percentage of monounsaturated fatty acids consists of fatty acids with one double carbon bond such as octadecenoic or oleic acid (18:1). The polyunsaturated fatty acids consist of di- and tri-unsaturated fatty acids (e.g., 18:2 and 18:3). The percentage of saturated fatty acids consist of the fatty acids with no double carbon bonds such as hexadecanoic (16:0), octadecanoic (18:0), eicosanoic (20:0), docosanoic (22:0), and tetracosanoic (24:0).

The virgin Envirotemp®FR3™ samples had monounsaturated fatty acid ranging from 23.8% ± 0.2%, polyunsaturated fatty acids ranging from 59.9% ± 0.1%, and saturated fatty acids ranging from 15.7% ± 0.1%. This agrees closely with the formulation reported by Cooper. The in-service Envirotemp®FR3™ samples had monounsaturated fatty acid ranging from 22.0% to 23.8%, polyunsaturated fatty acids ranging from 59.8-62.4%, and saturated fatty acids ranging from 15.2-16.3%. The in-service sample results are also consistent with Cooper's reported formulation.

Table 11. AOAC Results for In-Service Envirotemp®FR3™ Samples

Analyte		**Sample Number**			
		ISFR3-01	**ISFR3-02**	**ISFR3-03**	**ISFR3-06**
Total Fatty Acids					
Hexadecanoic (Palmitic)	16:0	10.60%	10.60%	10.20%	10.20%
Octadecanoic (Stearic)	18:0	4.03%	3.99%	5.15%	5.10%
Octadecenoic (Oleic)	18:1	21.80%	21.80%	23.50%	23.50%
Octadecadienoic (Linoleic)	18:2	54.20%	54.20%	52.50%	52.60%
Octadecatrienoic (Linolenic)	18:3	8.14%	8.15%	7.35%	7.34%
Eicosanoic (Arachidic)	20:0	0.30%	0.30%	0.43%	0.42%
Eicosenoic (Gadolelc)	20:1	0.20%	0.20%	0.24%	0.24%
Docosanoic (Behenic)	22:0	0.31%	0.31%	0.36%	0.36%
Tetracosanoic (Lignoceric)	24:0	<0.1%	<0.1%	0.10%	<0.1%
Unknown components		0.00%	0.06%	<0.1%	<0.1%
Phenolic Antioxidants (AOAC Method 983.15)	**(ppm)**	3,954	4,598	4,108	4,181
Polymers and Oxidation Products (%)		<1.0	2.3	2.7	2.8

AOAC Method 983.15, *Phenolic Antioxidants in Oils, Fats, and Butter Oil*, was used to determine the concentration of 7 commonly used antioxidants in food grade oils and fats. The results for the virgin and in-service transformer samples are presented in Tables 10 and 11. Antioxidants were detected in all the virgin product between 2,787 ppm ± 834 ppm. The in-service transformer samples had antioxidant concentrations between 3,950 ppm and 4,600 ppm. The higher antioxidant content in the in-service samples compared to the virgin samples reflects a formulation change by Cooper.

The polymers and oxidation products listed in Tables 10 and 11 above are simple indicators used in the food industry to assess the quality of vegetable oil after exposure to heat. If higher values are reported for an oil as it is reheated, the difference is assumed to show an increase in non-elution material (compounds not removed using a solvent) that indicates the polar compounds in the oil are degrading. Compared to the average virgin product value of 1.2% ± 0.3%, three of the four in-service fluid samples appear to have degraded slightly due to use.

Virgin and in-service samples were screened for 65 standard SVOC compounds using U.S. EPA Method 8270/3580. All the virgin samples and in-service samples were extracted outside the 7-day extraction window, which deviated from the holding time requirements listed in the test evaluation plan. HML noted the recovery of pyrene in the matrix spikes could not be reliably calculated due to matrix interference. HML also noted difficulty in analyzing both the virgin and in-service fluid samples. The samples may contain non-volatile components that do not readily elute from the chromatographic column. Due to this difficulty and extraction times exceeding those listed in the test plan, the reported SVOC results should be regarded as approximations and not be used in lieu of actual waste characterization data.

None of the 65 standard SVOC compounds analyzed by the HML lab were detected in the virgin product samples. For the in-service samples, bis-(2-ethylhexyl)phthalate, butyl benzyl phthalate, and di-n-butyl phthalate were detected. These compounds were also detected in the equipment blank and all but butyl benzyl phthalate were detected in the field blank. These compounds were probably contaminants introduced from the Tygon tubing and/or deionized (DI) water used. Other tentatively identified compounds were bis-2-ethylhexyl hexanedoic acid (DEHA), squalene, and sterols such as tocopherol, stigmasterol, campesterol, and gamma sitosterol. These sterols are normally found in vegetable oils. Due to the deviations discussed above, the SVOC data should be considered a qualitative measurement but does not change the assessment that Envirotemp®FR3™ fluid consists primarily of vegetable oil and a small percentage of antioxidants.

Virgin and in-service samples were analyzed by U.S. EPA Method 6010/5030. Other than the sample preparation method used, no other deviations to the final test evaluation plan were noted by the laboratory. Barium and zinc were detected in the virgin product samples at concentrations ranging from 26 mg/kg to 36 mg/kg and from 11 mg/kg to 24 mg/kg, respectively. No metals were detected in the equipment blank. For the in-service transformer samples, metals were detected in two of the four in-service transformer samples. ISFR3-01 and ISFR3-02 had barium and zinc concentrations ranging from 25 mg/kg to 27 mg/kg and from 12 mg/kg to 13 mg/kg, respectively. Cadmium and molybdenum were also detected in the sample ISFR3-01 at 0.42 mg/kg and 2.6 mg/kg, respectively. No metals were detected in the equipment blank associated with the in-service transformer sampling. Quality assurance/quality control (QA/QC) results met the criteria outlined in the HML User's manual for EPA Method 6010. The barium and zinc might have been introduced during degassing process or from the finishing tank used to store all new batches manufactured. These metals do not appear to have been introduced due to sampling since they were not detected in the equipment blank. It is also not clear why barium or zinc was not detected in the ISFR3-03 and ISFR3-06.

Worker Health and Safety Aspects

This section presents some of the potential hazards associated with Envirotemp®FR3™ fluid and compares them to those for select mineral oil-based and silicone oil-based transformer fluids. This is not considered a comprehensive review where all potential hazards associated with Envirotemp®FR3™ fluid has been identified. End-users should review all applicable worker health and safety regulations for use of this product.

Envirotemp®FR3™ fluid is used to cool the core and coils within a transformer. The fluid is held in a tank inside the transformer. The tank is equipped with a pressure relief valve where gases in the headspace may be released to the ambient air. Transformers that use mineral oil or other types of insulating fluid are also equipped with pressure relief valves. Transformers that use Envirotemp®FR3™ are usually located in or adjacent to buildings, or in underground vaults where higher fire protection is required.

The Envirotemp®FR3™ dielectric insulating fluid is composed >98.5% vegetable oil and <1.5% additives (e.g., antioxidants and color). The antioxidants used in this product are not listed as a hazardous material and have been cleared for use as a food grade antioxidant. Although the components of Envirotemp®FR3™ fluid are food-grade, this product was not intended for human consumption and should not be used as a food product.

According to the Envirotemp®FR3™ material safety data sheet (MSDS), this product is also not considered a hazardous substance as defined under Title 8, California Code of Regulations, Section 5194, Hazard Communications. However, this does not relieve the end-user who uses this product from providing workers with information and training necessary to handle Envirotemp®FR3™ fluid safely. Workers should review the MSDS and be familiar with the information concerning first aid procedures, physical properties, personal protective equipment (PPE), respiratory protection, and slip hazards. Workers should wash skin that has contacted the product with soap and water. For eye contact, the eyes should be flushed with water. The primary physical property workers should be aware of is the product’s flash point of greater than 300°C. In the case of an Envirotemp®FR3™ spills, employees should be aware of the increased slip hazard in the affected area due to the product.

Before working with Envirotemp®FR3™ fluid, employees should ensure the work area has adequate ventilation, and the appropriate respiratory protection and protective clothing are selected. When working with hot Envirotemp®FR3™ fluid, workers should don neoprene gloves, rubber boots and aprons. Respiratory protection should only be worn if oil mists or dusts contaminated with oil are detected at concentrations equal to or exceeding the permissible exposure limit (PEL). Occupational Safety and Health Administration (OSHA) has set the permissible exposure limit (PEL) for vegetable oil mist as a nuisance particulate at 15 mg/m^{3} and 5 mg/m^{3} for respiratory protection for an 8-hour time-weighted average (TWA) exposure. In California, the nuisance particulate PEL is 10 mg/m^{3}. The end-user should consult the appropriate regulatory authority about applicable nuisance particulate PELs used in their area.

If the transformer is located in a poorly ventilated area, then workers should use appropriate engineering controls to ventilate the area. Based on the MSDS information on

Envirotemp®FR3™'s antioxidants, Envirotemp®FR3™ fluid may produce carbon monoxide, carbon dioxide, nitrogen oxides, and other toxic compounds when the antioxidants thermally decompose. Mineral oil-based and silicone oil-based transformer fluids may also thermally decompose and produce fumes, smoke, carbon monoxide, aldehydes and other products. For some mineral oil-based transformer fluids, sulfur oxides are also listed as a possible decomposition product while silicon dioxide is listed for some silicone oil-based fluids. No data are available on the composition of emissions from transformers in general.

When comparing the PPE requirements for handling Envirotemp®FR3™ fluid to select mineral oil-based transformer fluids, the requirements were found to be similar. This comparison is based on MSDS information for select mineral oil-based transformer fluids obtained from the Vermont Safety Information Resources, Inc. (SIRI) MSDS archive. Respiratory protection for the mineral oil-based transformer fluids is required at a lower nuisance particulate OSHA PEL of 5 mg/m^3 for an -8-hour TWA exposure compared to Envirotemp®FR3™ fluid. For select silicone oil-based transformer fluids found in the Vermont SIRI MSDS archive, workers are advised to don impervious gloves and chemical goggles when handling the fluid.

Occupational exposure to transformer fluid is limited and associated to infrequent activities such as filling, draining, or sampling of transformers. These activities are not likely to generate a mist or aerosol at concentrations approaching the PEL. Potential hazards associated with filling or draining the transformer include slipping on work surfaces where the product was spilled, or splashing of the material into the eyes or onto the skin. Potential hazards associated with sampling the transformer include coming in contact with extremely hot oil, potential electrical arcing from the transformer, or slipping hazards due to spilled Envirotemp®FR3™ fluid on the floor.

MSDS information for three silicone transformer fluids identified as less-flammable transformer oils by UL and FMRC were reviewed along with several mineral oil-based transformer fluids listed in the Vermont SIRI MSDS Archive. Health and safety information on the components listed on the MSDSs was compared to information listed in Sax's Dangerous Properties of Industrial Materials. The primary component of the mineral oil-based transformer fluid was a hydrotreated light naphthenic petroleum distillate (CAS No 64742-53-6) ranging from 30-100% which was identified as an International Agency for Research on Cancer (IARC) confirmed carcinogen based on experimental data for animals (Lewis, 2000). The primary ingredient of the silicone oil-based transformer fluids was dimethyl polysiloxane (CAS No. 63148-62-9) listed at 100% and identified as a combustible liquid, a teratogen, and the cause of reproductive effects based on experimental data on animals (Lewis, 2000).

Estimated Cost of Using Envirotemp®FR3™ versus Mineral Oil

An average life for a transformer using Envirotemp®FR3™ fluid is estimated to be 20 years. A new Cooper transformer unit containing Envirotemp®FR3™ fluid costs approximately 1.2 to 1.3 times more than a comparable new Cooper mineral oil transformer. The price of the Envirotemp®FR3™ fluid is approximately $9 to$10 per gallon depending on the volume purchased. Prices for mineral oil typically range from $2 to $4 per gallon depending on quantity (Luksich, 2001). The fluid is available in 5-gallon containers, 55-gallon drums, 200-gallon totes, 6,000-gallon tanker trucks, or by the rail car. Monitoring costs will vary depending on the maintenance program the purchaser has in place. The waste characterization cost for a transformer using Envirotemp®FR3™ fluid or mineral oil is anticipated to be approximately the same except for mineral oil suspected to contain PCBs where the costs will be higher. The disposal cost for mineral oil and Envirotemp®FR3™ fluid are assumed to be comparable since data are not available on the waste characteristics of Envirotemp®FR3™ fluid after 20 years of use.

For a retrofilled transformer, no additional costs due to modifications on the transformer unit are incurred for using Envirotemp®FR3™ fluid. The costs associated with draining and disposing of the used oil are expected to be the same for both mineral oil and Envirotemp®FR3™ fluid. The cost of flushing and filling the transformer with Envirotemp®FR3™ fluid versus mineral oil will be higher and ranges from approximately $5 to $8 per gallon. The accelerated life testing results performed by Cooper indicate the paper insulation around the windings showed less degradation for the Envirotemp®FR3™ transformers than the identical mineral oil transformers. Less degradation of the paper insulation indicates the Envirotemp®FR3™ transformers may have a longer service life per this test.

Section 5. Regulatory Considerations

A review of Federal and California regulations was conducted to identify applicable regulations for virgin and spent Envirotemp®FR3™ fluid. This review is not considered to be a comprehensive review of existing regulations. Waste management is based on the limited amount of data available on this product. The reader should consult with their local environmental regulatory agency concerning other applicable local and State regulations, and the status of the regulations cited below. These regulations may have been updated or superseded since this review was conducted.

Virgin (or unused) Envirotemp®FR3™ fluid is a vegetable oil-based dielectric fluid consisting of >98.5% food-grade vegetable oil and < 1.5% additives such as antioxidants and color. The product has a flash point of 255 C by ASTM Method D93 and an average of 328 C by ASTM Method D92. The product has a neutral pH (pH = 7.0) and is not reactive with other chemicals at room temperature but is incompatible with strong oxidizers. As part of this verification/certification, three samples of virgin Envirotemp®FR3™ fluid were tested and had an acute aquatic LC_{50} value of less than 250 mg/L. The historical LC_{50} value provided by Cooper was greater than 1,000 mg/L. The difference between the results was thought to be due to the sample preparation method used. The lower LC_{50} value was thought to reflect the physical impacts of an oil spill to fish while the higher LC_{50} was thought to reflect the systemic (chemical) impacts to fish.

5.1 Regulation of Virgin Envirotemp®FR3™ Dielectric Fluid

Information on new product and materials introduced for commercial use are submitted to the U.S. EPA for review under the Toxic Substances Control Act (TSCA) unless the new product is a mixture of listed materials. The components of Envirotemp®FR3™ are listed under the TSCA as Chemicals in Commerce. None of the components are listed as an imminently hazardous chemical substance or mixture which the EPA Administrator has "taken action under" Section 7. Envirotemp®FR3™ and its components are also not listed as hazardous substances under Section 3001 of Resource Conservation and Recovery Act (RCRA), and Section 112 of the Clean Air Act (CAA). The product is included under Section 311 of the Clean Water Act (CWA), which addresses oil, and hazardous substance releases to water. The product is shipped as a non-hazardous material per Department of Transportation regulations.

The components of Envirotemp®FR3™ fluid are not listed in the Consolidated List of Chemicals Subject to Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the CAA and therefore, is not reportable under Section 313. However, a material safety data sheet (MSDS) is required as part of the EPCRA under Section 311. California facilities should consult Health and Safety Code (HSC) Chapter 6.8 and determine if business plans need to be modified in the areas of emergency preparedness and response, and water quality if Envirotemp®FR3™ fluid is used at their facilities.

5.2 Waste Characterization/Disposal Requirements

5.2.1 Waste Characterization and Disposal of Virgin Envirotemp®FR3™ Fluid

Under the RCRA definition of a hazardous waste, a waste is considered hazardous if it is a listed waste under Section 261.2 or exhibits a hazardous characteristic as defined in 40CFR261.20 through 40CFR261.24. A hazardous characteristic is defined as either having a flash point less than 60°C (ignitability), has a pH < 2.5 or pH > 12.5 (corrosivity), is reactive, or contains a contaminant equal to or greater than the regulatory value listed in 40CFR 261.24 (toxicity) per the Toxicity Characteristic Leaching Procedure (TCLP). The virgin Envirotemp®FR3™ fluid is not a listed RCRA waste nor does it meet the definition of a hazardous waste per 40CFR261.20 through 40CFR261.24. Virgin Envirotemp®FR3™ fluid which is off-specification or has exceeded its shelf life is not listed as a hazardous waste per 40CFR 261.33 and may be returned to the manufacturer or disposed of as a non-hazardous material.

In California, a waste is considered hazardous if it is a RCRA listed waste or exhibits a hazardous characteristic per California Code of Regulations (CCR), Title 22, Division 4.5, Chapter 11, Article 3, Section 66261.20 (22CCR66261.20). The ignitability, corrosivity, and reactivity criteria listed under 22CCR66261.20 are the same as those listed for 40CFR261.20 through 40CFR261.23. The toxicity characteristic defined under 22CCR261.24 lists several criteria which are as follows: (1) the waste meets the criteria per 40CFR261.24, (2) the waste contains a substance listed in 22CCR66261.24 as determined by the Waste Extraction Test (WET), (3) the waste has an acute oral lethal dose (LD_{50}) of less than 5,000 mg/kg, (4) the waste has an acute dermal LD_{50} of 4,300 mg/kg, (5) the waste has an acute inhalation lethal concentration (LC_{50}) of less than 10,000 ppm as a gas or vapor, (6) the waste has a acute aquatic 96-hour LC_{50} of less than 500 mg/L, or the waste contains any of the substances listed in 22CCR66261.24(a)(7). Spent Envirotemp®FR3™ fluid, which includes off-specification material, may exhibit a hazardous characteristic and therefore may be subject to hazardous waste management regulation. Off-specification material may be considered a retrograde material if it meets the criteria per HSC 25121.5 and may be returned to the manufacturer without a manifest.

5.2.2 Waste Characterization of Spent Envirotemp®FR3™ Fluid

Spent Envirotemp®FR3™ fluid should be characterized by the generator per 40CFR261.20 through 40CFR261.24 or by the applicable State requirements prior to disposal. To date, the longest continuous use of Envirotemp®FR3™ in a transformer has been approximately 4.8 years. The average service life of a transformer is approximately 20 years. Since changes to the oil may occur due to use, the generator must characterize the spent Envirotemp®FR3™ prior to disposal. As part of the waste characterization for transformers that exclusively used Envirotemp®FR3™ fluid, the generator should determine the metals concentration per EPA Method 1311 and the TCLP. For retrofilled transformers, the spent Envirotemp®FR3™ must also be tested for PCBs per EPA Method 8082 if the transformer was known or suspected to have contained PCBs prior to using Envirotemp®FR3™ fluid. If the spent Envirotemp®FR3™ fluid is characterized as hazardous, then the fluid must be managed as a hazardous waste per the applicable State and federal regulations.

For spent Envirotemp®FR3™ fluid generated in California, the Waste Extraction Test (WET) should also be performed as defined in 22CCR Section 66261.24 (a)(1) and 66261.24 (a)(2), respectively, in addition to EPA Method 1311. The used oil should also be characterized for acute aquatic toxicity per 22CFR66261.24(a)(6) in addition to the TCLP. If the spent Envirotemp®FR3™ fluid is characterized as hazardous per the federal definition, then the fluid must be managed as a hazardous waste. If the spent Envirotemp®FR3™ fluid is characterized as hazardous per 22CCR66261.20, then the fluid must be managed as used oil per the Used Oil Management Program (22CCR66279).

Characterization results for Envirotemp®FR3™ fluid for a specific transformer model may be used for others if the transformer has only used Envirotemp®FR3™ fluid during its service life and has not been retrofilled with a different dielectric fluid during its service life. Depending on the results of the waste characterization, the spent Envirotemp®FR3™ fluid may be sent to a waste oil recycler or fat renderer for facilities located outside California. Facilities outside of California should consult their State environmental agency for certified waste oil recyclers or fat renderers in their area and the recyclers' acceptance criteria for used vegetable oil. In California, the spent Envirotemp®FR3™ fluid may only be sent to licensed waste oil recycler if the waste characterization results show the fluid to exhibit a hazardous characteristic per 22CCR66261.20.

5.2.3 Disposal of Spent Envirotemp®FR3™ Fluid

Under the federal Used Oil Management Program, spent Envirotemp®FR3™ fluid is not included. The U.S. EPA defines used oil as being "refined from crude oil or any synthetic oil, that has been used and as a result of such use is contaminated by physical or chemical impurities" (40CFR279.1). The U.S. EPA has stated that animal and vegetable oils are excluded from the federal used oil definition even when used as a lubricant (U.S. EPA, 1996). Spent Envirotemp®FR3™ fluid may be subject to hazardous waste management under RCRA if the spent oil meets the federal hazardous waste characteristics listed in 40CFR261.20 through 40CFR261.24 or contains a listed RCRA hazardous waste. End-users outside California should contact their local or State environmental agency on applicable used oil management regulations in their area.

In California, used Envirotemp®FR3™ fluid may be included in the Used Oil Program under the definition of a synthetic oil per 22CCR 66279.1(d). As part of the synthetic oil definition, "vegetable or animal oil used as a lubricant, hydraulic fluid, heat transfer fluid or for other similar industrial purposes shall be managed as used oil if it is identified as a non-RCRA hazardous waste. Used vegetable or animal oil identified as RCRA hazardous waste is not used oil" (22CCR66279.1(d)) and must be managed as a hazardous waste. A non-RCRA hazardous waste is one that does not contain a RCRA listed waste, does not exhibit a hazardous waste characteristic per 40CFR261.20 through 40CFR261.24 but does exhibit a hazardous waste characteristic per 22CCR66261.20. Transformer oils are included under the California program if the oil does not exhibit a federal hazardous waste characteristic, does not contain a RCRA listed waste, contains no more than 5 ppm of PCBs, or has a total halogen content of less than 1,000 ppm.

Used oil (e.g., mineral oils, synthetic oils) managed under the California program must be managed as a hazardous waste unless it is shown to meet one of the specifications for recycled oil in Health and Safety Code (HSC) Section 25250.1(b) or qualifies for a recycling exclusion under HSC 25143.2. Used oil generators are required to meet all used oil generator requirements except householders who perform their own oil changes. DTSC issues an EPA Identification Number for each site where used oil is stored except for generators of 100 kilograms or less of hazardous waste per month (including used oil) who ship used oil under a modified manifest. Above-ground storage tanks and containers accumulating used oil, and fill pipes used to transfer used oil to underground storage tanks must be labeled with the words "USED OIL _ HAZARDOUS WASTE" and the initial date of accumulation. Used oil must be sent to an authorized used oil storage or treatment facility by a registered hazardous waste transporter.

However, spent Envirotemp®FR3™ fluid may be exempt from the used oil regulations if the oil is removed from a transformer, filtered, and then reused on-site in electrical equipment as a dielectric fluid (HSC 25250.4(b)). This exemption does not apply to transformer fluid that has been removed, filtered, and then sent off-site for reuse. Facilities should contact their local environmental agencies on applicable recycling regulations.

5.2.4 Disposal of Waste the Clean-up of Virgin and Spent Envirotemp®FR3™ Spills

In the event of a spill, responders should consult the MSDS and their spill prevention, control, and countermeasures (SPCC) plan or facility response plan (FRP), if applicable, for the appropriate clean-up measures. End-users should consult with their local environmental regulatory agencies on clean-up levels and disposal options for waste generated from these spills. Since spent Envirotemp®FR3™ fluid may exhibit a hazardous characteristic per California's hazardous waste definition, the waste generated from spill clean-ups in California should be presumed hazardous until the waste has been characterized.

5.3 Spill Management

The spill management regulations listed in this section apply to both virgin and spent Envirotemp®FR3™ fluid. Facilities should contact their local environmental regulatory agency on other local regulations pertaining to oil spill management.

Oil Discharge

Under 40CFR 110, Discharge of Oil Regulation, facility owners and operators that handle, store, or transport oils are required to report an oil discharge which "may be harmful to the public health or welfare, or the environment". A reportable spill is defined as one that either; (1) violates water quality standards, (2) causes a sheen or discoloration on the surface of a body of water, or (3) causes a sludge or emulsion to be deposited beneath the surface of the water or on adjoining shorelines. The term "oil" applies to petroleum based oil products and non-petroleum based oil products, which include animal fats, vegetable seed-based oils, and synthetic oils. Adding dispersants or emulsifiers to the oil prior to discharge are prohibited under 40 CFR Section 110.4.

Oil discharged into or upon the navigable waters of the United States must be reported to the National Response Center, contained, and cleaned up. Depending on the discharge volume, extent and proximity to sensitive areas (e.g., wildlife areas), coordination and involvement of local emergency response agencies and the National Response Center may be required for the clean up effort. These reporting requirements apply to mineral oils and synthetic oils, as well as vegetable oils.

Oil Pollution Prevention

Under 40 CFR Part 112.1 through 112.7 of the Oil Pollution Prevention; Non-Transportation Related Onshore Facilities, facilities "that could be expected to discharge oil into or upon the navigable waters of the United States or adjoining shorelines, and that have (1) a total underground buried storage capacity of ≥ 42,000 gallons, (2) a total aboveground oil storage capacity of ≥ 1,320 gallons, or (3) an aboveground oil storage capacity in a single container of ≥ 660 gallons" are required to prepare and submit a SPCC plan. Some facilities may not be regulated if, due to their location, they could not reasonably be expected to discharge oil into navigable waters of the U.S. or adjoining shorelines.

Under the 40 CFR Part 112, facilities are required to prepare and submit a facility response plan (FRP) if they transfer ≥ 42,000 gallons of oil over water to a vessel or have a storage capacity ≥ 1,000,000 gallons and meet at least one of these four criteria; inadequate secondary containment, proximity to environmentally sensitive areas, proximity to public drinking water intakes, or occurrence of a 10,000 gallon or more oil spill in the last 5 years. The FRP includes response for worst-case discharges, estimates of planned resources, emergency response plans, and training drills/exercises. Under this regulation, the requirements for animal fats and vegetable oils are similar to those for petroleum oils, but involve new specific methodology for planning response actions for vegetable oils and animal fats.

The U.S. EPA's analysis of the impacts of the SPCC program indicated that a majority of electric utility substations and transformer installations would meet the aboveground storage capacity thresholds. Facilities such as schools and small business complexes are not anticipated to meet the SPCC or FRP program requirements. Typically, these facilities have several pad-mounted transformers with an average oil tank capacity of 40 gallons. For compliance, the facility owner is required to determine if oil storage capacity at a given site meets the criteria listed in the SPCC and FRP.

Section 6. Conclusions

6.1 Objective 1, General Performance

The general performance specifications are useful for end users to determine whether the product will meet their needs. Envirotemp®FR3™ fluid meets Cooper's performance specifications for dielectric breakdown (minimum and gap), pour point, viscosity (40°C, 100°C), water content, interfacial tension, and neutralization number. When compared to the ASTM, IEEE, and IEC specifications, Envirotemp®FR3™ fluid meets these specifications for the dielectric breakdown (minimum, gap, impulse). It also meets ASTM D3487, IEEE, and IEC specifications for the neutralization number. However, it had an average dissipation factor at 25°C that did not meet the Cooper specification. It also had higher dissipation factors at 100°C compared to those reported for three past samples tested by Cooper. These higher dissipation factors may be due to contaminants introduced during product storage, sample collection, sample preparation, or sample testing. Envirotemp®FR3™ fluid did not meet and was not expected to meet the ASTM, IEEE, and IEC specifications for dissipation factor, pour point, water content, interfacial tension, and viscosity since these specifications were based on fluids with different physical and chemical properties.

The in-service transformer fluid sample results for the dissipation factor, neutralization number, interfacial tension, conductivity and water content met all the Cooper and IEC 1203 specifications for in-service fluid. Based on the historical data for the oldest in-service transformers, Envirotemp®FR3™ fluid appears to have degraded little over the units' service life.

6.2 Objective 2, Aquatic Biodegradability

The average biodegradability of Envirotemp®FR3™ fluid was 120% ± 33% after 28 days based on U.S. EPA Method OPPTS 835.3110 results. These results may be biased high due to possible CO_2 losses in the control samples and should be considered a qualitative measure of the product's ready biodegradability. Based on these results, the virgin Envirotemp®FR3™ fluid appears to biodegrade more readily than mineral oil. Although Envirotemp®FR3™ fluid readily biodegrades per this test, the product's ability to degrade in the environment is dependent on site-specific factors such as climate, geology, moisture, pH, temperature, oxygen concentration, dispersal of oil, the presence of other chemicals, soil characteristics, nutrient quantities, and populations of various microorganisms at the location (U.S.EPA 1997). Therefore, releases to the water should be prevented.

6.3 Objective 3, Flammability

The flash and fire point for the virgin and in-service fluids were consistently above the minimum performance values specified by ASTM D3487, D5222, and Cooper. The fire point results obtained also agreed with values reported by UL.

6.4 Objective 4, Acute Toxicity

The average LC_{50} for virgin Envirotemp®FR3™ fluid was less than 250 mg/L. Based on this limited set of data for virgin product, the spent Envirotemp®FR3™ fluid may exhibit a hazardous characteristic per 22CCR 66261.24(a)(6). The end-user should characterize their spent Envirotemp®FR3™ fluid at the time of disposal since changes to the oil may occur due to use, storage, or age. End-users should also consult their appropriate local, State, or federal regulatory authority about applicable waste characteristic regulations and available disposal options in their area.

6.5 Other Verification/Certification Objectives

Chemical Composition

The AOAC results for the virgin Envirotemp®FR3™ samples showed the fluid consisted of 23.8% ± 0.2% monounsaturated fatty acids, 59.9% ± 0.1% polyunsaturated fatty acids, and 15.7% ± 0.1% saturated fatty acids. The in-service transformer fluid consisted of 22.0% to 23.8% monounsaturated fatty acids, 59.8% to 62.4% polyunsaturated fatty acids, and 15.2% to 16.3% saturated fatty acids. These results were all consistent with Cooper's reported formulation.

Antioxidant concentrations in the virgin Envirotemp®FR3™ samples ranged from 2,787 ppm ± 834 ppm. Antioxidant concentrations in the in-service transformer samples ranged from 3,550 ppm to 4,595 ppm. The antioxidants detected agreed with ingredients list provided by Cooper.

For the 65 standard SVOC compounds analyzed by the HML lab, none were detected in the virgin product samples. Bis-(2-ethylhexyl)phthalate, butyl benzyl phthalate, and di-n-butyl phthalate were detected in the in-service transformer samples. These compounds were suspected to be contaminants introduced from the sampling equipment and DI water used. Other tentatively identified compounds were various sterols normally found in vegetable oils.

Barium and zinc were detected in the virgin product samples at 26 mg/kg and 36 mg/kg, and at 11 mg/kg and 24 mg/kg, respectively. Barium and zinc were also detected in two in-service transformer samples at 25 mg/kg and 27 mg/kg, and at 12 mg/kg to 13 mg/kg, respectively. Cadmium and molybdenum were detected in one in-service transformer sample at 0.42 mg/kg and 2.6 mg/kg, respectively. The barium and zinc might have been introduced during the processing of the basestock oil, degassing of the oil, or storage in the finishing tank.

Worker Health and Safety

When comparing the PPE requirements for handling Envirotemp®FR3™ fluid to select mineral oil-based transformer fluids, these requirements were found to be similar. This comparison is based on MSDS information for select mineral-oil-based transformer fluids obtained from the Vermont SIRI MSDS archive. However, respiratory protection for the mineral oil-based transformer fluids is required at a lower nuisance particulate OSHA PEL than Envirotemp®FR3™

fluid. Envirotemp®FR3™ fluid also has less stringent PPE requirements for workers compared to select silicone oil-based transformer fluids found in the Vermont SIRI MSDS archive.

The ingredients for Envirotemp®FR3™ fluid appear to have less serious health effects listed than those for select mineral oil-based and silicone oil-based transformer fluids reviewed as part of this verification/certification. These select mineral oil-based transformer fluids listed a hydrotreated light naphthenic petroleum distillate, which is an IARC confirmed carcinogen. The silicone oil-based transformer fluids listed dimethyl polysiloxane as the primary ingredient, which is a teratogen in animals. The end-user must comply with all applicable worker health and safety regulations for this product.

Estimated Cost of Using Envirotemp®FR3™ Fluid versus Mineral Oil

The initial purchase cost of a new transformer unit containing Envirotemp®FR3™fluid is approximately 1.2 to 1.3 times more than a comparable mineral oil transformer. Envirotemp®FR3™ fluid costs approximately \$5 to \$8 more per gallon than mineral oil-based transformer fluid depending on the volume purchased.

Section 7. Vendor's Comment Section

The following information was provided by Cooper Power Systems. The purpose is to provide the vendor with the opportunity to share their comments on their environmental technology verification report. This information does not reflect agreement or approval by U.S. EPA and Cal/EPA.

Vendor's Comment:

The aquatic toxicity test performed by the California EPA is not in accordance with the recommended sample preparation method for insoluble materials cited in the California Code of Regulations. Rather than using the appropriate solvent blending method for insoluble materials, they instead created an emulsion by extreme blending (several hours) of the vegetable oil based Envirotemp FR3 fluid with water. The resulting heavy emulsion produced is a physical hazard to fish. This prevented any evaluation of possible toxicological effects of the product.

Testing of acute aquatic toxicity on Envirotemp FR3 fluid was performed by an independent laboratory using the appropriate sample preparation method for insoluble materials. The tests resulted in a zero mortality of the trout fry throughout the test duration (96 hours).

We believe that it is essential that the acute aquatic toxicity test method be used for its stated purpose, the determination of relative systemic toxicity, and not misused to test physical hazard. Our environmental claim involving acute aquatic toxicity was limited to relative toxicity. Cooper Power Systems stands by its Verification Claim #4 submitted to the California EPA that Envirotemp FR3 dielectric coolant is not toxic to trout fry.

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