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An American National Standard

Standard Specification for Diesel Fuel Oils[1]

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers five grades of diesel fuel oils suitable for various types of diesel engines. These grades are described as follows:

1.1.1 *Grade Low Sulfur No. 1-D*—A special-purpose, light distillate fuel for automotive diesel engines requiring low sulfur fuel and requiring higher volatility than that provided by Grade Low Sulfur No. 2-D.[2]

1.1.2 *Grade Low Sulfur No. 2-D*—A general-purpose, middle distillate fuel for automotive diesel engines requiring low sulfur fuel. It is also suitable for use in non-automotive applications, especially in conditions of varying speed and load.[2]

1.1.3 *Grade No. 1-D*—A special-purpose, light distillate fuel for automotive diesel engines in applications requiring higher volatility than that provided by Grade No. 2-D fuels.

1.1.4 *Grade No. 2-D*—A general-purpose, middle distillate fuel for automotive diesel engines, which is also suitable for use in non-automotive applications, especially in conditions of frequently varying speed and load.

1.1.5 *Grade No. 4-D*—A heavy distillate fuel, or a blend of distillate and residual oil, for low- and medium-speed diesel engines in non-automotive applications involving predominantly constant speed and load.

NOTE 1—A more detailed description of the grades of diesel fuel oils is given in X1.2.

1.2 This specification, unless otherwise provided by agreement between the purchaser and the supplier, prescribes the required properties of diesel fuels at the time and place of delivery.

1.2.1 Nothing in this specification shall preclude observance of federal, state, or local regulations which may be more restrictive.

NOTE 2—The generation and dissipation of static electricity can create problems in the handling of distillate diesel fuel oils. For more information on the subject, see Guide D 4865.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

D 56 Test Method for Flash Point by Tag Closed Tester[3]
D 86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure[3]
D 93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester[3]
D 97 Test Method for Pour Point of Petroleum Products[3]
D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[3]
D 130 Test Method for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test[3]
D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)[3]
D 482 Test Method for Ash from Petroleum Products[3]
D 524 Test Method for Ramsbottom Carbon Residue of Petroleum Products[3]
D 613 Test Method for Cetane Number of Diesel Fuel Oil[3]
D 976 Test Methods for Calculated Cetane Index of Distillate Fuels[3]
D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)[3]
D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption[3]
D 1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)[3]
D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)[3]
D 1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)[3]
D 2274 Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)[3]

[1] This specification is under the jurisdiction of ASTM Committee is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.E0 on Burner, Diesel, Non–Aviation Gas Turbine, and Marine Fuels.

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[2] This fuel complies with 40 CFR Part 80—Regulation of Fuels and Fuel Additives: Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years.

[3] *Annual Book of ASTM Standards*, Vol 05.01.

D 2276 Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling[3]
D 2500 Test Method for Cloud Point of Petroleum Oils[3]
D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry[3]
D 2709 Test Method for Water and Sediment in Distillate Fuels by Centrifuge[3]
D 2880 Specification for Gas Turbine Fuel Oils[3]
D 3117 Test Method for Wax Appearance Point of Distillate Fuels[3]
D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry[3]
D 3828 Test Methods for Flash Point by Small Scale Closed Tester[4]
D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[4]
D 4294 Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectroscopy[4]
D 4539 Test Method for Filterability of Diesel Fuels by Low Temperature Flow Test (LTFT)[4]
D 4737 Test Method for Calculated Cetane Index by Four Variable Equation[4]
D 4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems[4]
D 5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence[5]
D 5771 Test Method for Cloud Point of Petroleum Products (Optical Detection Stepped Cooling Method)[5]
D 5772 Test Method for Cloud Point of Petroleum Products (Linear Cooling Rate Method)[5]
D 5773 Test Method for Cloud Point of Petroleum Products (Constant Cooling Rate Method)[5]
D 6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball–on–Cylinder Lubricity Evaluation (SLBOCLE)[5]
D 6079 Test Method for Evaluating Lubricity of Diesel Fuels by the High–Frequency Reciprocating Rig (HFFR)[5]
D 6217 Test Method for Particulate Contamination in Middle Distillate Fuels by Laboratory Filtration[5]
D 6371 Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels[6]
D 6468 Test Method for High Temperature Stability of Distillate Fuels[6]
D 6469 Guide for Microbial Contamination in Fuels and Fuel Systems[6]

2.2 *Other Documents:*

26 CFR Part 48 Manufacturers and Realtors Excise Taxes[7]
40 CFR Part 80 Regulation of Fuels and Fuel Additives[7]
IP 309 Diesel and Domestic Heating Fuels—Determination of Cold Filter Plugging Point[8]

3. Test Methods

3.1 The requirements enumerated in this specification shall be determined in accordance with the following methods:

3.1.1 *Flash Point*—Test Methods D 93, except where other methods are prescribed by law. For all grades, Test Method D 3828 can be used as an alternate with the same limits. For Grades Low Sulfur No. 1-D, Low Sulfur No. 2-D, No. 1-D, and No. 2-D, Test Method D 56 can be used as an alternate with the same limits, provided the flash point is below 93°C and the viscosity is below 5.5 mm^2/s at 40°C. This test method will give slightly lower values. In cases of dispute, Test Methods D 93 shall be used as the referee method.

3.1.2 *Cloud Point*—Test Method D 2500. For all grades, the automatic Test Methods D 5771, D 5772, or D 5773 can be used as alternates with the same limits. Test Method D 3117 can also be used since it is closely related to Test Method D 2500. In case of dispute, Test Method D 2500 shall be the referee method.

3.1.3 *Water and Sediment*—Test Method D 2709 is used for Grades Low Sulfur No. 1-D, Low Sulfur No. 2-D, No. 1-D, and No. 2-D. Test Method D 1796 is used for Grade No. 4-D.

3.1.4 *Carbon Residue*—Test Method D 524.

3.1.5 *Ash*—Test Method D 482.

3.1.6 *Distillation of Low Sulfur No. 1-D, Low Sulfur No. 2-D, No. 1-D, and No. 2-D Fuel Oils*—Test Method D 86.

3.1.7 *Viscosity*—Test Method D 445.

3.1.8 *Sulfur*—Test Method D 2622 is used for Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D. Test Methods D 1266, D 3120 and D 4294 are also suitable for determining up to 0.05 % sulfur in diesel fuels. Test Method D 129 is used for Grades No. 1-D, No. 2-D and No. 4-D. Test Methods D 1552, D 2622, and D 4294 can also be used for these grades. In addition, Test Method D 1266 can be used for Grade No. 1, but only with samples having sulfur contents of 0.4 mass % and less (down to 0.01 %). Test Method D 5453 can be used for Grades 1 and 2 diesel fuels, but only with samples having sulfur contents of 0.8 mass % and less (down to 0.0001 %). In case of dispute, Test Method D 2622 is the referee sulfur test method for Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D. Test Method D 129 is the referee sulfur test method for Grades No. 1-D, No. 2-D, and No. 4-D.

3.1.9 *Corrosion*—Test Method D 130, 3 h test at 50°C.

3.1.10 *Cetane Number*—Test Method D 613.

3.1.11 *Cetane Index*—Test Methods D 976–80.

3.1.12 *Aromaticity*—Test Method D 1319. This test method provides an indication of the aromatics content of fuels. For fuels with a maximum final boiling point of 315°C, this method is a measurement of the aromatic content of the fuel.

4. Workmanship

4.1 The diesel fuel shall be visually free of undissolved water, sediment, and suspended matter.

[4] *Annual Book of ASTM Standards*, Vol 05.02.
[5] *Annual Book of ASTM Standards*, Vol 05.03.
[6] *Annual Book of ASTM Standards*, Vol 05.04.
[7] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
[8] Available from Institute of Petroleum (IP), 61 New Cavendish St., London, WIG 7AR, U.K.

5. Requirements

5.1 The grades of diesel fuel oils herein specified shall be hydrocarbon oils conforming to the detailed requirements shown in Table 1.

5.2 *Grades No. 2-D and Low Sulfur No. 2–D*—When a cloud point less than −12°C is specified, the minimum flash point shall be 38°C, the minimum viscosity at 40°C shall be 1.7 mm^2/s, and the minimum 90 % recovered temperature shall be waived.

6. Keywords

6.1 diesel; fuel oil; petroleum and petroleum products; specification

TABLE 1 Detailed Requirements for Diesel Fuel Oils[A]

Property	ASTM Test Method[B]	Grade Low Sulfur No. 1-D[C]	Grade Low Sulfur No. 2-D[C,D]	Grade No. 1-D[E]	Grade No. 2-D[D,E]	Grade No. 4-D[E]
Flash Point, °C, min.	D 93	38	52[D]	38	52[D]	55
Water and Sediment, % vol, max	D 2709	0.05	0.05	0.05	0.05	...
	D 1796	...	...	...	...	0.50
Distillation Temperature, °C 90 % % vol Recovered	D 86					
min		...	282[D]	...	282[D]	...
max		288	338	288	338	...
Kinematic Viscosity, mm^2/S at 40°C	D 445					
min.		1.3	1.9[D]	1.3	1.9[D]	5.5
max	...	2.4	4.1	2.4	4.1	24.0
Ash % mass, max	D 482	0.01	0.01	0.01	0.01	0.10
Sulfur, % mass, max[F]	D 2622[G]	0.05	0.05	...	...	...
	D 129	...	...	0.50	0.50	2.00
Copper strip corrosion rating max 3 h at 50°C	D 130	No. 3	No. 3	No. 3	No. 3	...
Cetane number, min[H]	D 613	40[I]	40[I]	40[I]	40[I]	30[I]
One of the following properties must be met:						
(1) Cetane index, min.	D 976[G]	40	40	...	...	...
(2) Aromaticity, % vol, max	D 1319[G]	35	35	...	...	...
Operability Requirements						
Cloud point, °C, max	D 2500	[J]	[J]	[J]	[J]	[J]
or						
LTFT/CFPP, °C, max	D 4539/ D 6371					
Ramsbottom carbon residue on 10 % distillation residue, % mass, max	D 524	0.15	0.35	0.15	0.35	...

[A] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and manufacturer.
[B] The test methods indicated are the approved referee methods. Other acceptable methods are indicated in 3.1.
[C] Under United States regulations, if Grades Low Sulfur No. 1-D or Low Sulfur No. 2-D are sold for tax exempt purposes then, at or beyond terminal storage tanks, they are required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb per thousand barrels of the solid dye standard Solvent Red 26, or the tax must be collected.
[D] When a cloud point less than − 12°C is specified, the minimum flash point shall be 38°C, the minimum viscosity at 40°C shall be 1.7 mm^2/s, and the minimum 90 % recovered temperature shall be waived.
[E] Under United States regulations, Grades No.1–D, No. 2–D, and No. 4–D are required by 40 CFR Part 80 to contain a sufficient amount of the dye Solvent Red 164 so its presence is visually apparent. At or beyond terminal storage tanks, they are required by 26 CFR Part 48 to contain the dye Solvent Red 164 at a concentration spectrally equivalent to 3.9 lb per thousand barrels of the solid dye standard Solvent Red 26.
[F] Other sulfur limits can apply in selected areas in the United States and in other countries.
[G] These test methods are specified in 40 CFR Part 80.
[H] Where cetane number by Test Method D 613 is not available, Test Method D 4737 can be used as an approximation.
[I] Low ambient temperatures as well as engine operation at high altitudes may require the use of fuels with higher cetane ratings.
[J] It is unrealistic to specify low temperature properties that will ensure satisfactory operation at all ambient conditions. In general, cloud point (or wax appearance point) Low Temperature Flow Test, and Cold Filter Plugging Point Test may be used as an estimate of operating temperature limits for Grades Low Sulfur No. 1; Low Sulfur No. 2; and No. 1 and No. 2 diesel fuel oils. However, satisfactory operation below the cloud point (or wax appearance point) may be achieved depending on equipment design, operating conditions, and the use of flow-improver additives as described in X4.1.2. Appropriate low temperature operability properties should be agreed upon between the fuel supplier and purchaser for the intended use and expected ambient temperatures. Test Methods D 4539 and D 6371 may be especially useful to estimate vehicle low temperature operability limits when flow improvers are used. Due to fuel delivery system, engine design, and test method differences, low temperature operability tests may not provide the same degree of protection in various vehicle operating classes. Tenth percentile minimum air temperatures for U.S. locations are provided in Appendix X4 as a means of estimating expected regional temperatures. The tenth percentile minimum air temperatures may be used to estimate expected regional target temperatures for use with Test Methods D 2500, D 4539, and D 6371. Refer to X4.1.3 for further general guidance on test application.

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF ASTM SPECIFICATION FOR DIESEL FUEL OILS

X1.1 Introduction

X1.1.1 The properties of commercial fuel oils depend on the refining practices employed and the nature of the crude oils from which they are produced. Distillate fuel oils, for example, may be produced within the boiling range of 150 and 400°C having many possible combinations of various properties, such as volatility, ignition quality, viscosity, and other characteristics.

X1.2 Grades

X1.2.1 This specification is intended as a statement of permissible limits of significant fuel properties used for specifying the wide variety of commercially available diesel fuel oils. Limiting values of significant properties are prescribed for five grades of diesel fuel oils. These grades and their general applicability for use in diesel engines are broadly indicated as follows:

X1.2.2 *Grade Low Sulfur No. 1-D*—Grade Low Sulfur No. 1-D comprises the class of low-sulfur, volatile fuel oils from kerosine to the intermediate distillates. Fuels within this grade are applicable for use in high-speed engines that require low sulfur fuel and in services involving frequent and relatively wide variations in loads and speeds, and also for use in cases where abnormally low fuel temperatures are encountered.

X1.2.3 *Grade Low Sulfur No. 2-D*—Grade Low Sulfur No. 2-D includes the class of low-sulfur, distillate gas oils of lower volatility than Grade Low Sulfur No. 1-D. These fuels are applicable for use in high-speed engines that require low sulfur fuels and in services involving relatively high loads and uniform speeds, or in engines not requiring fuels having the higher volatility or other properties specified for Grade Low Sulfur No. 1-D.

X1.2.4 *Grade No. 1-D*—Grade No. 1-D comprises the class of volatile fuel oils from kerosine to the intermediate distillates. Fuels within this grade are applicable for use in high-speed engines in services involving frequent and relatively wide variations in loads and speeds, and also for use in cases where abnormally low fuel temperatures are encountered.

X1.2.5 *Grade No. 2-D*—Grade No. 2-D includes the class of distillate gas oils of lower volatility. These fuels are applicable for use in high-speed engines in services involving relatively high loads and uniform speeds, or in engines not requiring fuels having the higher volatility or other properties specified for Grade No. 1-D.

X1.2.6 *Grade No. 4-D*—Grade No. 4-D covers the class of more viscous distillates and blends of these distillates with residual fuel oils. These fuels are applicable for use in low- and medium-speed engines employed in services involving sustained loads at substantially constant speed.

X1.3 Selection of Particular Grade

X1.3.1 The selection of a particular diesel fuel oil from one of these three ASTM grades for use in a given engine requires consideration of the following factors:

X1.3.1.1 Fuel price and availability,

X1.3.1.2 Maintenance considerations,

X1.3.1.3 Engine size and design,

X1.3.1.4 Emission control systems,

X1.3.1.5 Speed and load ranges,

X1.3.1.6 Frequency of speed and load changes, and

X1.3.1.7 Atmospheric conditions. Some of these factors can influence the required fuel properties outlined as follows:

X1.4 Cetane Number

X1.4.1 Cetane number is a measure of the ignition quality of the fuel and influences combustion roughness. The cetane number requirements depend on engine design, size, nature of speed and load variations, and on starting and atmospheric conditions. Increase in cetane number over values actually required does not materially improve engine performance. Accordingly, the cetane number specified should be as low as possible to assure maximum fuel availability.

X1.5 Distillation

X1.5.1 The fuel volatility requirements depend on engine design, size, nature of speed and load variations, and starting and atmospheric conditions. For engines in services involving rapidly fluctuating loads and speeds as in bus and truck operation, the more volatile fuels may provide best performance, particularly with respect to smoke and odor. However, best fuel economy is generally obtained from the heavier types of fuels because of their higher heat content.

X1.6 Viscosity

X1.6.1 For some engines it is advantageous to specify a minimum viscosity because of power loss due to injection pump and injector leakage. Maximum viscosity, on the other hand, is limited by considerations involved in engine design and size, and the characteristics of the injection system.

X1.7 Carbon Residue

X1.7.1 Carbon residue gives a measure of the carbon depositing tendencies of a fuel oil when heated in a bulb under prescribed conditions. While not directly correlating with engine deposits, this property is considered an approximation.

X1.8 Sulfur

X1.8.1 The effect of sulfur content on engine wear and deposits appears to vary considerably in importance and depends largely on operating conditions. Fuel sulfur can affect emission control systems performance. To assure maximum availability of fuels, the permissible sulfur content should be specified as high as is practicable, consistent with maintenance considerations.

X1.9 Flash Point

X1.9.1 The flash point as specified is not directly related to engine performance. It is, however, of importance in connection with legal requirements and safety precautions involved in fuel handling and storage, and is normally specified to meet insurance and fire regulations.

X1.10 Cloud Point

X1.10.1 Cloud point is of importance in that it defines the temperature at which a cloud or haze of wax crystals appears in the oil under prescribed test conditions which generally relates to the temperature at which wax crystals begin to precipitate from the oil in use.

X1.11 Ash

X1.11.1 Ash-forming materials may be present in fuel oil in two forms: *(1)* abrasive solids, and *(2)* soluble metallic soaps. Abrasive solids contribute to injector, fuel pump, piston and ring wear, and also to engine deposits. Soluble metallic soaps have little effect on wear but may contribute to engine deposits.

X1.12 Copper Strip Corrosion

X1.12.1 This test serves as a measure of possible difficulties with copper and brass or bronze parts of the fuel system.

X1.13 Aromaticity

X1.13.1 This test is used as an indication of the aromatic contents of diesel fuel. Aromatic content is specified to prevent an increase in the average aromatics in Grades Low Sulfur No.

1-D and Low Sulfur No. 2-D fuels. Increases in aromatic content of fuels over current levels may have a negative impact on emissions.

X1.14 Cetane Index

X1.14.1 Cetane Index is specified as a limitation on the amount of high aromatic components in Grades Low Sulfur No. 1-D and Low Sulfur No. 2-D.

X1.15 Other

X1.15.1 *Microbial Contamination*—Refer to Guide D 6469 for a discussion of this form of contamination.

X2. STORAGE AND THERMAL STABILITY OF DIESEL FUELS

X2.1 Scope

X2.1.1 This appendix provides guidance for consumers of diesel fuels who may wish to store quantities of fuels for extended periods or use the fuel in severe service or high temperature applications. Fuels containing residual components are excluded. Consistently successful long-term fuel storage or use in severe applications requires attention to fuel selection, storage conditions, handling and monitoring of properties during storage and prior to use.

X2.1.2 Normally produced fuels have adequate stability properties to withstand normal storage and use without the formation of troublesome amounts of insoluble degradation products. Fuels that are to be stored for prolonged periods or used in severe applications should be selected to avoid formation of sediments or gums, which can overload filters or plug injectors. Selection of these fuels should result from supplier-user discussions.

X2.1.3 These suggested practices are general in nature and should not be considered substitutes for any requirements imposed by the warranty of the distillate fuel equipment manufacturer or by federal, state, or local government regulations. Although they cannot replace a knowledge of local conditions or good engineering and scientific judgment, these suggested practices do provide guidance in developing an individual fuel management system for the middle distillate fuel user. They include suggestions in the operation and maintenance of existing fuel storage and handling facilities and for identifying where, when, and how fuel quality should be monitored or selected for storage or severe use.

X2.2 Definitions

X2.2.1 *bulk fuel*—fuel in the storage facility.

X2.2.2 *fuel contaminants*—foreign materials that make fuel less suitable or unsuitable for the intended use.

X2.2.2.1 *Discussion*—Fuel contaminants include materials introduced subsequent to the manufacture of fuel and fuel degradation products.

X2.2.3 *fuel-degradation products*—those materials that are formed in fuel during extended storage or exposure to high temperatures.

X2.2.3.1 *Discussion*—Insoluble degradation products may combine with other fuel contaminants to reinforce deleterious effects. Soluble degradation products (soluble gums) are less volatile than fuel and may carbonize to form deposits due to complex interactions and oxidation of small amounts of olefinic or sulfur-, oxygen- or nitrogen-containing compounds present in fuels. The formation of degradation products may be catalyzed by dissolved metals, especially copper salts. When dissolved copper is present it can be deactivated with metal deactivator additives.

X2.2.4 *long-term storage*—storage of fuel for longer than 12 months after it is received by the user.

X2.2.5 *severe use*—use of the fuel in applications which may result in engines operating under high load conditions that may cause the fuel to be exposed to excessive heat.

X2.3 Fuel Selection

X2.3.1 Certain distilled refinery products are generally more suitable for long-term storage and severe service than others. The stability properties of middle distillates are highly dependent on the crude oil sources, severity of processing, use of additives and whether additional refinery treatment has been carried out.

X2.3.2 The composition and stability properties of middle distillate fuels produced at specific refineries may be different. Any special requirements of the user, such as long-term storage or severe service, should be discussed with the supplier.

X2.3.3 Blends of fuels from various sources may interact to give stability properties worse than expected based on the characteristics of the individual fuels.

X2.4 Fuel Additives

X2.4.1 Available fuel additives can improve the suitability of marginal fuels for long-term storage and thermal stability, but may be unsuccessful for fuels with markedly poor stability properties. Most additives should be added at the refinery or during the early weeks of storage to obtain maximum benefits.

X2.4.2 Biocides or biostats destroy or inhibit the growth of fungi and bacteria, which can grow at fuel-water interfaces to give high particulate concentrations in the fuel. Available biocides are soluble in both the fuel and water or in the water phase only.

X2.5 Tests for Fuel Quality

X2.5.1 At the time of manufacture, the storage stability of fuel may be assessed using Test Method D 2274 or D 5304. However, these accelerated stability tests may not correlate well with field storage stability due to varying field conditions and to fuel composition.

X2.5.2 Performance criteria for accelerated stability tests that assure satisfactory long-term storage of fuels have not been established.

X2.5.3 Test Method D 6468, provides an indication of thermal oxidative stability of middle distillate fuels when heated to temperatures near 150°C.

X2.6 Fuel Monitoring

X2.6.1 A plan for monitoring the quality of bulk fuel during prolonged storage is an integral part of a successful program. A plan to replace aged fuel with fresh product at established intervals is also desirable.

X2.6.2 Stored fuel should be periodically sampled and its quality assessed. Practice D 4057 provides guidance for sampling. Fuel contaminants and degradation products will usually settle to the bottom of a quiescent tank. A "Bottom" or "Clearance" sample, as defined in Practice D 4057, should be included in the evaluation along with an "All Level" sample.

X2.6.3 The quantity of insoluble fuel contaminants present in fuel can be determined using Test Method D 6217.

X2.6.4 Test Method D 6468, can be used for investigation of operational problems that might be related to fuel thermal stability. Testing samples from the fuel tank or from bulk storage may give an indication as to the cause of filter plugging. It is more difficult to monitor the quality of fuels in vehicle tanks since operation may be on fuels from multiple sources.

X2.6.5 Some additives exhibit effects on fuels tested in accordance with Test Method D 6468 that may or may not be observed in the field. Data have not been developed that correlate results from the test method for various engine types and levels of operating severity.

X2.7 Fuel Storage Conditions

X2.7.1 Contamination levels in fuel can be reduced by storage in tanks kept free of water, and tankage should have provisions for water draining on a scheduled basis. Water promotes corrosion, and microbiological growth may occur at a fuel-water interface. Underground storage is preferred to avoid temperature extremes; above-ground storage tanks should be sheltered or painted with reflective paint. High storage temperatures accelerate fuel degradation. Fixed roof tanks should be kept full to limit oxygen supply and tank breathing.

X2.7.2 Copper and copper-containing alloys should be avoided. Copper can promote fuel degradation and may produce mercaptide gels. Zinc coatings can react with water or organic acids in the fuel to form gels that rapidly plug filters.

X2.7.3 Appendix X2 of Specification D 2880 discusses fuel contaminants as a general topic.

X2.8 Fuel Use Conditions

X2.8.1 Many diesel engines are designed so that the diesel fuel is used for heat transfer. In modern heavy-duty diesel engines, for example, only a portion of the fuel that is circulated to the fuel injectors is actually delivered to the combustion chamber. The remainder of the fuel is circulated back to the fuel tank, carrying heat with it. Thus adequate high temperature stability can be a necessary requirement in some severe applications or types of service.

X2.8.2 Inadequate high temperature stability may result in the formation of insoluble degradation products.

X2.9 Use of Degraded Fuels

X2.9.1 Fuels that have undergone mild-to-moderate degradation can often be consumed in a normal way, depending on the fuel system requirements. Filters and other cleanup equipment can require special attention and increased maintenance. Burner nozzle or injector fouling can occur more rapidly.

X2.9.2 Fuels containing very large quantities of fuel degradation products and other contaminants or with runaway microbiological growth require special attention. Consultation with experts in this area is desirable. It can be possible to drain the sediment or draw off most of the fuel above the sediment layer and use it with the precautions described in X2.9.1. However, very high soluble gum levels or corrosion products from microbiological contamination can cause severe operational problems.

X3. DIESEL FUEL LUBRICITY

X3.1 Introduction

X3.1.1 Diesel fuel functions as a lubricant in certain items of fuel injection equipment such as rotary/distributor fuel pumps and injectors. In limited cases, fuel with very specific properties can have insufficient lubricating properties which can lead to a reduction in the normal service life of fuel pumps or injectors.

X3.2 Fuel Characteristics Affecting Equipment Wear

X3.2.1 Two fuel characteristics that affect equipment wear are low viscosity and lack of sufficient quantities of trace components, which have an affinity for metal surfaces. If fuel viscosity meets the requirements of a particular engine, a fuel film is maintained between the moving surfaces of the fuel system components. This prevents excessive metal-to-metal contact and avoids premature failure due to wear. Similarly, certain surface active molecules in the fuel adhere to, or combine with, metallic surfaces to produce a protective film which also can protect surfaces against excessive wear.

X3.3 Fuel Lubricity

X3.3.1 The concern about fuel lubricity is limited to situations in which fuels with lower viscosities than those specified for a particular engine are used or with fuels which have been processed in a manner that results in the elimination of the trace levels of the surface active species that act as lubricating agents. Presently the only fuels of the latter type shown to have lubricity problems resulted from sufficiently severe processing to reduce aromatics substantially below current levels. Research is in progress to identify the characteristics of such fuels and where the use of a lubricity improver additive is required, to ensure satisfactory operation in the sensitive areas of the vehicle fuel system.

X3.3.2 Work in the area of diesel fuel lubricity is ongoing by several organizations, such as the International Standard Organization (ISO) and the ASTM Diesel Fuel Lubricity Task Force. These groups include representatives from the fuel injection equipment manufacturers, fuel producers, and additive suppliers. The charge of the ASTM task force has been the recommendation of test methods and a fuel specification for Specification D 975. Two test methods were proposed and approved. These are Test Method D 6078, a scuffing load ball-on-cylinder lubricity evaluator method, SLBOCLE, and Test Method D 6079, a high frequency reciprocating rig method, HFRR. The inclusion of a single fuel specification in the main table for Grade No. 2 requires further research because 1) the correlation of the data among the two test methods and the fuel injection equipment needs further clarification, 2) both methods in their current from do not apply to all fuel-additive combinations, and 3) the reproducibility values for both test methods are large. In the meantime, the following information may be of use and serve as a general guideline to fuel suppliers and users.

X3.3.3 The following guidelines are generally accepted and may be used in the absence of a single test method and a single fuel lubricity value: Fuels having a SLBOCLE lubricity value below 2000 g might not prevent excessive wear in injection equipment[9] while fuels with values above 3100 g should provide sufficient lubricity in all cases.[10] If HFFR at 60°C is used, fuels with values above 600 microns might not prevent excessive wear[11] while fuels with values below 450 microns should provide sufficient lubricity in all cases.[10] More accurately, an industry-accepted long-term durability pump test, such as the ones used on a test stand or in a vehicle, can be used to evaluate the lubricity of a diesel fuel. A poor result in such a test indicates that the fuel has low lubricity and can cause excessive wear.

NOTE X3.1—Some injection equipment can be fitted with special components that can tolerate low lubricity fuels.

[9] Westbrook, S. R., "Survey of Low Sulfur Diesel Fuels and Aviation Kerosenes from U.S. Military Installations," SAE Technical Paper 952369, 1995.

[10] Nikanjam, M., "ISO Diesel Fuel Lubricity Round Robin Program," SAE Technical Paper 952372, 1995.

[11] Nikanjam, M., "*Diesel Fuel Lubricity: On the Path to Specifications*," SAE Technical Paper 1999-01-1479, 1999.

X4. TENTH PERCENTILE MINIMUM AMBIENT AIR TEMPERATURES FOR THE UNITED STATES (EXCEPT HAWAII)

X4.1 Introduction

X4.1.1 The tenth percentile minimum ambient air temperatures shown on the following maps (Figs. X4.1-X4.12) and in Table X4.1 were derived from an analysis of historical hourly temperature readings recorded over a period of 15 to 21 years from 345 weather stations in the United States. This study was conducted by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, Aberdeen Proving Ground, MD 21005. The tenth percentile minimum ambient air temperature is defined as the lowest ambient air temperature which will not go lower on average more than 10 % of the time. In other words, the daily minimum ambient air temperature would on average not be expected to go below the monthly tenth percentile minimum ambient air temperature more than 3 days for a 30-day month. See Table X4.1.

X4.1.2 These data may be used to estimate low temperature operability requirements. In establishing low temperature operability requirements, consideration should be given to the following. These factors, or any combination, may make low temperature operability more or less severe than normal. As X4.1.2.1 through X4.1.2.12 indicate, field work suggests that cloud point (or wax appearance point) is a fair indication of the low temperature operability limit of fuels without cold flow additives in most vehicles.

X4.1.2.1 Long term weather patterns (Average winter low temperatures will be exceeded on occasion).

X4.1.2.2 Short term local weather conditions (Unusual cold periods do occur).

X4.1.2.3 Elevation (High locations are usually colder than surrounding lower areas).

X4.1.2.4 Specific engine design.

X4.1.2.5 Fuel system design (Recycle rate, filter location, filter capacity, filter porosity, and so forth.)

X4.1.2.6 Fuel viscosity at low temperatures

X4.1.2.7 Equipment add-ons (Engine heaters, radiator covers, fuel line and fuel filter heaters and so forth.)

X4.1.2.8 Types of operation (Extensive idling, engine shutdown, or unusual operation).

X4.1.2.9 Low temperature flow improver additives in fuel.

X4.1.2.10 Geographic area for fuel use and movement between geographical areas.

X4.1.2.11 General housekeeping (Dirt and/or water in fuel or fuel supply system).

X4.1.2.12 Impact failure for engine to start or run (Critical vs. non-critical application).

X4.1.3 *Historical Background*—Three test methods have been widely used to estimate or correlate with low temperature vehicle operability. Cloud point, Test Method D 2500, is the oldest of the three and most conservative of the tests. The cloud point test indicates the earliest appearance of wax precipitation that might result in plugging of fuel filters or fuel lines under prescribed cooling conditions. Although not 100 % failsafe, it is the most appropriate test for applications that can not tolerate much risk. The Cold Filter Plugging Point (CFPP) test, Test Method D 6371, was introduced in Europe in 1965. The CFPP was designed to correlate with the majority of European vehicles. Under rapid cooling conditions, 20 cc fuel is drawn through a 45 micron screen then allowed to flow back through

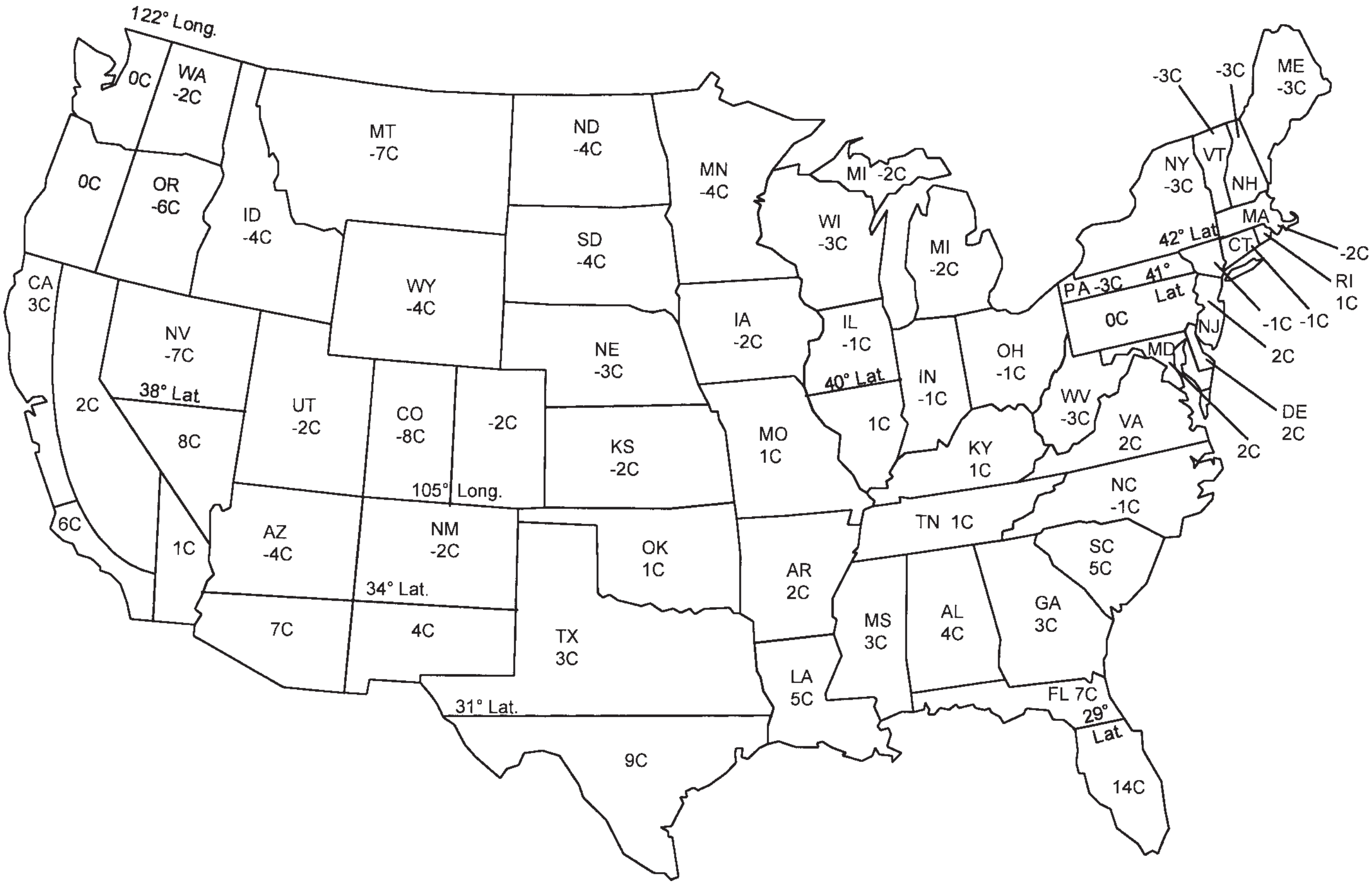

FIG. X4.1 October—10th Percentile Minimum Temperatures

the screen for further cooling. This process is continued every 1°C until either the 20 cc fuel fails to be drawn through the screen in 60 s or it fails to return through the screen in 60 s. It was field tested many times in Europe[12] before being widely accepted as a European specification. Field tests have also shown CFPP results more than 10°C below the cloud point should be viewed with caution because those results did not necessarily reflect the true vehicle low temperature operability limits.[13] CFPP has been applied to many areas of the world where similar vehicle designs are used. The Low Temperature Flow Test (LTFT), Test Method D 4539, was designed to correlate with the most severe and one of the most common fuel delivery systems used in North American Heavy Duty trucks. Under prescribed slow cool conditions (1°C/h), similar to typical field conditions, several 200 cc fuel specimens in glass containers fitted with 17 µm screen assemblies are cooled. At 1°C intervals one specimen is drawn through the screen under a 20 kPa vacuum. Approximately 90 % of the fuel must come over in 60 s or less for the result to be a pass. This process is continued at lower temperatures (1°C increments) until the fuel fails to come over in the allotted 60 s. The lowest passing temperature is defined as the LTFT for that fuel. In 1981, a CRC program was conducted to evaluate the efficacy of cloud point, CFPP, pour point, and LTFT for protecting the diesel vehicle population in North America and to determine what benefit flow-improvers could provide. The field test consisted of 3 non-flow improved diesel fuels, 5 flow improved diesel fuels, 4 light-duty passenger cars, and 3 heavy-duty trucks. The field trial resulted in two documents[14,15] that provide insight into correlating laboratory tests to North American vehicle performance in the field. The general conclusions of the study were:

(1) In overnight cool down, 30 % of the vehicles tested had a final fuel tank temperature within 2°C of the overnight minimum ambient temperature.

(2) The use of flow-improved diesel fuel permits some vehicles to operate well below the fuel cloud point.

(3) Significant differences exist in the severity of diesel vehicles in terms of low temperature operation.

(4) No single laboratory test was found that adequately predicts the performance of all fuels in all vehicles.

(5) CFPP was a better predictor than pour point, but both methods over-predicted, minimum operating temperatures in many vehicles. For this reason, these tests were judged

[12] "Low Temperature Operability of Diesels. A Report by CEC Investigation Group IGF-3," CEC P-171–82.

[13] "SFPP-A New Laboratory Test for Assessment of Low Temperature Operability of Modern Diesel Fuels," CEC/93/EF 15, 5–7, May 1993.

[14] CRC Report No. 537, "The Relationship Between Vehicle Fuel Temperature and Ambient Temperature, 1981 CRC Kapuskasing Field Test," December 1983.

[15] CRC Report No. 528, "1981 CRC Diesel Fuel Low-Temperature Operability Field Test," September 1983.

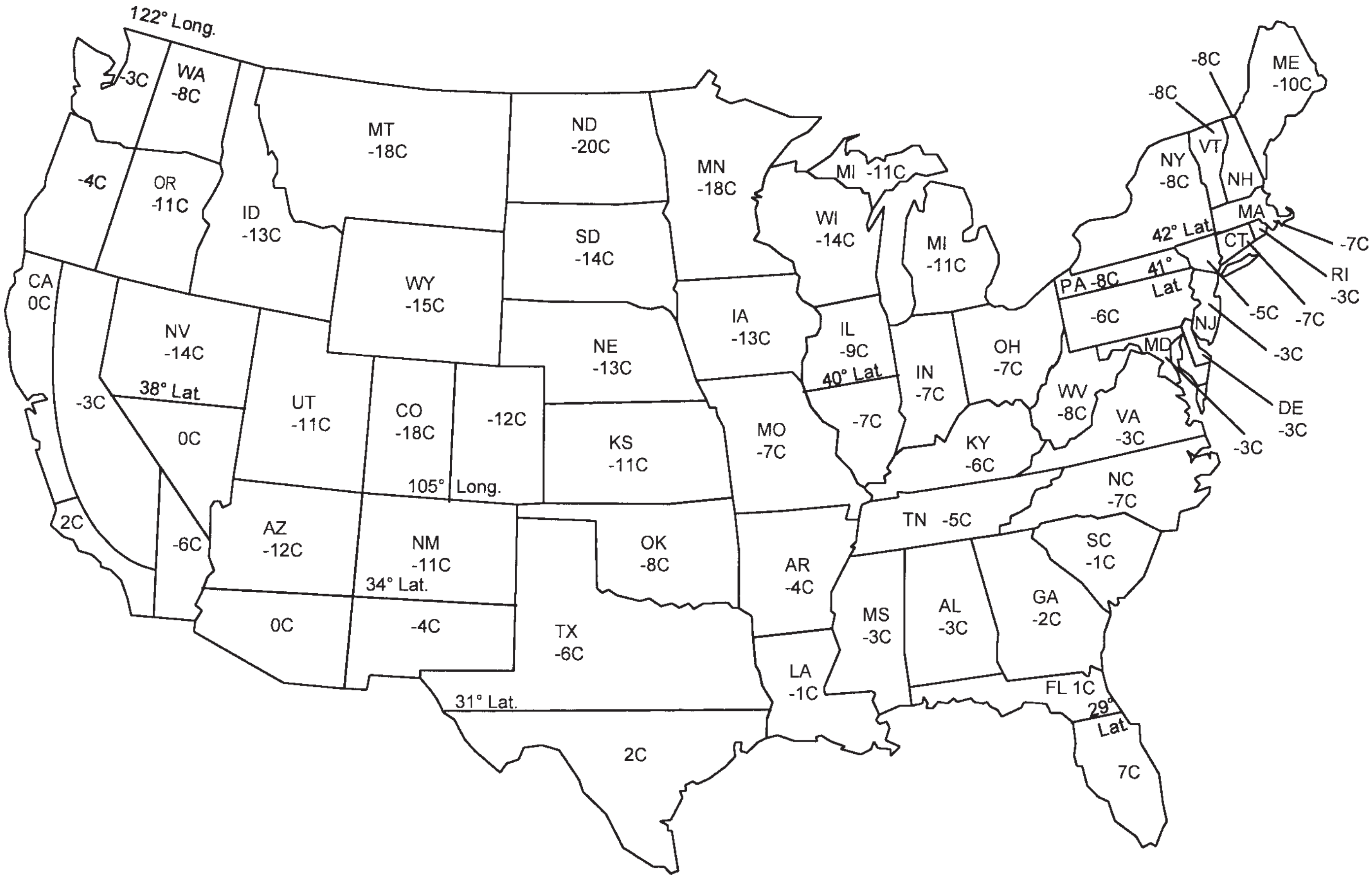

FIG. X4.2 November—10th Percentile Minimum Ambient Air Temperatures

inadequate predictors of low-temperature performance and dismissed from further consideration.

(6) Cloud point and LTFT showed varying degrees of predictive capability, and offered distinctively different advantages. Both predicted the performance of the base fuels well, but LTFT more accurately predicted the performance of the flow-improved fuels. On the other hand, cloud point came closest to a fail-safe predictor of vehicle performance for all vehicles.

Since the 1981 field test, non-independent studies[16] using newer vehicles verified the suitability of the LTFT for North American heavy-duty trucks. Users are advised to review these and any more recent publications when establishing low temperature operability requirements and deciding upon test methods.

X4.1.3.1 *Current Practices*—It is recognized that fuel distributors, producers, and end users in the United States use cloud point, wax appearance point, CFPP, and LTFT to estimate vehicle low temperature operability limits for diesel fuel. No independent data has been published in recent years to determine test applicability for today's fuels and vehicles.

[16] SAE 962197, SAE 982576, SAE 2000-01-2883.

X4.2 Maps

X4.2.1 The maps in the following figures were derived from CCL Report No. 316, "A Predictive Study for Defining Limiting Temperatures and Their Application in Petroleum Product Specifications," by John P. Doner. This report was published by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC), Coating and Chemical Laboratory, and it is available from the National Technical Information Service, Springfield, VA 22151, by requesting Publication No. AD756-420.

X4.2.2 Where states are divided the divisions are noted on the maps and table with the exception of California, which is divided by counties as follows:

California, North Coast—Alameda, Contra Costa, Del Norte, Humbolt, Lake, Marin, Mendocino, Monterey, Napa, San Benito, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity.

California, Interior—Lassen, Modoc, Plumas, Sierra, Siskiyou, Alpine, Amador, Butte, Calaveras, Colusa, El Dorado, Fresno, Glenn, Kern (except that portion lying east of the Los Angeles County Aqueduct), Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Yolo, Yuba, Nevada.

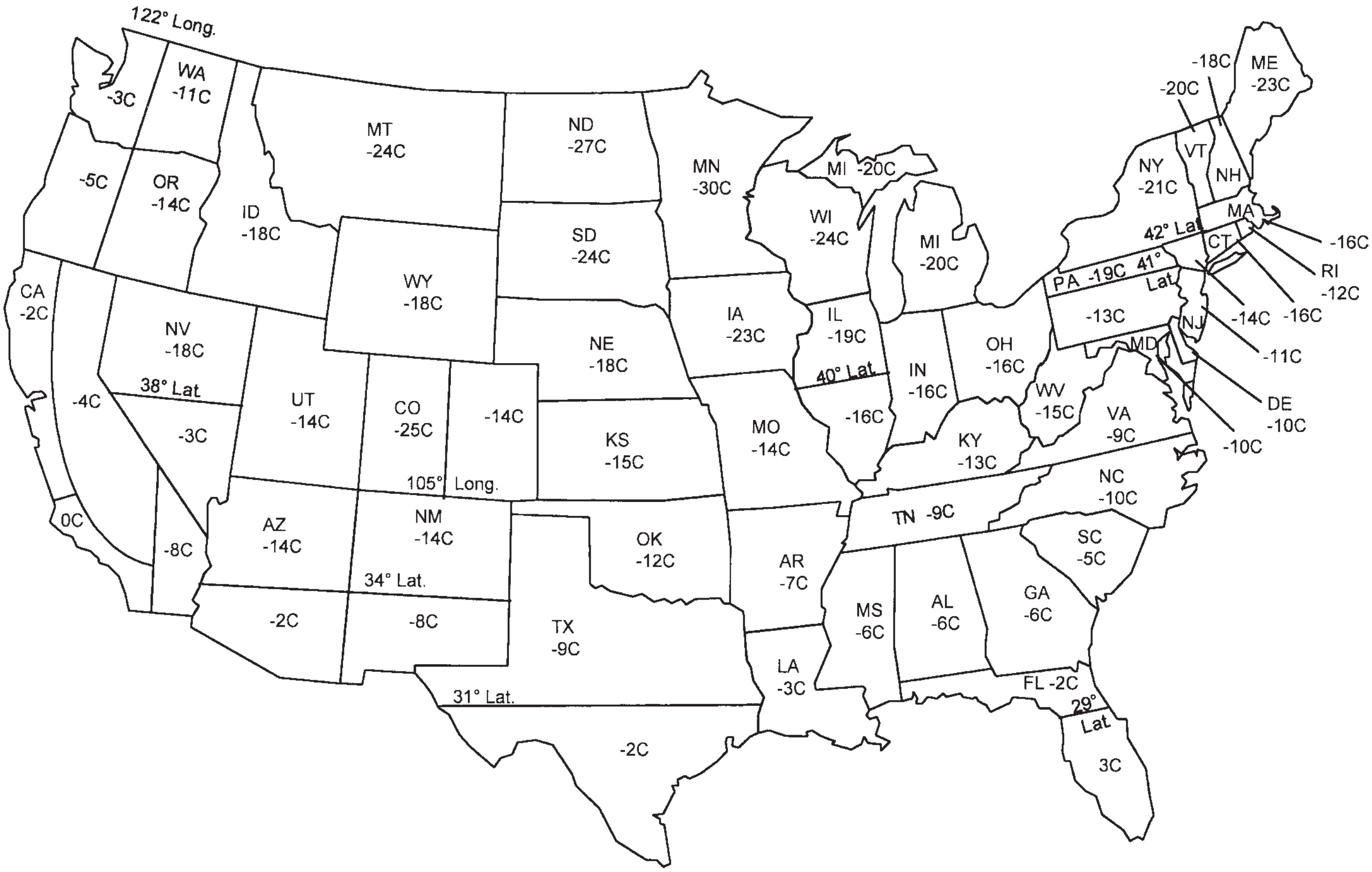

FIG. X4.3 December—10th Percentile Minimum Ambient Air Temperatures

California, South Coast—Orange, San Diego, San Luis Obispo, Santa Barbara, Ventura, Los Angeles (except that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct).

California, Southeast—Imperial, Riverside, San Bernardino, Los Angeles (that portion north of the San Gabriel Mountain range and east of the Los Angeles County Aqueduct), Mono, Inyo, Kern (that portion lying east of the Los Angeles County Aqueduct).

X4.2.3 The temperatures in CCL Report No. 316 were in degrees Fahrenheit. The degree Celsius temperatures in Appendix X4 were obtained by converting the original degree Fahrenheit temperatures.

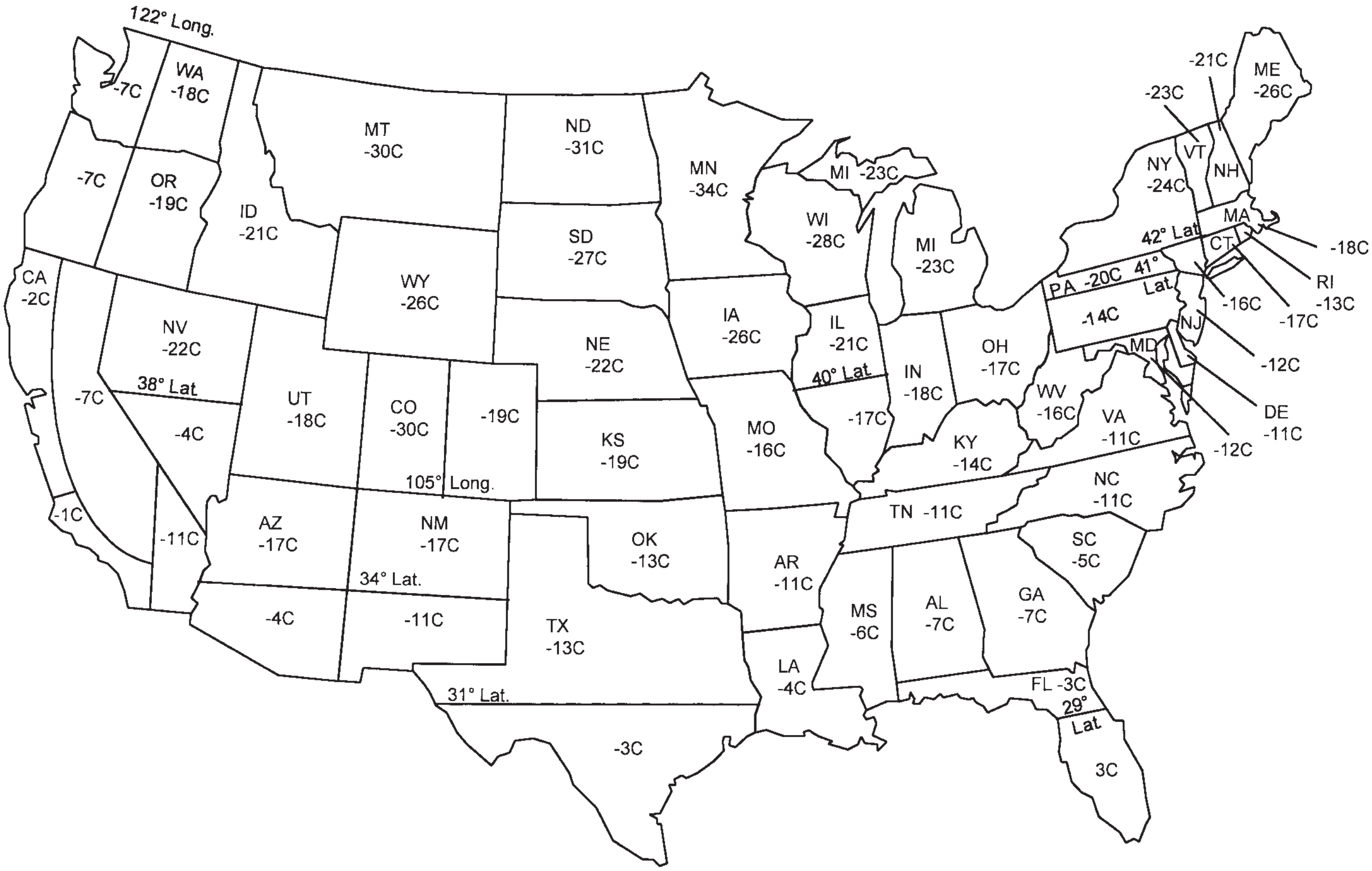

FIG. X4.4 January—10th Percentile Minimum Ambient Air Temperatures

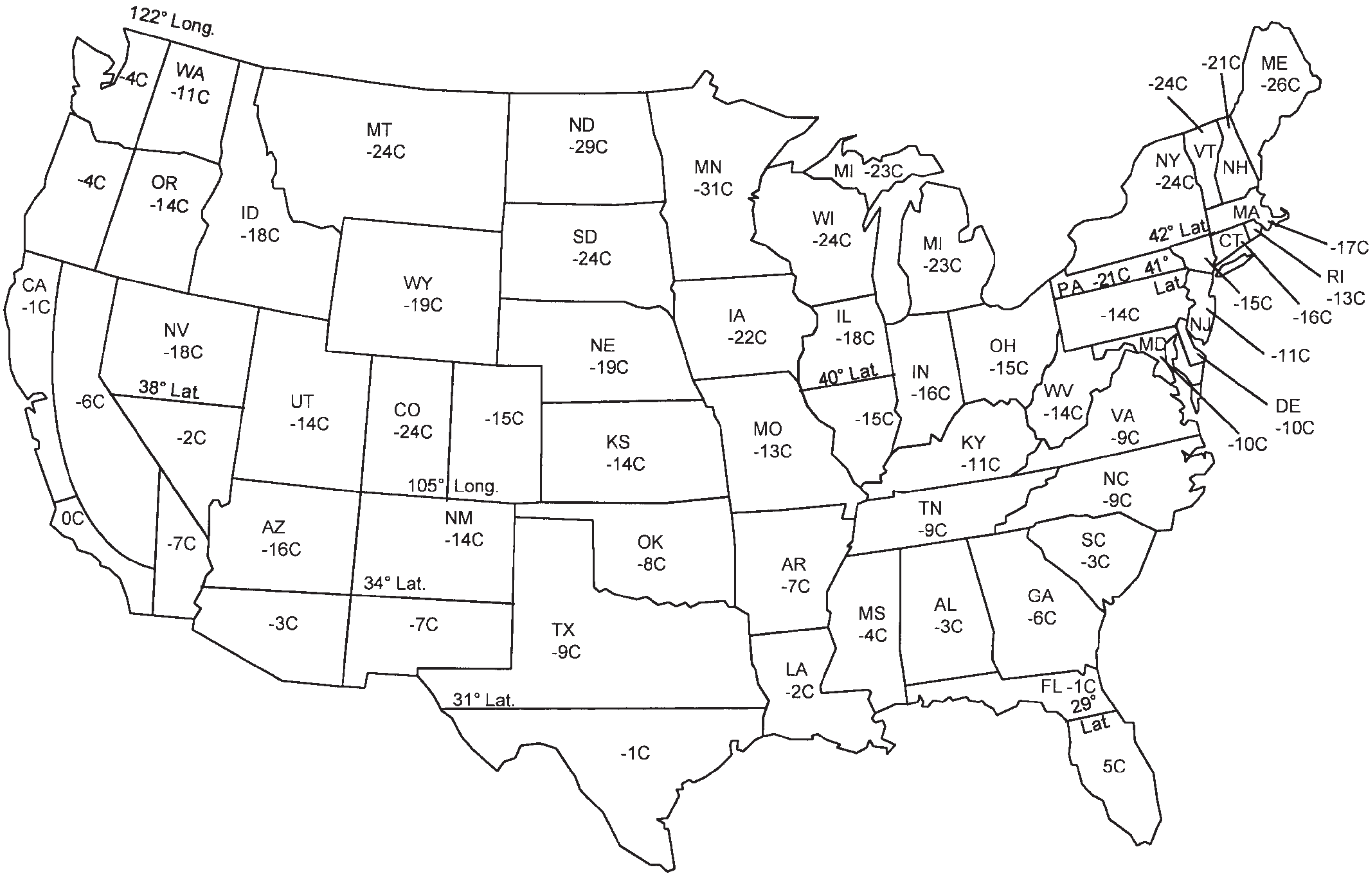

FIG. X4.5 February—10th Percentile Minimum Ambient Air Temperatures

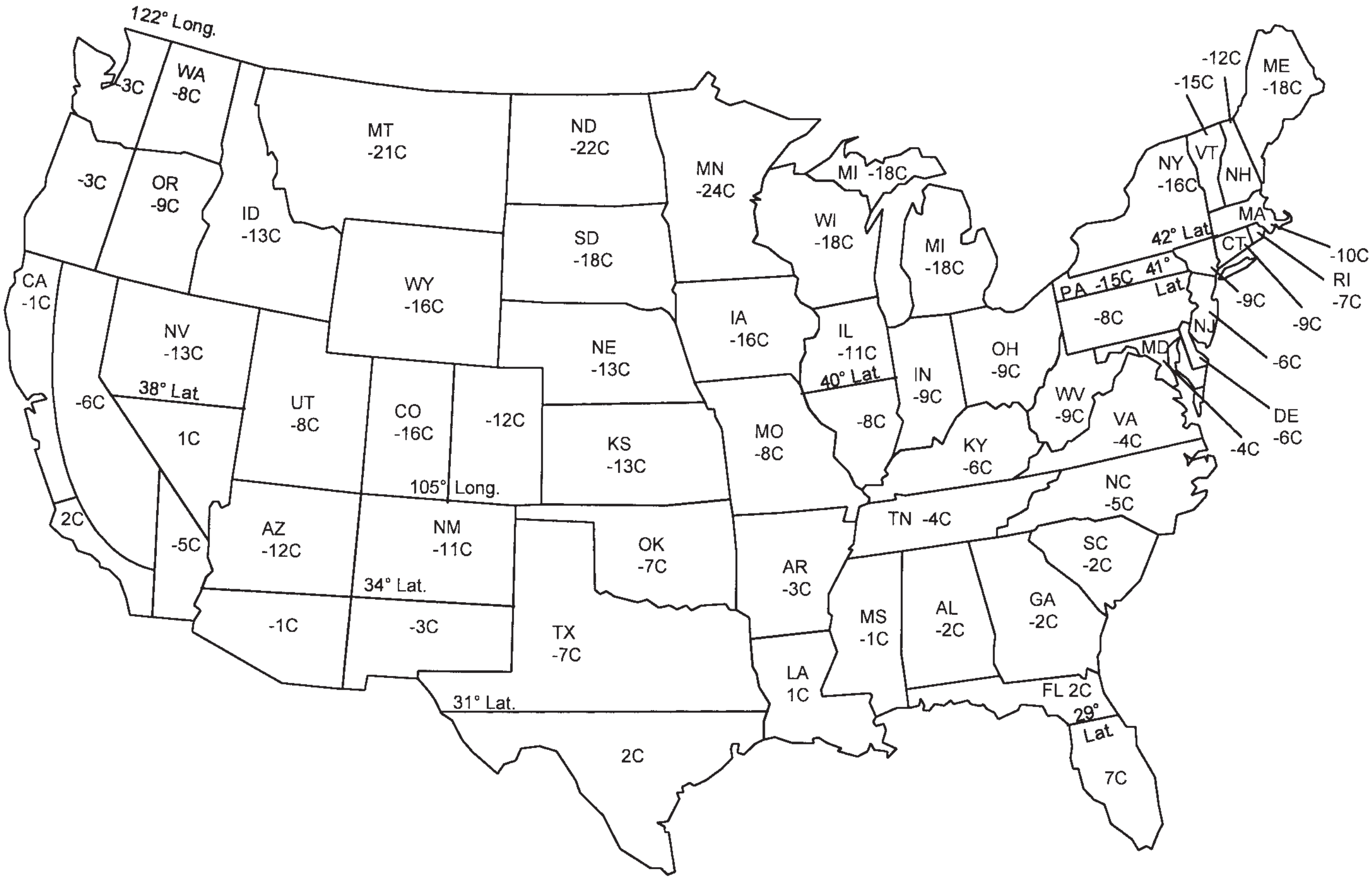

FIG. X4.6 March—10th Percentile Minimum Ambient Air Temperatures

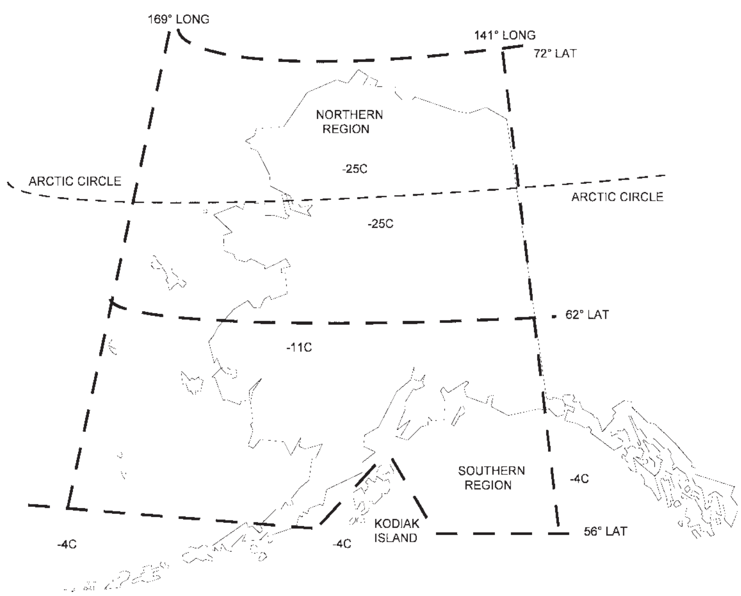

FIG. X4.7 October—10th Percentile Minimum Ambient Air Temperatures

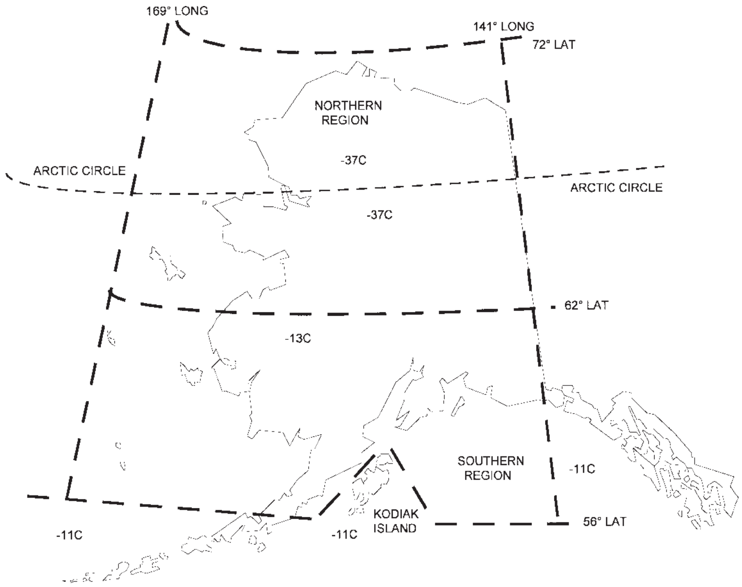

FIG. X4.8 November—10th Percentile Minimum Ambient Air Temperatures

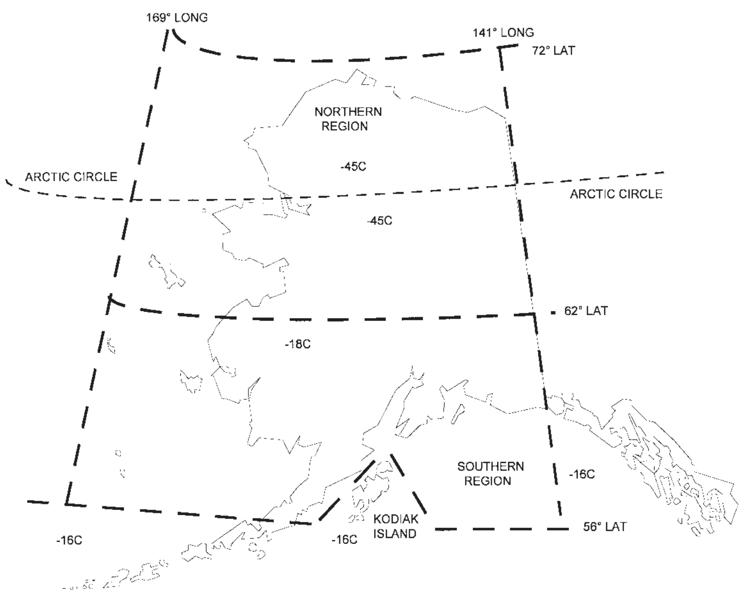

FIG. X4.9 December—10th Percentile Minimum Ambient Air Temperatures

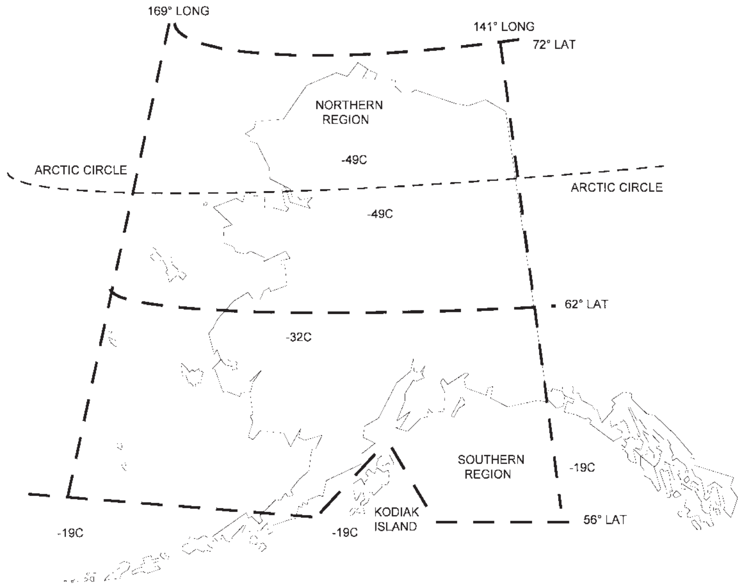

FIG. X4.10 January—10th Percentile Minimum Ambient Air Temperatures

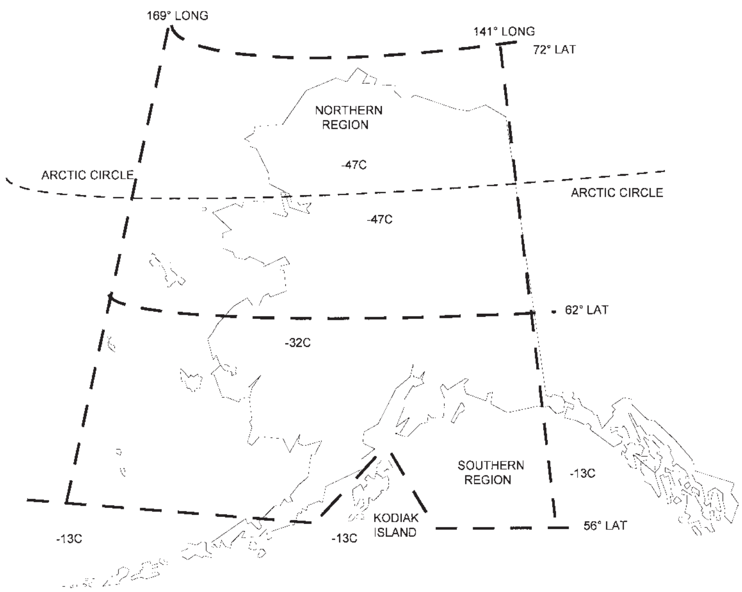

FIG. X4.11 February—10th Percentile Minimum Ambient Air Temperatures

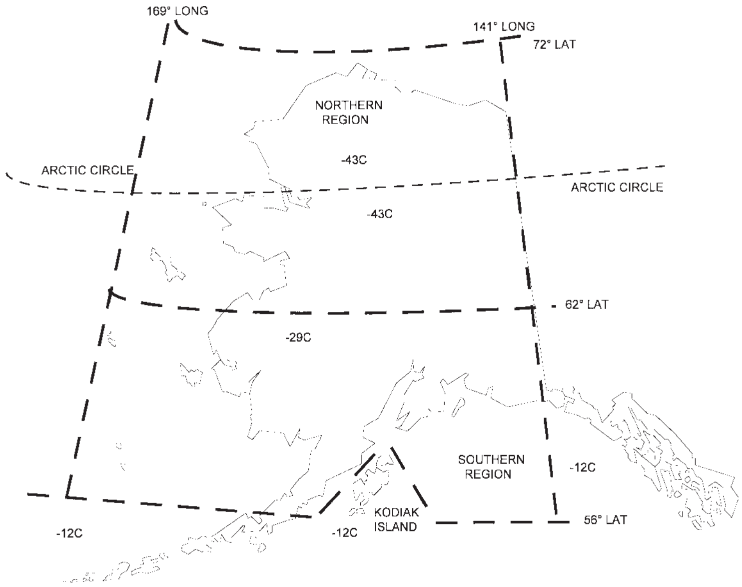

FIG. X4.12 March—10th Percentile Minimum Ambient Air Temperatures

TABLE X4.1 Tenth Percentile Minimum Ambient Air Temperatures for the United States (except Hawaii)

State		10th Percentile Temperature°C, min					
		Oct.	Nov.	Dec.	Jan.	Feb.	March
Alabama		4	−3	−6	−7	−3	−2
Alaska	Northern	−25	−37	−45	−49	−47	−43
	Southern	−11	−13	−18	−32	−32	−29
	South East	−4	−11	−16	−19	−13	−12
Arizona	North 34° latitude	−4	−12	−14	−17	−16	−12
	South 34° latitude	7	0	−2	−4	−3	−1
Arkansas		2	−4	−7	−11	−7	−3
California	North Coast	3	0	−2	−2	−1	−1
	Interior	2	−3	−4	−7	−6	−6
	South Coast	6	2	0	−1	0	2
	Southeast	1	−6	−8	−11	−7	−5
Colorado	East 105° long	−2	−12	−14	−19	−15	−12
	West 105° long	−8	−18	−25	−30	−24	−16
Connecticut		−1	−7	−16	−17	−16	−9
Delaware		2	−3	−10	−11	−10	−6
Florida	North 29° latitude	7	1	−2	−3	−1	2
	South 29° latitude	14	7	3	3	5	7
Georgia		3	−2	−6	−7	−6	−2
Idaho		−4	−13	−18	−21	−18	−13
Illinois	North 40° latitude	−1	−9	−19	−21	−18	−11
	South 40° latitude	1	−7	−16	−17	−15	−8
Indiana		−1	−7	−16	−18	−16	−9
Iowa		−2	−13	−23	−26	−22	−16
Kansas		−2	−11	−15	−19	−14	−13
Kentucky		1	−6	−13	−14	−11	−6
Louisiana		5	−1	−3	−4	−2	1
Maine		−3	−10	−23	−26	−26	−18
Maryland		2	−3	−10	−12	−10	−4
Massachusetts		−2	−7	−16	−18	−17	−10
Michigan		−2	−11	−20	−23	−23	−18
Minnesota		−4	−18	−30	−34	−31	−24
Mississippi		3	−3	−6	−6	−4	−1
Missouri		1	−7	−14	−16	−13	−8
Montana		−7	−18	−24	−30	−24	−21
Nebraska		−3	−13	−18	−22	−19	−13
Nevada	North 38° latitude	−7	−14	−18	−22	−18	−13
	South 38° latitude	8	0	−3	−4	−2	1
New Hampshire		−3	−8	−18	−21	−21	−12
New Jersey		2	−3	−11	−12	−11	−6
New Mexico	North 34° latitude	−2	−11	−14	−17	−14	−11
	South 34° latitude	4	−4	−8	−11	−7	−3
New York	North 42° latitude	−3	−8	−21	−24	−24	−16
	South 42° latitude	−1	−5	−14	−16	−15	−9
North Carolina		−1	−7	−10	−11	−9	−5
North Dakota		−4	−20	−27	−31	−29	−22
Ohio		−1	−7	−16	−17	−15	−9
Oklahoma		1	−8	−12	−13	−8	−7
Oregon	East 122° long	−6	−11	−14	−19	−14	−9
	West 122° long	0	−4	−5	−7	−4	−3
Pennsylvania	North 41° latitude	−3	−8	−19	−20	−21	−15
	South 41° latitude	0	−6	−13	−14	−14	−8
Rhode Island		1	−3	−12	−13	−13	−7
South Carolina		5	−1	−5	−5	−3	−2
South Dakota		−4	−14	−24	−27	−24	−18
Tennessee		1	−5	−9	−11	−9	−4
Texas	North 31° latitude	3	−6	−9	−13	−9	−7
	South 31° latitude	9	2	−2	−3	−1	2
Utah		−2	−11	−14	−18	−14	−8
Vermont		−3	−8	−20	−23	−24	−15
Virginia		2	−3	−9	−11	−9	−4
Washington	East 122° long	−2	−8	−11	−18	−11	−8
	West 122° long	0	−3	−3	−7	−4	−3
West Virginia		−3	−8	−15	−16	−14	−9
Wisconsin		−3	−14	−24	−28	−24	−18
Wyoming		−4	−15	−18	−26	−19	−16