Backup Power Working Group Best Practices Handbook for Maintenance and Operation of Engine Generators, Volume 1 (U)

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DOE BACKUP POWER WORKING GROUP

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FORWARD

Chapters in this handbook are intended to supplement original equipment manufacturer (OEM) information and practices primarily for stationary gasoline and diesel engines. The guidelines presented in the following chapters were based on available literature and the experience of the Engine Generator Subcommittee members. Hopefully, this and subsequent volumes will promote consistent best practices throughout the DOE complex in meeting the requirements contained in DOE-STD-3003-94, DOE Standard Backup Power Sources for DOE Facilities.

This document is suitable for voluntary use by engineers responsible for Backup Power Sources at DOE facilities.

Beneficial comments, including additions, deletions or corrections are encouraged and may be forwarded to the BPWG through Mr. John Fredlund, DP-45 GTN, U.S. Department of Energy, Germantown, MD 20874-1290; (301) 903-3059, FAX (301) 903-8754.

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CHAPTER 1

Diesel Fuel Oil

Peter Fairchild, Robert Gross

I. INTRODUCTION

1. Background / Purpose

Diesel engines have a high incidence of failure resulting from poor diesel fuel quality. Since standby diesel engines do not run continuously it is necessary to implement periodic surveillance's to ensure the quality of diesel fuel is acceptable for reliable operation when a loss of power occurs. The information contained in this volume is a compilation of best practices to be used as a guide to design and maintain a reliable diesel fuel system.

2. Engine Effects

Fuel oil normally recommended by engine vendors and used most commonly in backup power diesel engines is diesel fuel oil grade No. 2-D or DF-2. NFPA 30 designates grade 1-D and 2-D diesel fuel oils as Class II combustible liquids having flash points of 100 to 140 degrees Fahrenheit.

The diesel engine fuel system is sensitive to various design aspects, to contamination, or to poor fuel quality that may cause the engine to fail to perform its design function. Excessive water, dirt, debris, oxidation products, and microbiological growth can cause plugged filters and early fuel injector failure. Water and dirt are especially destructive to the tight clearances and valve seat arrangements in modern fuel injectors. Erosion and corrosion of valve seats and lapped metal-to-metal interfaces cause poor combustion, smoke, and high or low combustion temperatures in the cylinder. A poorly adjusted or performing injector can wash the cylinder walls of its lubricating oil film causing premature wear and failure of piston rings, pistons and cylinder liners. It is important to realize that over an extended period of time diesel fuel oil will degrade through oxidation and from normal condensation buildup in the tank. Since the rate at which diesel fuel degrades is unpredictable, it is important to take the necessary precautions to increase fuel system reliability. Good design, preferred fuel properties, sampling, testing and maintenance all contribute to fuel quality that can maintain your diesel generator as a reliable backup power source.

Specifications and publications are listed in the text and in the reference section which may be consulted for further guidance.

II. DESIGN CONSIDERATIONS

1. Tank Construction

NFPA-31 recommends using a low pressure tank defined as storage tanks designed to withstand internal pressures above 0.5 psig but not more than 15 psig measure at the top of the tank. They comprise the majority of tanks used for mid-size backup power generators at DOE sites. NFPA-30 gives further recommendations on use of UL listed tanks, vent piping and vent capacity, tank openings, and drainage. Reactive metals such as galvanized steel, zinc, and copper should not be used in fuel system construction as these types of metals can serve as an oxidation catalyst with diesel fuel.

NFPA-37, Stationary Combustion Engines and Gas Turbines, provides minimum thickness of steel for tanks, and requires a curb or dike or double wall tank to contain the tank contents should the tank rupture or leak. If a dike is used it should be sized to contain six inches of rain water as well as the fuel volume of the tank.

Piping should be in accordance with NFPA-30 to provide sufficient valves for controlling the flow of liquid fuel during normal operation and to shut off flow in the event of a pipe break. API Standard 650, Welded Steel Tanks for Oil Storage contains further details on the materials, design, fabrication, and inspection of diesel fuel tanks. If modifications are made to a tank subsequent to initial construction and testing, re-verification of tank tightness is highly recommended. API 650 provides more detail on testing methodology.

For larger tanks, or those underground that may be difficult to access, an installed filtration system is recommended. In the event that a tank becomes contaminated with particulate, sediment or water (either free or absorbed), filtration with filters as small as 0.3 to 0.8 micron pore size may be required to clean the fuel to like new condition. A filtration system designed to handle any contamination problem should consist of a coalescer filter to remove free water, a small particulate filter and a clay filter element to polish the fuel of absorbed water. If the tank design is equipped properly, sampling can be accomplished from this flow loop if suction lines are installed to the appropriate sample locations.

2. Supply Tank Connections

Supply tanks may be sized based on the facilities requirements for operation at the diesel generator's continuous rating. Nuclear Regulatory Guide 1.137 and ANSI/ANS 59.51-1989 may be consulted for further guidance.

The fuel supply line to the diesel generator should be sized and piped in accordance with the engine vendor's specifications. Generally, fuel supply level, supply and return lines should be kept below the centerline of the engine's fuel injectors to prevent siphoning. However, the fuel level must not be such that it exceeds the lift capability of the attached engine fuel pump. The vertical distance the pump needs to lift, total length and size of pipe and fittings, and elevation above sea level are all important when calculating whether the lift pump's capability will be exceeded. The Diesel Engineering Handbook provides a general rule of thumb that when the tank is placed below the engine, the suction lift imposed on the engine fuel pump should not be over six feet.

A fuel return line allows unused fuel to return to the supply tank. Since this fuel has been through the engine's fuel system and used to cool the injectors and fuel pump, it must be returned to a large enough volume of fuel so that fuel temperature does not rise appreciably. Elevated fuel temperatures will accelerate fuel oxidation and stability. It should be recognized that every 10 degrees F rise in fuel temperature above 90 degrees F, engine horsepower output is reduced by 1%. Fuel injection equipment will be poorly lubricated and inadequately cooled if the fuel temperature rises above 125 degrees F. A typical fuel supply system is shown in the EGSA handbook.

3. Sloped Tanks

Tanks should be sloped approximately 1/4-1/2 inch per foot of tank length away from the fuel supply connection to provide space for water and sediment to collect. Figure 1 shows a sloped underground (UG) tank. Both UG and aboveground (AG) tanks should be sloped similarly. Accumulated bottom sediment and water will clog filters and harm fuel injectors if allowed to enter the engine supply piping. It is important that the tank construction does not prevent water and sediment in the tank bottom from flowing down the slope to the low point. Drain valves are normally installed on the tank bottom. A sampling connection should be made available at the same level as the tank's fuel outlet to engine fuel pump or sample access should be provided at the top of the tank. This will allow drawing periodic samples for sediment, water and particulate analysis.

4. Heat Tracing

Adequate heating should be provided, or other suitable means made available to maintain the fuel oil in a usable and ignitable condition in the coldest months. This may be accomplished, according to Nuclear Regulatory Guide 1.137 by using an oil with a cloud point lower than the 3-hour minimum soak temperature expected at the site, or by keeping onsite fuel oil above the cloud point temperature. Heat tracing and insulation of exposed fuel tank and piping are desirable for maximum reliability. Federal Specification VV-F-800D Fuel Oil, Diesel, Appendix A, provides 10th percentile minimum temperatures for regions of the country from September through March. Satisfactory operation should be achieved if the cloud point is specified at or below the 10th percentile minimum temperature.

5. Flame Arrestors

Underwriter Laboratories, Inc. (UL) or Factory Mutual (FM) listed flame arrestors should be utilized on all vent openings. Vent lines should not be less than 1.5 inches in diameter, and should comply with NFPA 30, Flammable and Combustible Liquids Code or API Standard 2000, Venting Atmospheric and Low Pressure Storage Tanks. OSHA 1910.106 and NFPA 30 discuss typical emergency vent flow capacity. Typical vent valves and flame arrestor configurations are available from the BPWG.

6. Alarms and Indicators

Level indication is necessary to determine by visual inspection or other means the fuel level in the tank. Warning lights, or alarm lights are recommended for high and low tank levels. Low levels affect operability while high levels may indicate an impending overflow condition. Expansion of the fuel due to daytime temperature rise should be

anticipated. Sufficient expansion space should be available if tanks are filled to about 7/8 full. The rupture basin, or dike, that captures the tanks contents if the tank were to fail, can be monitored and may be alarmed to signal an overflow or leak into the basin.

III. PROCUREMENT QUALITY

1. Effects of Properties on Diesel Engine Operation

The purpose of receipt sampling is to verify the delivered product has the correct properties for diesel operation and to screen for contamination problems. Sediment and water and visual appearance are checked to detect contaminated fuel oil. The viscosity of the fuel oil has a strong influence on the spray pattern through the injectors while the API Gravity is an indication of the energy content in the fuel. As long as the fuel is relatively clean, of the appropriate energy content and has the proper flow characteristics, it is acceptable to off-load the fuel at risk until the other parameters can be analyzed. For more information on how fuel properties affect diesel engine operation see the ASTM Manual on Significance of Tests for Petroleum Products, MNL-1, or SAE J313 DEC87.

2. Engineering Requirements

When purchasing diesel fuel for a stationary D/G it is important to request a Certificate of Conformance (CoC) or equivalent that references the purchase agreement. A CoC is used to verify there is a clear understanding between the buyer and the vendor as to what is being requested and what is being delivered. Most vendors do not perform fuel analysis on their deliveries, consequently, CoC provided with each load of fuel typically reflects what the vendor intended to deliver and not tested parameters for that particular batch.

Unless the engine manufacturer has fuel requirements that are more restrictive, fuel oil should be purchased to meet the parameters listed in Table 1. See ASTM D 975 or Federal Specification VV-F-800D for more information and to specify the Cloud Point maximum based on the region of the facility. It is also important to state in the purchase agreement that the fuel delivery tanker must be clean and dry prior to loading the diesel fuel oil. This should prevent cross contamination with fertilizers, gasoline, heating oil or other products the vendor may distribute from the same tanker.

Table 1- New Product Specifications#

Flash Point, degrees F , min.	125
Water / Sediment, % by vol.	0.05
Cloud Point , max.*	see below
Carbon Residue, 10% residuum %max.	0.35
Particulate Contamination , mg/L	10
Distillation, degrees F, 90% min.	540
90% max.	640
Ash , weight %	0.01
Kinematic Viscosity cSt @ 40 degrees C	1.9-4.4
Sulfur weight % max.	0.5
Cu Strip Corrosion , max.	No. 3
Cetane Number, min.	40
Visual Appearance	clear/bright
API Gravity	27-39

* Regional- see ASTM D975 or VV-F-800D for guidance

Each parameter is subject to change if the above standards are revised.

3. Receipt Sampling

All fuel for safety related diesel engines should be sampled on receipt. When the fuel shipment is sampled and how the sample is obtained will depend on the logistics of delivering the fuel at each facility. A facility can request that a vendor wait while the initial analysis is performed or a facility may sample a fuel delivery ahead of time and control the batch until it is unloaded at the site. It is essential that a representative sample of all fuel is taken and the load of fuel is monitored or secured from the time it is sampled until the time it is unloaded. If the fuel is delivered by truck or by rail a composite sample consisting of equal parts from the lowest point of each compartment should be obtained. ASTM D270 or D4057 can be used as a reference for sampling methods or standard procedures can be obtained from the Backup Power Working Group. Approximately one to two liters of fuel is required for laboratory testing. The exact quantity depends on the laboratory that performs the fuel analysis.

4. Receipt Analysis

Each load of diesel fuel should be analyzed to verify it meets each property specified in the purchase agreement. The following properties should be analyzed as a minimum prior to loading fuel to a facility tank:

- 1) Verify the diesel fuel is clear and bright
- 2) Sediment and Water- 0.05% max.
- 3) Kinematic Viscosity -1.9-4.4 cSt @ 100 degrees F
- 4) API Gravity- 27-39 degrees API

The diesel fuel should be "Clear and Bright" as described in ASTM D4176. The ASTM distributes a card to be used as a visual guide. The card is placed behind the fuel sample as an aide in grading a sample's clarity. The card is very helpful in quantifying this inspection per D4176 on a scale from 1 to 5. Using the D4176 card, a fuel equal to or higher than a 3 should be rejected. It is important to realize that clear and bright determinations are made regardless of the color of the fuel, and as long as the fuel is translucent a clear and bright determination can be made. Any fuel oil with sulfur levels above 0.05% by weight may be dyed red, and for a brief period after the Clean Air Act was implemented in October of 1993 the higher sulfur fuels were dyed blue. Although these fuels may not be of traditional color, a practical approach is to grade the clarity as long as the card can be seen through the sample. There may be future guidance concerning fuel analysis on dyed diesel fuels as more research is completed.

All other properties in the purchase agreement can be analyzed within one to two weeks after the fuel has been unloaded. Diesel Fuel Stability testing (ASTM D2274) is not recommended as it can be misleading when applied to backup power supplies, since periodic additions to a diesel fuel tank are often required. There may be differences in each load of fuel depending on where the crude oil was drilled and where the diesel fuel was refined; any addition to the tank can invalidate previous test data once the diesel fuels are mixed. The better approach is to periodically check for particulate contamination and remove or clean up the particulate contamination before it jeopardizes operability.

IV. DIESEL FUEL STORAGE

A quarterly particulate analysis and a monthly check for accumulated water is recommended while the diesel fuel is stored on site. Most of the other properties will not drastically change and do not warrant performing periodic analysis as long as any fuel added to the tank meets the procurement specification. The quality of diesel fuel in extended storage can be unpredictable due to the accumulation of particulates resulting from oxidation. Each time new diesel fuel is added to an existing stock the risk of accelerating the oxidation process is present. The best maintenance for diesel fuel oil is consumption of the fuel. It is extremely advantageous to establish a load test schedule that will "turn over" the fuel tank contents in one year or less. In many cases this is not practical and periodic surveillances are necessary to verify the fuel quality.

Checking for water contamination is required as water will collect due to normal condensation on the tank walls and in some cases, water may seep into the fuel supply if the water table is high enough at the tank location. The best practice is to remove all water to keep the tank water-free and treat the fuel with biocide. If fuel tank levels are maintained near full, condensation on the tanks free surface area can be minimized. This will prevent most problems associated with water contamination of diesel fuel. Some facilities periodically test for microbiological growth, but if the tank is kept water-free and treated with a biocide the risk of *microbiological contamination* is minimal. If the tank is treated with a biocide and is water free, periodic testing for microbiological growth is probably unnecessary unless a problem is suspected or if sampling detects water that cannot be removed. Caution should be used when sampling for water as some ribbed tanks or underground tanks that have shifted in the soil may hold water in locations that go undetected when sampling.

1. Treatment with Biocide and Stabilizer Additives

Biocides and stabilizers are used commonly throughout the industry to prevent degradation of the fuel when stored for longer than six months. When purchasing a biocide or stability additive package it is important to use additives that are developed for diesel fuel oil. It may be helpful to restrict the purchase to vendors providing additives that conform to MIL-S-53021 since the military has proven the effectiveness of these products.

Stabilizers are used to inhibit oxidation of the fuel oil. When chemically unstable diesel fuel oxidizes, it precipitates insoluble particulates and gum which can clog fuel filters and foul diesel engine injectors. Most diesel fuels available are chemically cracked, of lower quality than a straight-run product, and have a shelf life of about one year. After one year the fuel oil can become highly susceptible to oxidation. Since the time a fuel spends at a depot cannot be controlled, shelf life of the fuel is a significant problem. Stability additives are recommended to extend the shelf life of the diesel fuel. Trying to predict how long fuel can be stored is a complex problem with many variables, but commercial power plants have experienced satisfactory storage periods of up to one year when stability additives were used. Furthermore, many stabilizers contain metal deactivators to prevent reactive metals from serving as an oxidation catalyst, dispersants for reducing the size of particulates to prevent filter clogging and corrosion inhibitors to protect the internals of diesel fuel systems.

Biocide additives are very effective by prohibiting biological growth in the water / fuel interface. Eliminating accumulated water is also important as all microorganisms require water to live. A consistent fuel draining program backed by biocide treatment program can significantly lower the risk of having fuel oil contaminated with biological growth.

It is important to realize that biocides and stabilizers are not effective in correcting existing fuel contamination problems. Extreme caution should be taken not to treat a tank that is in service with a known problem. Stabilizers will not reduce the combustible particulates in fuel, but will prevent more particulate from forming in the fuel. Furthermore, if a diesel fuel tank has large microbiological colonies treating the fuel tank with a biocide while it is in service may result in engine failure if the colonies are killed and float to the engine suction line. If a tank is known to have severe to moderate biological growth problems the tank should be taken out of service and cleaned prior to adding a biocide.

2. Cold Weather Considerations

During periods of cold weather a standby D/G could experience operational problems if the temperature of the fuel falls below the cloud point of the diesel fuel. The cloud point is the temperature at which the paraffin in the fuel crystallizes. Wax crystals can plug the diesel fuel filter, starving the engine of fuel. The maximum cloud point should be based on facility location. In some cases it may be justified to specify a cloud point in the purchase specification based on the probability that an accident will occur on a day the temperature is below the specified cloud point long enough for the fuel to form wax crystals.

A. Cloud Point Depressants

The recommended method of lowering the cloud point is to blend the diesel fuel with kerosene or No. 1 diesel as many of the commercially available cloud point depressants are not effective. Blending with a lighter fuel will lower energy content and will reduce viscosity and lubricating properties. Fuel injectors and pumps may be damaged if operated with low viscosity fuel oil. Calculations should be made to ensure enough of your blended fuel is available to meet minimum run time requirements. Load tests should be performed to verify the D/G fuel system is adjusted to maintain the accident loads since the fuel rate required for a given load will increase. Verifying the quality of the lighter fuel and the final blend may actually double the fuel quality program costs. Minimum viscosity requirements when using blended fuel should be discussed with the engine vendor. Heat tracing and insulation may be the better option.

B. Heat Tracing

The diesel fuel system can be protected against cold weather effects by applying heat trace and insulation to the tank and exposed piping. Heat tracing systems are relatively inexpensive and materials are readily available to install on externally exposed piping and tanks.

3. Sampling Methods

It is recommended to sample a diesel fuel supply for particulate contamination and for water as explained in detail below. Standard procedures for each method can be obtained

from the Backup Power Working Group. Sampling in the appropriate manner and keeping the sample apparatus clean are extremely important. It is generally acceptable to rinse the sample containers and sampling apparatus with the fuel to be sampled. It is not practical to use solvents as recommended in the sampling standards. Any inaccuracies introduced from this practice will be small and conservative in this application as long as good techniques and precautions are taken to prevent contamination of the sample.

A. Sampling for Particulate Contamination.

All diesel fuel supply and day tanks should be sampled for particulate contamination quarterly at a minimum to verify the stored fuel has not degraded from oxidation. For the purpose of particulate analysis samples should be taken no lower than the engine or day tank fuel supply line. The sampling methods used should obtain a average sample from all levels of the tank above the height of the engine or day tank supply line. A long tube with a foot valve can be used for particulate sampling as can a sampling thief (railroad thief) as described in ASTM D270 and ASTM D4057. It is a good practice to place an extension on the bottom of the sampling apparatus to prevent the sample from being taken at the tank low point and to ensure the sample is taken at the appropriate level. The length of the extension depends on the tank construction. When a railroad type sample thief is used, it should be lowered until the extension touches the bottom of the fuel tank. The sampler should then be held open and simultaneously raised at a rate such that the sampler is about 3/4 full when it reaches the surface. The sampler should then be closed and the contents transferred to the sample container.

Some diesel fuels will react to light and will oxidize once the fuel is in the sample bottle. If the sample is not going to be analyzed in a short period of time it should be wrapped in an opaque material to protect it from direct rays of the sun.

The best available method for particulate analysis is the laboratory filtration method contained in ASTM D5452. The older versions of ASTM D2276 contain the same laboratory filtration method. In 1994 the laboratory filtration method was taken from ASTM D2276 and is now ASTM D5452. This method is the best method available but it was specifically developed to measure the particulate contamination in aviation turbine fuels. In the near future a new method will be approved by ASTM that will be a laboratory filtration method specifically for middle distillate fuels. This procedure, Standard Test Method for Particulate Contamination in Non-Aviation Middle Distillate Fuels by Laboratory Filtration is in ASTM committee approval cycle. Once issued by ASTM this will be the most appropriate method for measuring particulate contamination in diesel fuels. The new method will be more repeatable than using D5452 for diesel fuel as diesel fuel typically contains more sediment than aviation turbine fuels. The new method will also allow using a smaller sample which will be easier to handle.

Regardless of which method is used the maximum particulate contamination allowed is 20 mg/liter as recommended by the Military Standardization Handbook, MIL-HDBK-200G, and the EPRI Guide for Storage and Handling of Diesel Fuel for Standby Diesel

Generators. It is important to take corrective action at 10 mg/liter to avoid inoperability if the particulate contamination exceeds 20 mg/liter. It is considered an acceptable risk to allow about two weeks to confirm a failed analysis and to correct an out of limit condition before declaring the D/G set inoperable.

B. Sampling for Water

All fuel supply and day tanks should be sampled for water monthly. Tanks equipped with a low point drain should have a quantity of diesel fuel drained into a bucket and visually inspected. Tanks that do not have a low point drain, such as underground tanks, can be thief-sampled by lowering the sample thief to the tank bottom and collecting a sample. The sample thief can be drained to a bucket for visual inspection as well. It has been industry experience that water finding paste can be inconclusive as the fuel can displace the water from the paste. See ASTM D270 and ASTM D4057 for more information on sampling methods, or contact the Backup Power Working Group for standard procedures.

Any amount of water detected should be removed within 30 days of detection. If all water can be removed, no further action is required if the amount of water detected was not large enough to enter the supply line to the engine. If small amounts of water cannot be removed microbiological testing should be performed periodically. If the amount of water in a tank is large enough such that the water could enter the engine suction line or if significant microbiological growth develops the engine should be considered inoperable. There are no standards for testing diesel fuel for microbiological growth but many commercial test kits are available. Use a test kit from a reputable vendor of diesel fuel test products since the interpretation of the results will be based on the vendor's experience.

V. HANDLING

1. Safety

When loading any diesel fuel tank from the top cover the fuel truck should be grounded to the fuel tank to prevent a static charge from igniting the fuel vapors. Tanks must be grounded to prevent conditions which would result in an oil fire being ignited by electrical sparks and arcs from natural causes. API recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents discusses methods which the petroleum industry is applying for prevention of ignition from these sources.

When using biocide and stabilizer additives see the MSDS sheets and use safe handling practices based on the hazards present.

2. Flashpoint

The flashpoint of the diesel fuel is the temperature at which the fuel will produce a vapor than can be ignited when exposed to an open flame. Minimum limits are typically set to reduce the hazard of storing a combustible material inside a facility. The specified flash point in Table 1 is typically adequate but always evaluate the specified flash point based on facility requirements.

Even though flashpoint is an important parameter from the fire safety standpoint it is not related to the performance of the fuel in a diesel engine. Flash Point testing can detect gasoline contamination of the delivery tanker since the flashpoint of gasoline is much lower than diesel fuel oil (-45 degrees F).

VI. TANK MAINTENANCE

1. Cleaning

Tanks should be cleaned initially to remove all accumulated sediment, and as a minimum inspected and cleaned on a 10 year frequency after that. API Publication 2015, Cleaning Petroleum Storage Tanks provides further guidance. Pressure testing to 1.10 times system design pressure may also be accomplished at the 10 year interval. Regulatory Guide 1.137 provides further guidance on testing.

2. Water Draining

Tanks should be drained of water monthly to minimize corrosion of the inner tank surface, and to ensure that free water does not enter the diesel fuel supply line.

3. Integrity Checks

The facility may wish to implement a planned response to federal regulations in developing a spill prevention, control, and countermeasure plan. Federal Regulation 40 CFR 110, Discharge of Oil, and 40 CFR 112, Oil Pollution Prevention provide further guidance and requirements for any facility that stores or uses oil.

To ensure tank integrity periodically, non-destructive shell thickness tests (UT) may be performed along with a visual inspection of tank supports and foundations for signs of distortion or degradation, and a visual check of the tank's piping and piping connections for signs of leaks or deterioration. Written records are required to be maintained and compared with past and future test and inspection results.

4. Dikes

It is recommended to have a spill containment dike around any above ground fuel tank that is large enough to hold the tank contents plus rain water. A containment pit capable of holding a significant spill should be provided under the truck unloading station. The truck unloading pit should be sized according to the anticipated size of a delivery.

VII. STANDARD PROCEDURES

Contact Backup Power Working Group for standard procedures. The following have been developed:

1. Diesel Fuel Oil Tank Integrity Tests and Inspections
2. Diesel Fuel Oil Tank Flushing
3. Diesel Fuel Microbiological Test
4. Diesel Fuel Oil Sampling for Particulates
5. Fuel Oil Receipt Sampling
6. Sampling Diesel Fuel Oil Supply Tanks for Water
7. Fuel Tanks / Systems Work Safety Practices
8. Diesel Fuel Oil Supply Tank Chemical Addition for Stability and Bacterial Control

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CHAPTER 2

Automatic Transfer Switch Selection

Teresa Lam, Jack Janes

I. INTRODUCTION

This paper describes the different types of automatic transfer switches (ATS) and their associated features. This chapter describes technical considerations and best practices to support proper selection and maintenance of ATS's. The information was developed to support the goal of the Backup Power Working Group to consolidate information on backup power supplies and promote uniformity in their application and maintenance across the DOE Complex.

An automatic transfer switch is one of the basic building blocks of a backup power system. It performs a key role in power reliability. Without an ATS, the load cannot be automatically transferred to an alternate source in case of normal power failure. A power outage can result in loss of crucial equipment. Typical applications in the DOE complex include transferring power sources for ventilation and environmental systems in radiological areas, chemical process equipment, power distribution equipment and computer systems.

There are different types of transfer switches available with various options. Selection of a new or replacement ATS requires a thorough understanding of the facility, where the switch will be installed, and the technical attributes of ATS's. An evaluation of the facility's electrical system should be performed to determine the ATS specifications which satisfy the technical requirements and cost considerations for a particular location and application.

II. GENERAL CONSIDERATIONS

1. Types of Transfer Switches

Automatic Transfer Switches

Automatic transfer switches (ATS) are primarily used for emergency and standby power generation system rated 600V or less. Automatic transfer switch ratings range from 30A to 4000A. An automatic transfer switch is designed to switch connected loads between normal and alternate power sources without an operator's involvement. The alternate power source can be another power utility feed or a backup power supply (e.g. uninterruptible power supply (UPS), diesel generator set (D/G set)). The presence of the normal power is continuously monitored by an ATS. When the ATS senses a significant drop in voltage, typically 80% of nominal voltage, the ATS begins to transfer to an available and acceptable alternate power source. If a generator set is used as the backup power supply, the ATS control will signal the generator set to start. As the generator set starts, the ATS will monitor generator voltage until it reaches an acceptable level (typically 90% of the rated voltage and 95% of the rated frequency). When the predetermined voltage requirements are satisfied, the ATS disconnects the load from the normal power source and connects it to the alternate source. When normal voltage is restored to a predetermined level, the load is transferred back to the normal power source. If a generator set is used, the ATS control circuit may send a shutdown signal to the generator set after a time delay to allow the generator set to cool down properly. This transfer and re-transfer of the load are the two most basic functions of transfer switch. Options purchased with the ATS can expand or decrease the capabilities of the switch.

Manual Transfer Switches

Transfer of load can be performed with a manual transfer switch. Using a manual transfer switch, an operator must be present. There are two types of manual transfer switches, the first type has a quick-make/quick-break operating handle. The handle can be accessed from the exterior of the switch enclosure. The switch has three positions: normal, alternate, and center. The handle set to the normal position causes the normal power source to be connected to the load. Setting the handle to the alternate position causes the alternate power source to be connected to the load. If the alternate source is a generator set, The generator set has to be started and an acceptable voltage and frequency must be established before transfer. The handle set to the center position isolates the load from either source and the load is de-energized.

Another type of manual transfer switch is electrically operated with a remote control device. This transfer switch will connect to the selected source only if voltage is present at the source. Using the manual transfer switch is a supervisory operation. It requires additional events to take place along with switching between the two power sources. This type of switching has a long interrupting time and should not be used for an emergency system. Emergency systems are defined in article 517 and article 700 of National Electrical Code and NFPA 99. Emergency systems are those required by law to automatically supply alternate power to equipment that are vital to the protection of human life. The automatic restoration of electrical power must be completed within 10 seconds of power interruption.

Bypass Isolation Transfer Switches

There are two types of bypass-isolation switches. One type momentarily interrupts load during bypass. The other type bypasses without load interruption (non-load break design is also referred to as a bumpless transfer). The function of a bypass isolation switch is to bypass the ATS by supplying either normal or backup power directly to the load while isolating the transfer switch electrically and mechanically for maintenance and testing. Bypass-isolation switches (non-load break design) allow the ATS to be temporarily removed for repair without physically disconnecting power conductors. Bypass-isolation switches (non-load break design) are used in critical circuits of a backup power system. Hospitals, communication facilities and airports have used bypass isolation switches for years to maintain continuity of power during corrective maintenance and permit performance of routine preventive maintenance. The DOE complex, however, has not commonly used bypass isolation switches. As a result, facilities have neglected recommended preventive maintenance and have experienced unnecessary outages during corrective maintenance.

The bypass-isolation switch is manually operated and used in conjunction with an ATS. It is a manual transfer switch in parallel with an ATS. It can be part of an ATS package or it may be a separate switch.

The ATS can be isolated from the bypass switch. When the ATS connects to a normal power source, the bypass contacts also close to the normal power source. This allows an alternate current path to the load through the bypass switch. The ATS could now be opened and isolated. Because the power conductors of the ATS itself are not connected to any power source or load at this point, the ATS can be serviced without affecting power supply to the load.

2. Control Devices and Option Accessories

Most major ATS manufacturers have standard options for their switches. The options selected depend on cost and loading requirements.

Time Delays

Time delays are used extensively in ATS applications, and can range from a few seconds to 30 minutes. Time delays are crucial in many applications to allow stabilization and coordination of equipment. Most of the time delays are included as standard on ATS.

Start time delays are used to override monitored source deviation. It prevents the starting of an engine or transfer of load during momentary voltage dips. Timing starts the moment of normal power interruption or dip. If the duration of the interruption exceeds the delay time, the control system signals the generator set to start. Start time delay should not be set greater than few seconds for Emergency Systems, since NEC requires that automatic restoration of electrical power to be within 10 seconds of power interruption. Delays should be long enough to prevent response to voltage sags due to nearby faults or to momentary loss of voltage due to operation of reclosers in the electrical distribution system.

Transfer time delay allows adequate time for stabilizing of the generator set at the rated voltage and frequency before the load is applied. The range for adjustment is between 0 to 5 minutes.

Retransfer time delay allows time to stabilize the normal power source before accepting load. This also allows the generator set to operate under load for a minimum time and prevents multiple transfers during a temporary power recovery. The range for adjustment is between 0 to 30 minutes.

Engine warmup time delay allows time for automatic warm up of engines prior to loading during testing. This feature is not available from all ATS vendors. Frequent loading of cold engines (including those with jacket water heaters) may increase wear and thermal stresses in engines. Since standby engines normally accumulate a relatively small number of operating hours, the added wear and stress may not be of concern, especially for small and medium sized engines.

Stop time delay allows the generator set to cool down at no load conditions before stopping. This feature minimizes the possibility of a trip and in some cases an engine lockout due to an increase of the cooling water temperature after shutdown of a hot engine. It also permits the control system to conform to vendor recommendations for operation of larger engines. The delay logic also permits an immediate transfer of load back to the generator set if normal power source is lost during the cool down period. The range for adjustment is between 0 to 10 minutes. This delay feature should be specified on all ATS's associated with diesel generators.

In-Phase Monitor

This device monitors the relative voltage and phase angle between the normal and alternate power sources. It permits a transfer from normal to alternate and from alternate to normal only when acceptable values of voltage and phase angle difference are achieved. The advantage of the in-phase transfer is that connected motors continue to operate with little disturbance to the electrical system or to the process. It prevents residual voltage of the motors from causing an out-of-phase condition between two power sources. The phase difference can cause serious damage to the motors or driven loads. Transferring power to a source which is not in phase can result in an excessive current transient which may trip the overcurrent protective device or blow a fuse.

In-phase transfer is principally suited for low-slip motors driving high inertia constant loads on secondary distribution systems. Using in-phase monitors does not always provide a reliable solution to problems involved when using an ATS with some uninterruptible power supply (UPS) for reasons discussed in the next section. Some vendors provide different in-phase monitor modules, depending on whether the alternate power source (i.e. diesel generator) has a governor which operates in isochronous or speed droop modes. In-phase monitoring used as a gate to transfers generally works well with isochronous but not with droop-type governors.

This option should be considered for all ATS applications which will supply large motor loads and will not tolerate momentary interruptions (see next paragraph). The cost for this option is relatively low and, in some switch designs, the cost of a later retrofit may be quite high.

Motor Load Disconnect Control Device

This device initiates the opening of a pilot contact before transfer from either source, and then provides a timed closure after transfer. This will disconnect motors before transfer and reconnect the motors after transfer. It prevents residual voltage of the motors from causing mechanical shock to motors and driven loads and excessive current surges as described in the previous section.

This device is especially useful for ATS's which supply both motor and UPS loads and is recommended by most UPS vendors in this situation. During a loss of normal power, UPS control systems normally automatically turn off the gate drives of the silicon control rectifiers (SCR's) which control the DC voltage produced by the UPS inverter. Upon restoration of normal power, the UPS control system resets and sequences the inverter back to operation in a controlled manner. The residual voltage generated by induction motors during ATS switching may prevent the UPS from sensing loss of normal power. An instantaneous phase shift in the supply voltage which may occur during the switching can result in the SCR's producing a DC voltage sufficiently high to trip the UPS. Since the inverter output is also likely to be out of phase with the supply voltage at this time, static bypass switches may fail to transfer to the bypass supply.

The motor load disconnect control device can be used to send a loss of voltage signal to a UPS prior to operation of the ATS. This will permit the UPS inverter to shutdown and restart in the normal sequence. Motor loads, on the other hand, will not experience a loss of voltage and will continue to operate during the transfer. If it is desired to trip motors for load shedding or other purposes, the disconnect control device can be used for this function.

Program (delay) Transition

Program (delay) transition extends operation time of the transfer switch mechanism. A field adjustable setting can add an appropriate time delay that will momentarily stop the switch in a neutral position before transferring to the energized source. This will allow the motors to coast down and transformer fields to decay before connection to the oncoming source. This also reduces possible circuit breaker tripping and fuse blowing when transferring large inductive loads. This is another preferred device to be used with UPS applications as described in the preceding section. The feature avoids the need for control cables and devices to be tripped which is required by a motor load disconnect control device. However, motors which must be restarted will require appropriate control circuitry or sequencing equipment.

Closed Transition Transfer (Parallel Transfer)

Closed transition transfer momentarily parallels the two power sources during transfer from either direction. It closes to one source before opening to another. In this application, a transfer must be protected by other devices, such as in-phase monitor or active synchronizer. This type of transfer requires the sources be properly synchronized by voltage, frequency, and phase angle. Without proper synchronizing, close transition transfer can damage both supplies, and may cause a safety concern for personnel.

The applications of closed transition transfers include transferring the system in anticipation of a potential power outage, load switching for electronic load, motors and load curtailment systems.

Test Switches

Regular testing is necessary to maintain the backup power system, and to verify its reliability. It can uncover problems that could cause a malfunction during an actual power failure. The test switch is a switch for simulating failure of the normal power source. Activation of the test switch will start the transfer of the load to the alternate power source and then retransfer when the test switch is returned to the normal position or after a selected time delay. The advantage of a test switch is that it does not cause a loss of power to connected loads as it would if the main disconnect were opened to simulate a failure. It also allows the system to be proven under controlled conditions. It is not uncommon for the connected load characteristics to change over time, either by planned expansion of the system or by inadvertent connection of new loads. A periodic controlled function test insures the performance of the system.

Exercise Clock

Exercise clock is a programmable time switch. It automatically initiates starting and stopping of the generator set for scheduled exercise periods. The transfer of load from the normal to alternate source does not necessarily take place but is recommended in most cases.

Voltage and Frequency Sensing Controls

Voltage and frequency sensors, controls and meters add additional useful features to an ATS. The voltage and frequency sensing controls usually have adjustable settings for under and over conditions. The meters offer a precise indication of the voltage and frequency. The sensing controls provide flexibility in various applications.

III. TECHNICAL CONSIDERATIONS

1. ATS Required Capabilities

The ATS is usually located at the main or secondary distribution bus which feeds the branch circuits. The design and rating of a particular switch must include the following considerations.

Close Against High Inrush Currents

When a transfer switch closes on an alternate source, the contacts may be required to handle a substantial inrush of current and depends on the connected loads. In the case of a motor load, inrush current will be six to eight times the normal current. If the two power sources are not synchronized, or the residual voltage of the motor is 180 degrees out of phase with the source, the motor may draw as much as fifteen times the normal running current.

A minimum contact bounce will occur during switching. The contact material must have adequate thermal capacity so that melting will not occur as a result of high inrush current. Underwriters Laboratories (UL) Specification UL 1008 requires the use of a transfer switch capable of withstanding inrush current 20 times full load rating.

Withstand and Closing Rating (WCR)

When a short circuit occurs in a power system, a surge of current will flow through the system to the fault until the fault clears by a protective device opening. If the device supplying the transfer switch opens, the transfer switch will sense a loss of power and initiate transfer to the alternate source. On closing to the alternate source, the transfer switch will then close the source onto the fault. The entire available fault current from that source may flow through the switch. Devices designed to maintain the fault current have a withstand and closing rating or WCR. Transfer switches should be able to safely carry current under fault conditions and to close onto the fault and remain operational. Underwriters Laboratories sets minimum acceptable performance level for transfer switch WCR.

Carry Full Rated Current Continuously

Transfer switch must continuously carry current to critical loads for a minimum life of 20 years.

Complete temperature tests should be performed on the ATS to ensure that overheating will not occur. The maximum continuous load current should be estimated in selecting a transfer switch. The selected transfer switch should be able to carry continuous load current equal to or greater than the calculated value and is rated for the class of the connected load.

Interrupt Current

An arc is drawn when the contacts switch from one source to another under load. The duration of the arc is longer when the voltage is higher and the power factor is lower or

the amperage is higher. This arc must be properly extinguished prior to the contacts connecting to the other source. Arc interrupting devices such as arc splitters are often used. Wide contact gaps are also used to extinguish an arc. The ATS must be able to interrupt load current unless only no-load transfers will be allowed.

2. Additional Characteristics and Ratings of ATS

Rating Based on Load Characteristics

A transfer switch is rated based on various classes of loads. Most ATS's should meet all or some of the classifications as defined in UL 1008:

- A. Total system load consisting of any combination of motors, electric discharge lamps, electric heating (resistive) loads, and tungsten lamp loads, provided the latter does not exceed 30 percent of the continuous current rating of the transfer switch equipment.
- B. Tungsten lamp load consisting entirely of tungsten lamps.
- C. Electric discharge lamp load consisting entirely of electric discharge lamps.
- D. Resistive load consisting of heater and other non-inductive loads in which the inrush current does not exceed 150 percent of the continuous current rating of the switch.

NEMA Classification

Transfer switches are classified as NEMA Type A or NEMA Type B. The Type A transfer switch will not provide required overcurrent protection. An overcurrent protection device should be installed ahead of the ATS to clear fault current. The Type B transfer switch is capable of providing required overcurrent protection within the transfer switch.

System Voltage Ratings

The system voltage rating of transfer switches is normally 120, 208, 240, 480, or 600 VAC, single phase or polyphase. Standard frequencies are 50-60 hertz.

Seismic Requirement

Some DOE sites have specific seismic requirements for certain facilities. Normally, the ATS Manufacturer does not have their ATS seismic qualified. However, there are many vendors who specialize in seismic qualification. The ATS can be taken to those vendors for seismic qualification testing.

3. Cost of Outage

When a facility chooses not to use an automatic transfer switch or use only manual transfer switch for its backup system, processes may be stopped due to a power interruption. Some processes can not be re-started automatically due to their design, and may require extensive effort to restart. The costs of restoring normal conditions can

add up and exceed the cost of an automatic transfer switch. On the other hand, some processes are manned and can recover from short term outages easily. In these cases, a automatic transfer switch may not be required or a manual transfer switch may adequate.

4. Maintenance

A preventive maintenance program for the ATS is needed to minimize the probability of a major malfunction in the power system. The goal for a good PM program is to check and test the components to eliminate failure.

Preventive maintenance should include the following:

- A. Testing the emergency power system under conditions that simulate a normal power source failure. This can be done using the test switch on the ATS. Transfer switches should be operated at least once a month.
- B. Visual inspection should be performed on all electrical panels and components at least once a year. Check for loose/frayed control wires and damaged insulating parts. Look for welded or eroded main/arcing contacts and signs of arcing between live parts and to ground. Check for misalignment or incorrect contact surfaces.
- C. Thermographic analysis of the ATS should be performed under normal power conditions at least once a year. Examining ATS for hot spots using a thermographic image system will reveal the overall condition of the ATS. This inspection is not a substitute for visual inspection of switch contacts since direct thermographic observation is usually blocked by arc chutes or shields.
- D. Inspect for excessive dust, dirt, moisture (or evidence of moisture), or other contamination at least once a year. Dust and dirt can cause malfunctions in ATS. They should be cleaned with a vacuum or wiped with a dry cloth. Compressed air should not be used because flying dust and particles can get into other parts and cause further problems.
- E. Transfer switches may require re-lubrication when exposed to severe dust or abnormal operating conditions. Re-lubrication should be performed only to manufacturer's guidelines and use manufacturer's recommended lubricants.

Maintenance is most effective when the cause for a condition is determined and corrected. If equipment conditions show signs of deterioration, it should be repaired or replaced with manufacturer-recommended replacement parts. Diagnostic information in a manufacturer's instruction manual should be used and followed.

Safety precautions should be observed when performing maintenance on the ATS. Due to the design of the ATS, many ATS's have exposed energized buses or operating mechanisms inside the cabinet door.

Hazardous voltages will be present in the ATS during inspection and testing. Safety glasses and safety shoes should be worn at all times, low voltage gloves shall be used when working on or near energized circuits.

When transferring an energized ATS, workers should never stand in front of the ATS, but should stand to the hinged side of the ATS cabinet door. An electrical arc / blast can occur during switching if there is component failure. A strong fault can create a fire ball and the pressure can swing the door open. There is a potential for this blast to cause death or severe burns.

Maintenance personnel should never stand in front of an open ATS cabinet door during switch operation. Most new ATS designs have control components mounted on the door away from power carrying conductors. The control devices can be easily disconnected for troubleshooting with instruments of special test boxes. It may occasionally be necessary to use recording devices to perform measurements during troubleshooting of control circuits in older switches where control components are hard-wired and adjacent to high power conductors and moving components.

An ATS is also connected to two power sources. When performing work requiring a de-energized ATS, make sure that **BOTH** power sources are disconnected, locked out and tagged out. Always verified absence of voltage before starting work.

IV. RECOMMENDATIONS

This paper has described various types of transfer switches and their associated components. It is important for the users to establish their practical needs for a given system. The selection process would be easier when the system requirements are pre-determined.

When selecting an ATS and hardware, the following criteria are recommended:

1. Unsupervised transfer switches can transfer the load within 6 cycles. This might cause damage to motors if additional synchronized devices or controls are not used. When the transfer is out of phase, severe mechanical and electrical stress may be experienced by the motors, and can cause motor winding insulation to fail. Excessive torque may also cause damage to motor coupling or loads. Protective devices may be actuated which would cause loss of load.
2. Cost will rise as more hardware and options are selected. Select only components needed by the system or demanded by regulatory requirements. Cost of wear and maintenance to other components such as diesel engines may justify timing modules which facilitate routine testing.
3. Continuous operation of an uninterruptible power supply (UPS) system should be maintained by selecting an ATS with motor load disconnect control devices or ATS with program (delay) transition.
4. Future expansion and load growth should be taken into consideration.
5. Equipment design must consider maintenance requirements. Bypass-isolation switches are relatively high cost options but may be necessary if proper maintenance is to be performed when loads cannot be de-energized. The control circuit design should permit safe and thorough trouble shooting without de-energizing loads or requiring electricians to work in close proximity to high power, high voltage conductors.

For applications where uninterruptible service-to-load is critical, a Bypass-Isolation switch (non-load break design) used with an ATS would be the best choice.

V. ATS CODES AND STANDARDS

UL 1008	Standard for Automatic Transfer Switches
IEEE 602	IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book)
IEEE 241	IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book)
IEEE 446	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book)
NFPA 70	National Electrical Code (NEC)
NFPA 99	Standard for Health Care Facilities
NFPA 110	Standard for Emergency and Standby Power Systems
NEMA ICS 1.3	Preventive Maintenance of Industrial Control and Systems Equipment
NEMA ICS 10	Industrial Control and Systems AC Transfer Switch Equipment

ATTACHMENT
Checklist for ATS Selection

Location: _____

System Voltage:_____ Phases:_____ Frequency:_____

Current Requirement:_____ Available Fault Current:_____

Type of Alternate Power Source:_____

Type of Load:_____

- Automatic Transfer Switches Yes [] No []
Required for loads of an emergency nature requiring immediate automatic restoration of power within seconds of power failure.

- Manual Transfer Switches Yes [] No []
Can be used for some processes that can be manned and recovered from short term outages easily. Loads are not required for immediate automatic restoration.

- Bypass-Isolation Switches Yes [] No []
Selection of Bypass transfer switch (non-load break) design will be recommended if ATS cannot be interrupted to perform preventive maintenance required to ensure reliability. Bypass-Isolation Switches are strongly recommended for Emergency Systems.

- Time Delays Yes [] No []
Time delays are usually a standard on ATS, it allow stabilization and coordination of equipment. Stop time delay relays are recommended for ATS's connected to engine generators.

- In-Phase Monitors Yes [] No []
Recommended for all ATS applications without an UPS which supply motor loads that cannot tolerate momentary interruptions. In-Phase Monitor permits a transfer from normal to alternate and from alternate to normal only when acceptable values of voltage and phase angle difference are achieved

- Motor Load Disconnect Control Device Yes [] No []
This device is especially useful for ATS's which supply both motor and UPS loads and is recommended by most UPS vendors in this situation.

- Program (delayed) Transition Yes [] No []
This is another preferred device to be used with UPS applications as described in the preceding section. The feature avoids the need for control cables and devices to be tripped which is required by a motor load disconnect control device. However, motors which must be restarted will require appropriate control circuitry or sequencing equipment.

- Closed Transition Transfer Yes [] No []
Closed Transition Transfer requires the sources be properly synchronized by voltage, frequency, and phase angle. It must be protected by other devices, such as in-phase

monitor or active synchronizer. It is useful for the transfer of loads when loads cannot be interrupted.

- Test Switches Yes [] No []

A test switch should always be specified if not already a standard feature. Regular monthly testing of the switch is needed to verify its reliability.

- Exercise Clock Yes [] No []

Exercise clock can be used for automatic initiation of a testing of the system.

- Voltage and Frequency Sensing Controls Yes [] No []

Voltage and Frequency Sensing Controls should always be specified if not already a standard feature.

- NEMA Classification-Type A Yes [] No []

NEMA Classification Type A transfer switch required separate overcurrent protection device installed ahead of the ATS to clear fault current.

CHAPTER 3

LOW-VOLTAGE CIRCUIT BREAKERS

Howard Mason

1. SCOPE

1. Applicability. This document pertains to the requirements for the maintenance, testing, and operation of Backup Power Supply low-voltage open frame air circuit breakers.
2. Purpose. The purpose of this document is to provide the current requirements associated with Backup Power Supply low-voltage open frame and insulated-case air circuit breaker operation, testing, and maintenance.
3. Background Backup Power Supply configurations are varied. They encompass a wide range of overcurrent protective devices. In general a Backup Power Supply is composed of an engine driven generator, an overcurrent protective device to protect the generator, and a device (or devices) to transfer the generator power to a distribution network. Many Backup Power Supply Systems use circuit breakers to provide generator overcurrent protection and as a means to switch the generator power to the distribution network.

The circuit breakers used on Backup Power Supply Systems can be either Open Frame Air Circuit Breakers or Insulated-Case (Molded Case) Circuit Breakers.

II. APPLICABLE DOCUMENTS

1.	NFPA 110	Standard for Emergency and Standby Power Systems
2.	DOE 5480.19	Conduct of Operations Requirements for DOE Facilities
3.	DOE/ID-1060	Electrical Safety Guidelines
4.	DOE 4330.4B	Maintenance Management Program
5.	DOE-STD-3003-94	Backup Power Sources for DOE Facilities
6.	NETA ATS-1991	Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems

III. DEFINITIONS

<i>Electrical worker</i>	A job title for a qualified person assigned to electrical work.
<i>Qualified worker</i>	An individual who, by virtue of training, education, and experience, is familiar with the construction and the operation of the involved equipment and the associated hazards.
<i>Corrective maintenance</i>	The repair and restoration of equipment or components that have failed or are malfunctioning and are not performing their intended function.
<i>Preventive maintenance</i>	The periodic and planned maintenance actions taken to maintain a piece of equipment within design operating conditions and extend its life and is performed prior to equipment failure or to prevent equipment failure. This includes technical specification surveillance, in-service inspections, and other regulatory forms of preventive maintenance.
<i>Predictive maintenance</i>	The continuous or periodic monitoring and diagnosis in order to forecast component degradation so that "as-needed" planned maintenance can be performed prior to equipment failure. Not all equipment conditions and failure modes can be monitored; therefore, predictive maintenance must be selectively applied. Reliable predictive maintenance is normally preferable to periodic internal inspections or equipment overhauls.

IV. GENERAL

The National Electrical Code defines a circuit breaker as a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined overcurrent without injury to itself, when the circuit breaker is properly applied within its ratings.

There are two basic types of circuit breakers, air circuit breakers (frequently called switchgear) and molded- (insulated-) case breakers. A circuit-breaker assembly essentially includes (1) an operating mechanism, (2) a contact-and-arc extinguisher system, and (3) an intelligence or current-detection scheme.

Early switchgear circuit breakers utilized air dashpots, but modern designs use solid-state circuitry and current transformers. State of the art circuit breakers use current transformers and solid-state circuitry to provide inverse-time delay to overloads.

The following components are common in air-cooled circuit breakers:

- Main contacts
- Arcing contacts
- Arc chutes
- Operating mechanism
- Closing solenoid
- Shunt tripping Device
- Over-current tripping device
- Breaker stabs

1. Main Contacts

The main contacts shown in Figure 1 are designed to carry the operating load current. Each individual set of contacts is often referred to as a pole.

FIGURE 1

Each pole consists of a stationary contact and two movable contact arms. The movable contact and the stationary contact are faced with a silver alloy insert. The stationary contact is mounted on an insulated base of polyester glass mat. The movable contact has a flexible conductor fastened to it to allow movement of the contact. In a three-phase circuit breaker, there are three stationary contacts, one for each phase. These three stationary contacts are mounted on a common base of insulating material. The three movable contacts are mechanically joined to ensure that all three move together.

2. Arcing Contacts

The arcing contacts are located above the main contacts. These contacts, also shown in Figure 1, close first and open last during breaker operation. In an overcurrent situation, an arc will form across the arcing contacts to trip the breaker. The arcing

contacts are designed to withstand the high currents during closing and opening of the breaker under normal or fault conditions. This prevents burning, erosion, and pitting of the main contacts and increases their life span.

3. Arc Chutes

The arc chutes are designed to stretch, cool, and extinguish the arc across the arcing contacts during breaker operation. This stretching effect is shown in Figure 2. The arc chutes, supported by studs anchored to the breaker's base, fit over the arcing contacts, thereby confining the arc.

4. Operating Mechanism

The breaker's operating handle is connected to the operating mechanism, which is located at the front of the circuit breaker. The operating mechanism is mechanically trip-free, which means that it is impossible to hold the breaker closed on a fault with the overcurrent protective devices operating properly. The main purpose of the operating mechanism is to assure a fast-snap closing action regardless of the speed at which the closing handle is operated.

5. Closing Solenoid

Some circuit breakers provide for remote operation. The main contacts of these circuit breakers can be closed electrically through the use of a solenoid. The closing solenoid is located beneath the breaker opening and closing mechanism. When control voltage is applied to the solenoid coil, the magnetic force generated attracts the plunger. This snap action causes the contacts to close and latch, as shown in Figure 3.

CLOSING SOLENOID — DE-ENERGIZED

FIGURE 3

CLOSING SOLENOID — ENERGIZED

FIGURE 3

FIGURE 3

6. Shunt Tripping Device

A shunt tripping device is an electrically-activated trip unit used to open a circuit breaker on demand from a remote location. This device is composed of a tripping magnet, operating mechanism, and an armature. The shunt tripping device may be operated from either a push-button switch or a relay, depending on application. Any convenient source of voltage such as a storage battery, a control power transformer, or lighting system circuit may operate a shunt trip device.

G Overcurrent Tripping Device

The overcurrent tripping device is designed to open the breaker when an overcurrent or short-circuit condition exists. The two elements that monitor current flowing in a system and initiate the trip sequence of a circuit breaker when a fault occurs are the long time delay and the instantaneous trip. The long time delay is sensitive to an overcurrent condition over a prolonged length of time, usually rated at 80 to 160 percent of the breaker's ampere rating. An overcurrent condition greater than 160% of the ampere rating of the breaker will cause the breaker to open instantaneously.

H. Static Overcurrent Trip Devices

Static Overcurrent Trip Devices are completely static; that is there are no moving parts or contacts. The circuits of the device are designed for light loading of components and are temperature compensated for accuracy and stability of calibration over wide temperature ranges for indefinite periods of time. The static overcurrent trip devices,

which replace the electro-mechanical series overcurrent trip devices, perform the same function with a higher degree of accuracy and versatility. In common with series overcurrent trip devices, all energy for operation is obtained from overload of fault current. No batteries or other external power sources are required.

A complete static overcurrent trip system consists of three current transformers, one per phase, mounted on the circuit breaker primary connectors, a release magnet, and the static overcurrent trip device. This system operates to trip the circuit breaker when a system overload condition exceeds a pre-selected value of current. Tripping will occur after a predetermined time delay or instantaneously depending upon the adjustment selected and the magnitude of the overload.

1. Stabs

As shown in Figure 4, the stabs on the rear of the breaker provide for a positive mechanical connection of the breaker to the power distribution system bus. The main stabs are spring loaded to ensure a good electrical connection from the breaker to the metal projections in the rear of the breaker cubicle. These stabs are referred to as disconnect fingers.

There is one set of disconnect fingers for each of the three phases of the breaker within the breaker cubicle. The top row of disconnect fingers carries load-side power away from the breaker. The bottom row of disconnect fingers supplies power to the breaker. Control voltage stabs are usually located at the bottom of the breaker. The control voltage stabs mate with the connection in the rear of the cubicle and provide connection to external operating/indicating devices.

V. MAINTENANCE

1. Inspection and Cleaning

Occasional checking and cleaning of the breaker will promote long and trouble-free service. A periodic inspection and servicing at intervals of six months or one year should be included in the maintenance routine. Circuit breakers located in areas subject to acid fumes, cement dust, or other abnormal conditions, require more frequent servicing. After a severe overload interruption, the breaker should be inspected.

If the circuit breaker is not operated during extended periods, it should not remain in either the closed or open position any longer than six months. Maintenance opening and closing operations should be made to ensure freedom of movement of all parts.

Suggested maintenance inspections:

- Rack cubicle-mounted breakers of the drawout type to the disconnected position.
- Discharge stored-energy springs.
- Remove arc chutes and examine for burned, cracked, or broken parts.
- Wipe the contacts with a clean cloth saturated with a non-toxic cleaning fluid.
- Replace badly burned or pitted contacts.
- Wipe all insulated parts with a clean cloth saturated with a non-toxic cleaning fluid.
- Bearing pins and other sliding or rotating surfaces should be cleaned and then coated with a light film of lubricant (grease).
- Operate the breaker manually in maintenance closing position to check latch and linkage movement.
- Check breaker adjustments.

2. Lubrication

Lubrication should be a part of the service procedure. Needle bearings are packed with grease and should require no further attention. Old grease should be removed from bearing pins and other rotating or sliding surfaces, and they should be wiped with a thin film of petroleum-oil-base precision-equipment grease. Greasing should be done with care because excess grease tends to collect foreign matter which in time may make operation sluggish and may affect the dielectric strength of insulating members.

3. Maintenance Closing

During inspection prior to installation and for routine maintenance inspections, the breaker contacts may be closed slowly to check clearances, contact adjustments, and movement of links and latches. The manual closing handle is used for maintenance closing the breaker.

Electrically-operated breakers do not have a manual closing handle, but a manual closing handle-cam assembly is available as a maintenance item. After insertion of the maintenance closing handle assembly on the electrically-operated breaker, the actual maintenance closing operation is the same for both the electrically-operated breaker and the manually-operated breaker.

4. Adjustments

During maintenance inspections, the following items should be checked to ensure that the original settings are maintained:

- Trip Latch Engagement
- Main Contact Make
- Arcing Contact Make
- Electrically-Operated Breaker Motor-Cut-Off Switch and Spring-Position Switch
- Pick-up and timing of the long-time delay elements
- Pick-up of the instantaneous elements
- Pick-up of the short-time elements

5. Static Overcurrent Trip Devices

Each static overcurrent trip device is adjusted, calibrated, and tested before shipment and is ready for use after selecting appropriate settings and locking the potentiometer shafts.

Maintenance in the usual sense of clean, readjust, lubricate, etc. is not required on static overcurrent trip devices. The only maintenance that is recommended is periodic verification that the device is functioning. This may be supplemented as desired by checking the calibration, inspection for loose or broken external wiring, restoring lost calibration, etc.

VI. OPERATIONAL TESTING

1. Circuit breakers associated with Backup Power Supplies (i.e., Generator Output Breaker) should be inspected weekly and exercised annually. A weekly circuit breaker inspection would entail a visual inspection of the circuit breaker's alignment and general condition (i.e., no indication of fire).

Exception: Medium and high voltage circuit breakers should be exercised every six months and tested under simulated overload conditions every two years.

2. To operate an electrical circuit breaker, always stand to the hinged side of the breaker. If a breaker should fail, a "fire ball" of flame could come out of the breaker's compartment. This fire ball is composed of plasma or air that has caught fire. A person standing in front of the failed breaker could be severely burned, if not killed, by the fire. Standing to the hinged side of the compartment door will help to shield you. Additionally, if there is an explosion in the compartment, the door, will blow open knocking your hand or arm away and direct any fire away from you.

3. If a circuit breaker has tripped due to overload, determine the cause, reset the breaker and close it. If the breaker trips again, **DO NOT ATTEMPT** to reset it. Repeated attempts to reset a circuit breaker could cause the breaker to fail in the closed (shut) position. This could cause equipment damage and personnel injury.

VII. ACCEPTANCE TESTING ¹

Acceptance testing of low-voltage circuit breakers will indicate shipping and installation damage, field and factory wiring errors, manufacturing defects, systems and components not in accordance with drawings and specifications, etc. By finding these defects before start-up they can be corrected under warranty and without the safety hazards and possible equipment and consequential damages of loss of use/production that can occur if discovered too late. In addition, test results obtained during acceptance testing are invaluable as base reference data for the periodic testing that is an essential element of an effective maintenance program.

1. Low-Voltage - Power

A. Visual and Mechanical Inspection

1. Inspect for physical damage and compare nameplate data with drawings and specifications.
2. Perform mechanical operational test in accordance with manufacturer's instructions.
3. Check cell fit and element alignment and proper operation of racking interlocks.
4. Check tightness of connections using calibrated torque wrench.

5. Check arc chutes for damage.
6. Clean entire circuit breaker using approved methods and materials.
7. Lubricate as required.

B. Electrical Tests

1. Perform a contact-resistance test.
2. Perform an insulation-resistance test at 1000 volts dc from pole-to-pole and from each pole-to-ground with breaker closed and across open contacts of each phase.
3. Determine long-time minimum pickup current by primary current injection.
4. Determine long-time delay by primary injection.
5. Determine short-time pickup and delay by primary current injection.
6. Determine ground-fault pickup and delay by primary current injection.
7. Determine instantaneous pickup value by primary current injection.
8. Make adjustments for final settings in accordance with breaker setting sheet.
9. Activate auxiliary protective devices, such as ground-fault or under voltage relays, to ensure operation of shunt trip devices. Check the operation of electrically-operated breakers in their cubicle.
10. Check charging mechanism.

C. Test Values

1. Compare contact resistance or millivolt drop values to adjacent poles and similar breakers. Investigate deviations of more than fifty percent (50%).
2. Insulation resistance shall not be less than 100 megohms. Investigate values less than 100 megohms.
3. Trip characteristics of breakers when adjusted to setting sheet parameters shall fall within manufacturer's published time-current tolerance band.

2. Low-Voltage - Insulated-Case

A. Visual and Mechanical Inspection

1. Check circuit breaker for proper mounting and compare nameplate data to drawings and specifications.
2. Operate circuit breaker to ensure smooth operation.
3. Inspect case for cracks or other defects.
4. Check tightness of connections using calibrated torque wrench.

B. Electrical Tests

1. Perform a contact-resistance test.
2. Perform an insulation-resistance test at 1000 volts dc from pole to pole and from each pole to ground with breaker closed and across open contacts of each phase.
3. Determine long-time minimum pickup current by primary current injection where practical.
4. Perform long-time delay time-current characteristic tests by passing three hundred percent (300%) rated current through each pole separately. Record trip time.
5. Determine short-time pickup and delay by primary current injection, if applicable.
6. Determine ground-fault pickup and time delay by primary current injection, if applicable.
7. Determine instantaneous pickup current by primary injection using run-up or pulse method.

C. Test Values

1. Compare contact resistance or millivolt drop values to adjacent poles and similar breakers. Investigate deviations of more than fifty percent (50%). Investigate any value exceeding manufacturer's recommendations.
2. Insulation resistance shall not be less than 100 megohms.
3. Trip characteristic of breakers shall fall within manufacturer's published time-current characteristic tolerance band, including adjustment factors.

4. All trip times shall fall within Table 1. Circuit breakers exceeding specified trip time at three hundred percent (300%) of pickup shall be tagged defective.
5. Instantaneous pickup values shall be within values shown on Table 2.

TABLE 1: Insulated-Case Circuit Breaker Overcurrent Trip Test
(At 300% of Rated Continuous Current of Circuit Breaker)

Maximum Breaker Voltage Volts	Range of Related Continuous Current Amperes	Maximum Trip Time In Seconds*
240	15-45	50
240	50-100	70
600	15-45	70
600	50-100	125
240	110-225	200
240	250-400	300
600	110-225	250
600	250-400	300
600	450-600	350
600	700-1200	500
600	1400-2500	600
600	3000-5000	650

* For integrall-fused circuit breakers, trip times may be substantially longer if tested with the fuses replaced by solid links (shorting bars).

TABLE 2: Insulated-Case Circuit Breaker Instantaneous Trip Tolerances

Tolerances of High and Low Settings		
Frame Size, Amperes	High	Low
≤250	+40% -25%	+40% -30%
≥400	±25%	±30%

CHAPTER 4

ENGINE COOLING WATER SYSTEMS

Alvin Padgett, Ken Burrows, John Goodrich, Robert Gross

I. INTRODUCTION

The internal combustion engine cooling system is expected to absorb, dissipate and control the heat of combustion and friction by circulating a suitable coolant. The overall coolant volume and coolant flow required are directly related to the engine horsepower. An engine's heat is dissipated by convection, radiation and conduction. Convection heat transfer occurs through the flow of air currents across hot surfaces. Radiation occurs by emission and reflection of heat waves sent out from the vibrating molecules. As the coolant travels through hoses and passages to the cylinder block and head, heat is conducted through physical contact and carried to the radiator where unwanted heat is dissipated. A major concern with the internal combustion engine is maintaining a steady block temperature at any load range and at varying ambient conditions. It is important to keep the engine parts from being overstressed due to temperature gradients. Overheating can increase stress in engine parts and can also reduce their physical strength. Undisipated heat will induce thermal expansion and cracking of parts, reduce critical clearances, lower oil viscosity, and increase wear. A well designed and properly maintained jacket water cooling system is essential.

II. INSTALLATION AND DESIGN

Successful operation of any engine depends upon the removal of excess heat from cylinders, pistons, valves, etc. to keep the temperatures of these parts within allowable limits (Diesel Engineering Handbook, 12th edition). Open cooling water systems in which all or part of the circulating water is lost to some outflow or outfall are not normally in use today. The closed cooling water system is used for better control of scale-formation in the water jackets and passages surrounding the cylinder liners and cylinder heads. Scale formed and deposited on engine water jacket surfaces reduces heat transfer rates from the engine to the cooling water and leads to hot spots and high thermal stresses on engine components.

1. Design Considerations

Two chief design factors to consider for adequate cooling systems are a non-deposit forming water supply and a sufficient amount of water to control engine temperatures. Formulas for pounds or gallons of water required to cool an engine are based on removing 2500-3000 Btu-per-brake-horsepower-hour (bhp-hr) for naturally aspirated and 2000-2500 Btu/bhp-hr for turbocharged engines. Figure 22-1 and Table 22-1 of the Diesel Engineering Handbook provide approximate rates of water circulation knowing horsepower, type of engine, and temperature rise across the cylinder block. Most manufacturers recommend that jacket water discharge temperature from the engine be 160-195 degrees Fahrenheit (°F) and have a 10-15 °F rise from inlet to outlet. In some cases, more than 15°F rise may occur across larger engines and not be a concern. Individual manufacturers should be consulted for allowable design or operating limits.

2. Radiators, Louvers, and Enclosures

Radiators provide dry cooling in comparison to cooling provided by shell-and-tube heat exchangers. When radiators are used in stand-alone enclosures, louvers are used to channel intake and exhaust air to and from the enclosure. Either fixed or movable louvers may be used to keep weather from the enclosure when the engine is not running, but must be open or opened automatically when the engine is started. It is important that louvers allow sufficient cooling air to be drawn into the enclosure under the highest heat load conditions and at rated engine load. Also, air drawn in by the radiator fan and directed across the radiator fins picks up heat and must be removed from the immediate vicinity to effect design rate of heat removal. The design and placement of enclosures should take maximum advantage of natural air circulations. For example, an enclosure will not be effective at removing design heat load if it is located close to high vertical walls blocking the louvers. A flexible connection should be provided between the radiator discharge flange and the enclosure exhaust louvers to prevent air recirculation. The radiator should have sufficient capacity to support continuous operation for (your required) days at (your site's) highest ambient air temperature and maximum room temperature with normal evaporative losses.

3. System Sizing

The cooling system should be sized such that operating with clean, soft water and 50% ethylene or propylene glycol will not cause the engine to overheat at full rated load. Radiators and heat exchangers should be sized 10%-15% over design values to

anticipate plugged or leaking tubes or channels. A coolant expansion tank equal to 10% of cooling system volume should be provided. It is estimated that for engines up to 500 horsepower, approximately 4% of the engine horsepower is required to drive the radiator fan. Gaskets and packing used in the cooling system should be of material resistant to deterioration by ethylene or propylene glycol, corrosion inhibitors (e.g., nitrites) and preservative compounds.

Cooling systems can be atmospheric or pressurized. Pressurized systems will boil at higher temperatures, and since engines are more efficient operating at higher temperatures, the trend in manufacturers has been to higher pressure systems. Some engine cooling systems are now operating continuously at roughly 195 °F discharge temperature, and since this is very close to boiling at sea level (212 °F) a pressure cap is used. The system should be allowed to vent so that the cooling system is kept completely filled all the time. The level of fluid in the radiator or expansion tank is critical and should be checked periodically while the engine is in standby or prior to a test run. Radiator water level should not be checked on an engine unless the upper tank is cool or warm (not hot) to the back of the hand. Otherwise, the fluid may boil when pressure is released possibly causing personnel injury. Overflow tanks similar to those used in automobiles and Murphy type level gauges are in common use today; they allow continuous monitoring of coolant in the radiator while the engine is operating.

Shell and tube heat exchangers are used on larger engine generator units and typically use domestic water or cooling tower water (fresh water) on the tube side and engine jacket water on the shell side. For more information on types of heat exchangers, e.g., parallel, counter and cross flow and heat transfer characteristics of each, review Fundamentals of Heat Transfer (3).

4. Regulating Temperature

Thermostatic regulating valves should be included in the design so that the cooling system brings the water to normal operating temperature as soon as possible, and maintains the correct temperature rise across the engine block under all load/no-load conditions. Larger engine's are regulated by Sarco, Fulton Sylphon or Amot type bypass valves which bypass the heat exchanger until the engine is up to temperature. As the engine heats up, the bypass port begins to close and continues to close as more coolant is diverted to the heat exchanger keeping the coolant at the desired set temperature.

5. Altitude and Temperature Effects

Altitude and maximum ambient temperature must be considered when sizing the diesel and the coolant system's capacity. Due to the decrease in amount of oxygen in air at higher altitudes and to the reduction in specific weight of air at higher temperatures, adjustments to engine rating must be recognized. The Diesel Engine Manufacturers Association (DEMA) sixth edition Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines provides additional information on the effects to engine performance and rating. Generally, engine installations intended for air inlet temperatures ≥ 90 °F and/or at altitudes ≥ 1500 feet above sea level require reduction in rating. For naturally aspirated and non-turbocharged (super-charged) engines, the manufacturer's sea level engine rating is reduced 5% for every 20 °F above 90 °F and by 3.5-4% for every 1000 feet above 1500 feet. As an example, a 500 horsepower continuous engine rating at sea level and 90 °F would be adjusted down to approximately

360 horsepower if it were to be operated continuously at 7500 feet above sea level and at 110 °F (see references 1 and 2).

6. Alarms and Shutdowns

Cooling systems should incorporate alarms to warn operating personnel when temperatures and pressures vary from desired setpoints. Alarm signals may be audible, visible or both. It is sometimes desirable to have automatic engine shutdown devices which will operate when the cooling system temperature or pressures have reached set points. Shutdown devices should be set slightly beyond the pre-determined setpoint of alarms yet not in excess of the safe short-time engine operating limits.

If an engine generator set is critical to safety, it may be desirable to disable the coolant over-temperature shutdown function during normal operation and take advantage of the ultimate capability of the engine, i.e., to let it "die trying" to supply the safety-critical loads. This should be decided by means of a case-by-case comparison of the safety risk involved. Interruption of critical loads in the case of a spurious or premature shutdown should be compared with the risk of an extended loss of the engine. If the shutdown function is disabled during operation, the alarm function should be retained. Procedures should be in place to ensure that the shutdown function is active during routine testing, but disabled again after testing is completed.

The coolant over-temperature alarm should receive an operational test periodically, at least at every coolant drain-and-replacement interval. See DOE-STD-3003-1994 and NFPA-110 for additional discussion.

III. JACKET WATER SYSTEM PREHEATERS

1. Purpose

The preheater provides many advantages for the standby engine generator. It can provide quick starts and reduced warm-up times, and can prolong battery life because cranking time and starting torque are reduced. If the lubricating oil is also heated, preheaters can reduce starting wear because oil flows more rapidly to critical metal-to-metal interfaces. Electric heaters are normally used to maintain the jacket water at the desired temperature when an engine is not operating, and are interlocked by an oil pressure sensor to switch off when the engine starts. This conserves energy since the engine block temperature will quickly exceed the preheater setpoint. A check valve prevents coolant flow through the preheater while the engine is running; consequently the heater element may be damaged due to local boiling of coolant in the preheater if not switched off. Warranties are typically voided if an interlock is not utilized to disable the heater during engine operation. According to (4), white exhaust smoke, also called liquid smoke or "fog" (as opposed to soot or solid, black smoke), is due to partially burned or oxidized fuel and formaldehyde being exhausted. Preheaters will all but eliminate "white smoke" on start-up because the combustion chambers and inlet air are preheated to some degree reducing ignition delay and the proportion of unburned fuel.

2. Operating Preheaters

Typical preheaters used in the DOE Complex include Kim Hotstart and Watlow brands. They operate on the principle of thermo-siphon. The coolant in the preheater tank expands slightly as it is heated forcing a one-way valve on the intake side of the heater to a closed position. Water encased in the preheater tank surrounding the heater element is then heated. The coolant becomes lighter as it is heated and rises up by convection into the top of the engine. Cooler water from the cylinder liner and cylinder head sink towards the preheater inlet. As the temperature (and pressure) of water in the preheater tank increases, a flow is established as the heated water leaves the preheater outlet and cold coolant enters the inlet. A flow-through thermostat is installed on the inlet side of the heater and senses the temperature of the engine coolant as it enters the heater. The thermostat will keep the coolant at the desired temperature range. It is important to note that the thermostat controls the heater inlet temperature to the desired range.

3. Sizing and Settings

Preheaters are available in 120, 208, 240, 277 and 480 volt ratings. Vendors typically recommend that 3-5 watts per cubic inch engine displacement be used to size these heaters. Normally, 5 watts per cubic inch is provided when ambient temperatures are expected below -20°F. General purpose, watertight, and explosion resistant enclosures and switches are available. Fixed setting thermostats are better than adjustable, since the settings normally do not need changing but usually need verifying. A thermostat setting higher than 80°F-120°F wastes energy and risks drying the oil film on cylinder liners prematurely. Recall that the heater thermostat switch stays on energizing the heater as long as the coolant passing to it from the engine is less than its setting. Consequently, the preheater inlet hose must enter the preheater tank from the engine-to-radiator return line. Temperature gradients high enough to lift (open) the

engine thermostat have been observed on some engines. When the thermostat lifts, it causes preheated water to enter the radiator. The water cools as it passes through the radiator and that makes the preheater work even harder to maintain its inlet set temperature. Periodic block temperature checks should be made to ensure the heater setting is not causing the engine thermostat to lift thus diverting water flow to the radiator.

IV. CORROSION INHIBITORS AND ADVANCES IN COOLANT TECHNOLOGY

The internal components of the cooling system are made of ferrous and non-ferrous materials in contact with water that are subject to corrosion. Corrosion of ferrous components occurs readily, therefore a means to prevent this corrosion must be chosen to extend the life of the components. There have been several inhibitors used for corrosion protection through the years including soluble oils, chromate inhibitors, nitrite/nitrate inhibitors, ethylene glycols, and propylene glycols.

1. Typical Inhibitors

Soluble oils and chromate inhibitors have fallen out of favor due to environmental and health factors, but still may be used in older systems. Nitrite and nitrate inhibitors mixed with water are still widely used but these mixtures are subject to freezing in low ambient conditions since by themselves they offer insufficient freeze protection. The most popular freeze and corrosion protection solutions today are ethylene glycol (EG) and propylene glycol (PG). These two substances are excellent at raising the boiling point and lowering the freeze point of the coolant, which allows use of the diesel engine in varying ambient conditions. The glycols alone when mixed with water provide corrosion protection but only to a limited degree. Supplemental Coolant Additives (SCAs) still need to be added for long term corrosion protection and heavy duty service. Nitrite and nitrate inhibitors are typically added to ethylene and propylene glycol systems with good results.

2. Corrosion Protection

According to a leading lubricants company, the need for corrosion protection was compounded by increased power-to-weight ratios of diesel engines over the last 25 years. Increased excitation (vibration) of the engine liners accelerates a phenomena known as cavitation erosion/corrosion. Fleetguard, a Division of Cummins Engine Co., explains the process fairly concisely. Piston skirt "slap" against the liner occurs as the linear motion of the piston is transferred to the rotary motion of the crankshaft. This "slap" excites the liner much like the high frequency vibration of a bell being struck. As the cylinder liner then moves away from the coolant, small vapor bubbles are formed; these bubbles *collapse* or implode as the liner moves towards the coolant again. The resulting implosions induce local stresses of nearly 60,000 pounds per square inch (psi) across a very small area of the liner surface. Removal of the liner material, more commonly referred to as liner pitting, continues with each implosion until through-wall pinholes develop.

Whichever corrosion inhibitor is used, the method of protection is very similar. A thin, hard, protective layer of oxide forms on the ferrous components due to the inhibitor and then acts as sacrificial material. This hard layer is resistant to damage from the collapsing bubbles. As implosions occur, the oxide is slowly removed from the surface, rather than the ferrous cylinder liner material itself. If the corrosion inhibitor concentration level is within acceptable levels, then a new oxide film quickly forms where the inhibitor was removed thus protecting the component surface.

3. Recent Advances

Recent advances in coolant technology have led to more convenient, and durable corrosion protection packages. EG and PG mixtures can now be purchased premixed with SCAs, thus eliminating the need for pre-charging the system with SCAs. Pre-charging is difficult sometimes due to the need to know the system capacity for the proper quantity of SCAs to be added. Most recently, carboxylate protection has been introduced. This method also is provided pre-mixed with the EG or PG solution and can be used without the addition of a SCAs for up to two years or 150,000 miles. Silicates, nitrates, borates and phosphates can have a damaging effect on the cooling system in that they tend to plate out on the internals, drop-out (precipitate), or form gell-like substances. The net effect is to decrease jacket water system heat transfer rates. Phosphates cause hard water scale to form. In general, all of the above listed materials create abrasive dissolved solids that tend to ruin water pump seals. The new carboxylate formulations do not contain silicates, nitrates, borates or phosphates.

4. Glycols

The two types of antifreeze most often used in today's engines are ethylene glycol (EG) and propylene glycol (PG). The following is a general introduction to the two fluids and should not be used as the sole basis for choosing an antifreeze solution. When choosing the correct fluid for your application, many factors need to be weighed, such as present stock quantities, cost, risk of mixing fluids, disposal and/or recycling costs to name a few. For information, consult engine OEMs, EG/PG manufacturers, as well as local environmental codes. Society of Automotive Engineers (SAE) Technical Papers 900434 (March 1990) and 930473 (March 1993) provide more detailed information on propylene glycol capabilities, laboratory and field test results.

There are numerous differences between the two materials (EG, PG), but at this writing the most notable are cost and toxicity. EG is less expensive, but is also toxic. Conversely, PG in its virgin state has been granted GRAS (Generally Recognized As Safe) status by the US Food & Drug Administration and is used in many foods, pharmaceuticals, and cosmetics. While low in toxicity, the material may still be considered hazardous based on an analysis prior to disposal. Test results from Union Carbide, Cooperative Research Council, and the Factory Insurance Association from the 1940's & 1950's show that PG has some advantages when it comes to specific heat rates. PG has a better heat transfer rate when compared to an equivalent mixture of EG, therefore making it attractive for high heat load applications. While Ethylene Glycol is approved for all engines, Propylene Glycol use may be restricted by certain OEM's.

V. RECOMMENDED MAINTENANCE PRACTICES

1. Inspections

Before initiating coolant treatment, the interior and exterior of the jacket water cooling system should be inspected. If oil is present, clean the system in accordance with OEM procedures. If corrosion or scale deposits are noted, clean the system as directed by the OEM. *Routine* cleaning of the interior cooling system is not recommended since a small amount of the base metal will also be removed during cleaning. A system should be thoroughly flushed with clean, fresh water after any chemical cleaning to ensure the removal of all cleaning chemicals. Proper cooling system maintenance must start with a knowledge of the requirements of the cooling system and its components. If the cooling system contains an unknown coolant or initial fill, drain it, thoroughly flush the cooling system with clean, fresh water, inspect and then re-fill to a known concentration.

2. Use of Pre-Mixed (Formulated) Antifreeze

Normally accepted practice using Formulated Coolant Antifreeze:

1. Fill - use premix fully formulated coolant with Supplemental Coolant Additive (SCA) and fill the system to OEM recommended level.
2. Top Off - use premixed fully formulated coolant (50/50 with SCA) to top off cooling system when needed.
3. Replenish - at every oil change replace the coolant filter(s) which will replenish the SCAs. If system does not have a filter(s) use liquid SCA. If the system is very large (40+ gallons) use liquid SCA. Tests to determine SCA concentration must be used when adding liquid SCA.
4. Test the coolant twice a year for freeze protection and SCA levels. Refer to the Testing section for more information.
5. Drain and replace the coolant every 2 years, 6,000 hours of operation or when coolant analysis confirms the need.

3. Storage

Antifreeze additives can drop out of solution if stored for more than two years. The primary limiting factor in shelf life considerations is silicate instability. Since silicate will eventually polymerize to silicate gel, traditional silicate-based coolants have a shelf life of about 18 months. Long Life Coolant Antifreeze (new carboxyl technology) is silicate free and can be stored for extended periods of up to 5 years. Coolants of any kind deteriorate in direct sun light.

VI. WATER QUALITY

1. Characteristics

Water is used in cooling systems because it is the most efficient and readily available agent to assist in heat transfer. However, it is most important to know the quality of the water you are using in your diesel application. Poor quality water can allow formation of acids or scale deposits that will reduce the life of your cooling system. The five characteristics of water that concern us are chloride and sulfate content, total hardness, total solids and pH level. The following table is taken from engine vendor specifications ¹:

**Minimum Acceptable Water Characteristics
for Use in Engine Cooling Systems**

Properties	Limits	ASTM Test Methods
Chloride (Cl), gr/gal (ppm)	2.4 (40) max	D512b, D512d, D4327
Sulfate (SO ₄), gr/gal (ppm)	5.9 (100)max	D516b, D516d, D4327
Total hardness, gr/gal (ppm)	10 (170) max	D1126b
Total solids, gr/gal (ppm)	20 (340) max	D1888a
pH	5.5 - 9.0	D1293

2. Recommendations

Most manufacturers recommend the use of distilled or de-ionized water to help reduce the potential and severity of chemical insolubility. After suitable water is found, a Supplemental Coolant Additive (SCA) must be added. Most OEM's can recommend an additive that you can use. It must be noted that adding a Supplemental Coolant Additive does not make poor water quality acceptable. Coolant additives can help poor water quality but do not usually protect against corrosion or pitting. Use of water that does not meet the above recommended properties such as "hard" tap water will cause solids to "plate out" (deposit) on hot engine surfaces creating a layer of insulation. If treated water is not available, use the following guidelines:

1. Never use salt water
2. Select the best fresh water available
3. Use water analysis to define your water quality
4. Never use water alone as the coolant, water by itself is corrosive at engine operating temperature.

¹ Caterpillar Publication SEBD0518, Detroit Diesel Model 71 Maintenance Manual, and Electro-motive Division, GM Corp M.I. 1748.

VII. COOLANT TESTING AND ANALYSIS

1. Physical Property Testing

For the more advanced maintenance program, physical property tests and spectrochemical analysis of the coolant should be considered. This is a low cost means of evaluating the coolant and cooling system adequacy. Testing also provides valuable trend data and can indicate changeout frequencies. It is highly recommended that this analysis be performed due to its low cost and good return on investment.

2. Sample Process

- a) Draw the sample (approximately 100 cc) from the engine cooling system shortly after the engine has been shutdown and the pressure has subsided.
- b) Provide pertinent information to the analysis lab, such as: engine manufacturer and model, cooling system capacity, hours on the engine and coolant, type and manufacturer of coolant, coolant filters and SCAs being used, the amount of coolant added to the system as makeup, any additional comments such as recent problems, maintenance performed on the system. Be sure to include a unique identifier for the engine being sampled.
- c) Ship the sample to the laboratory that provides the analysis.
- d) Receive the report from the lab. This may occur in one of several ways; a hard copy through the mail or as a download to an onsite computer via modem.
- e) Feedback is the final step. Notify the lab of any inconsistency in what they recommended versus what was found during the corrective maintenance. Also alert them of actions taken based on the recommendations.

3. Analysis Reports

The lab report is usually divided into several sections including:

- a) Pertinent information that was transmitted to the analysis lab,
- b) Spectrochemical analysis results,
- c) Physical properties tests, and
- d) Condition report including customer comments provided with the sample and maintenance recommendations provided by the lab based on the analysis results.

4. Properties to Test

The physical properties typically tested are freeze protection level, coolant/water percentages, nitrite or SCA level, pH, visual color and appearance, and reserve alkalinity. These tests give a good indication of the coolant overall condition.

Spectrochemical tests provide an indication of the cooling system and coolant additive package condition. The results are reported in parts per million (ppm) by weight of the various elements. Sources of the elements and how they relate to engine condition are as follows: High levels of iron are indicative of liner pitting, cavitation erosion of water pump impellers, and/or corrosion of other internal ferrous cooling system components. Lead, copper and aluminum are indicative of radiator core, oil cooler or aftercooler core deterioration.

Coolant additive packages vary widely from one manufacturer to another, so mixing may cause additive dropout which will eventually lead to formation of a gel or solid deposit. Spectrochemical analysis can quickly identify when different coolant brands have been mixed in an engine. The typical additive package contains most of the following elements in varying quantities; silicon, boron, sodium, phosphorous, zinc, calcium, barium, magnesium, titanium, molybdenum, potassium, and antimony.

5. Established Criteria

Some typical limits or flag values for coolant analysis are as follows. These values are based on regional laboratory studies and consultations with OEM representatives. Contact members of the BPWG for more information.

PROPERTY	MINIMUM	MAXIMUM
Glycol (%)	33	68
Aluminum (ppm)	0	15
Copper (ppm)	0	20
Iron (ppm)	0	20
Lead (ppm)	0	20
Silicon (ppm)	50	200
Nitrite (ppm)	800	2400
Phosphorous (ppm)	0	9000
Reserve Alkalinity (ml)	5	20
pH	8	11
Glycol (%)	33	68
Freeze Point (deg F)	- 2	- 64

As the glycol percentage increases, the coolant's freeze point is lowered. Desirable concentrations really depend upon the end user's anticipated year-round ambient conditions. Filling with 100% EG or PG is not recommended as it lowers the specific heat and would afford only +9 °F freeze protection. Occasionally, the coolant should be sampled and visually inspected. It should be clear, and should not exhibit cloudiness or contain visible suspended solids. ²

² Union Carbide Chemicals Co., "Glycols" 1955

6. Sampling and Frequency

The frequency of testing will depend upon how the unit is operated. Typical standby engines which receive <150 operating hours per year need only be sampled every 6 months. Engines in continuous service should be sampled more frequently as the SCAs and coolant additive packages deplete during engine operation. Do not wait until the cooling system or the coolant shows evidence of degradation before beginning a sampling program.

The best sample is obtained shortly after an engine is run with the coolant still warm, but with the pressure in the cooling system subsided. The sampling location should be identified and maintained, to ensure consistent results. Also, cleanliness is extremely important in obtaining accurate results; do not reuse sample bottles or tubes for collection of samples. Never sample directly after charging the system with new coolant, or a large addition of SCAs as the results will not be representative.

7. Benefits to Cooling Water Analysis

Many engine manufacturers recommend replacement of engine coolants every 2 years for traditional coolants and every 4 years for the new long-life coolants. This is expensive and creates tremendous disposal problems when dealing with large systems and/or numerous installations. Anti-freeze recycling can curb these problems, but the coolant should not be replaced unless it is depleted or contaminated (dirt, debris or corrosion products). Coolant analysis allows the extension of coolant change-out frequencies, thereby reducing waste disposal and unneeded maintenance downtime.

Maintenance problems such as over concentration of SCAs and additive drop-out, gel formation, and mixing of different brands of coolant should be identified long before the condition becomes visibly evident. By the time the coolant looks deteriorated or depleted, the damage has already been done.

8. SCA Field Checks Using Test Kits

If the amount of coolant lost and current coolant condition is not known, use a test kit to determine the SCA level of the cooling system. Acceptable test kits are available from companies like Nalco Chemical and Fleetguard Inc. Carefully follow the instructions when testing the coolant, and take the appropriate action recommended by the kit. Testing is recommended if unsure of cooling system condition due to leaks, uncontrolled topping off, or major coolant loss. Testing is also recommended twice per year to monitor the SCA level. Follow the vendor's recommendations when maintaining SCA concentration in your engines.

VIII. UNACCEPTABLE MAINTENANCE PRACTICES

All diesel engines with wet liners are subject to liner pitting if the cooling system is not correctly maintained. Low SCA concentration of less than 1.2 units per U.S. gallon may not retard liner cavitation and may lead to engine failure. Higher SCA concentrations of 3.0 units per U.S. gallon may cause dissolved solid dropout. The use of high silicate antifreeze results in gelatin formation and water pump seal leakage. The following practices are considered unacceptable and can lead to engine failure:

1. Filling or topping off cooling systems with low silicate antifreeze but without proper SCAs or a Long Life Coolant
2. Use of high silicate antifreezes
3. High or low SCA concentrations
4. Use of sealing additives (stop-leak) in the cooling system
5. Use of soluble oils in the cooling system
6. Use of water with poor quality, and
7. Use of antifreeze or formulations that do not meet OEM specifications.

IX. SYSTEM TESTING

A profile or trend of the engine's inlet and outlet temperatures will facilitate troubleshooting, overheating and low temperature problems. On larger engines, periodic tightness testing of the jacket water system at 10-30 psig will reveal water leaks at jumpers, adapters, cylinder heads, and liner-to-block seals. If leaks are allowed to continue at these points they create hot spots, corrosion, and water contamination of the lube oil. Main and connecting rod damage have also been attributed to water leaks originating at cylinder liner jacket water headers and jumpers.

X. ENVIRONMENTAL CONCERNS

1. Antifreeze Types

There are two types of anti-freeze, ethylene glycol (EG), and propylene glycol (PG). Ethylene glycols are not used in applications which may result in accidental or inadvertent human ingestion; PG is used in those applications. EG and PG differ little in boiling and freezing points. EG is less expensive, but is considered a hazardous substance³. Conversely, PG in its virgin state has been granted GRAS (Generally Recognized As Safe) status by the US Food & Drug Administration and is used in many foods, pharmaceuticals, and cosmetics. While low in toxicity, PG may still be considered hazardous based on an analysis (of used coolant) prior to disposal.

REGULATORY COMPARISON	EG-H2O	PG-H2O
Hazardous Air pollutant	Yes	No
Reportable Quantity (5,000 lb)	Yes	No
Storm Discharge Control	Yes	No
OSHA Standards (Air)	Yes	No
Employee Monitoring	Yes	No
Hazardous Substance	Yes	No

2. Used Coolants

Used coolants, either EG or PG which contain 5 ppm of lead, 0.5 ppm of benzene, or regulated quantities of copper and chromium are considered by the Environmental Protection Agency to be a hazardous waste under the Resource Recovery and Conservation Act (RCRA) upon disposal. The reportable quantity of EG spills is now 5,000 pounds. Toxicity lethal dose of EG is 5 grams/kilograms of body weight or approximately one-half cup. The lethal dose of PG is not known. Contact your local environmental coordinator prior to handling any of these chemicals. Disposal, spills and discharges of used coolants are regulated by State and Federal Laws.

3. Handling

Control and handling of coolants requires the use of approved safety equipment and containment. Please note the following:

- A. Do not drink antifreeze
- B. Do not get antifreeze in your eyes
- C. Warnings (Ethylene Glycol)
 - 1. EG may catch fire when hot! Flash Pt 245°F, Fire Pt 250°F
 - 2. EG is toxic
 - 3. Airborne exposure 60 parts per million
 - 4. RQ spill 5,000 lb. (EPA Reportable Quantity)
- D. Warning (Propylene Glycol)
 - 1. PG may catch fire when hot! Flash Pt 225°F

³ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

4. Disposal

Used coolant, be it EG or PG, must be disposed of in accordance with local, state, and federal law. Used coolant may need to be tested before an authorized scavenger can incinerate it or deliver it to the designated landfill. Discharges into sanitary sewer systems may not be allowed based on applicable site permits. A broad spectrum test for heavy metals may be used to characterize used coolants. Local and state permission must be obtained prior to disposal.

5. Recycling

Millions of gallons of waste engine coolant are generated each year during routine preventative and corrective maintenance activities. The waste generator is held accountable for the waste. Waste engine coolants are basically composed of water, ethylene glycol, broken-down inhibitors, corrosion by-products and possibly heavy metals. Just any recycling process is not good enough. A *distillation* process must be used in order to meet OEM specifications. The distillation process has changed in the past few years. New technology has been developed and is called vacuum distillation.

Vacuum distillation is simply the distillation process engineered to take place in a completely closed vessel where a negative pressure exists. Distillation allows liquids with higher boiling points to vaporize at lower temperatures. This has been proven to produce the highest quality recycled coolant available, and the only one recognized and currently approved for use by original equipment manufacturers.

As supplemental coolant additives continue to be added during normal coolant maintenance, the level of total dissolved solids continues to climb. Eventually, the level of solids can reach the point where the liquid approaches saturation and the solids begin to dropout, causing problems such as water pump seal failure and blocked radiator tubes. Distillation is able to remove virtually all the solids, both dissolved and suspended. Distillation is the only process that allows removal of excess water. Other processes require the addition of expensive glycol to make a 50/50 mixture.

It has been said that distillation is slow and time consuming. While some of the older machines are slow, new systems are now available to process large quantities of waste coolant per day. After the initial capital purchase of equipment, distillation is one of the most inexpensive forms of recycling available. There are many methods of recycling waste engine coolants, and some of the most popular are: ion exchange/filtration, straight filtration, reverse osmosis/dialysis, and filtration/flocculation. Though some of these methods are faster, they cannot produce the distillate quality that the vacuum distillation system can provide.

XI. MAINTENANCE RECORDS

Log book entries or work packages should list the following information allowing later retrieval:

1. Type and system of antifreeze used
2. ASTM specifications for fluid used
3. Testing procedure (test kit and refractometer)
4. Test results
5. Water temperature drop across loops
6. PM checklist, repairs
7. Radiator inspection results
8. Last fluid changeout date.

XII. REFERENCES

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- (7) DOE Standard, Backup Power Sources for DOE Facilities, DOE-STD-3003-94, US-DOE Washington DC, September 1994.
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