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of Transportation
**Federal Railroad
Administration**

Office of Research and
Development
Washington, D.C. 20590

Review of Available Vehicle Tracking Systems for Use at the Transportation Technology Center

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March 2002
Draft Final Report

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13. ABSTRACT Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), performed a review of currently available Vehicle Tracking System (VTS) technologies and their applicability to operations at the Federal Railroad Administration's Transportation Technology Center (TTC), Pueblo, Colorado. This report summarizes that review and concludes with recommendations for selection of a VTS approach and vendor.			
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1.0 INTRODUCTION

Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), performed a review of currently available Vehicle Tracking System (VTS) technologies and their applicability to operations at the Federal Railroad Administration's Transportation Technology Center (TTC), Pueblo, Colorado. This report summarizes that review and concludes with recommendations for selection of a VTS approach and vendor.

TTCI used a number of sources of information to identify and review candidate VTS technologies. These sources included:

- Literature and internet searches for information on vehicle tracking systems,
- Railroad industry experts,
- Potential vendors,
- Current railroad VTS implementations, and
- Non-railroad VTS implementations.

Research showed that many vendors offer VTS solutions for a variety of commercial and governmental applications. TTCI reviewed 102 VTS-related Internet websites (Appendix B) and product literature from 18 VTS vendors, as well as information from railroad experts on four additional VTS systems. The review team selected a sample of these 124 VTS sources representing a range of solutions used in transportation and military applications for more detailed review. The systems reviewed in detail are listed in Table 1. Materials from these four are included in Appendix B.

Table 1. VTS Systems Examined in Detail

Vendor	System	Primary Application
Galaxy Scientific Corporation (GSC) Warminster, Pennsylvania	Airport Trak™	Vehicle tracking/management system for airports.
Meteorcomm - Meteor Communications Corp Kent, Washington	FleetTrak™	Fleet tracking/management with meteor-based and extended line-of-sight communications links. Extensive railroad applications with Burlington Northern Santa Fe Railroad.
National Systems & Research (NSR) Colorado Springs, Colorado	Autofind™	Vehicle asset management using cellular communications. Used extensively in trucking operations.
Science Applications International Corp. (SAIC) Albuquerque, New Mexico	Real-time VTS	Real-time VTS used for military test/evaluation support activities.

Table 2 shows how the capabilities and features of these systems compare to the VTS requirements for TTC. Of the systems reviewed, FleetTrak™ from Meterocomm is the only system that meets all the requirements. In addition, it possesses several important differentiating features, including:

- A very robust communications protocol that has a proven performance with a Class I railroad for over two years.
- An operational radio frequency for the local TTC radio frequency (RF) link (approximately 40 MHz) that is available and does not conflict with existing railroad radio frequencies.
- An additional meteor-based communications link that enables nationwide tracking of TTC and customer test resources.
- Peer-to-peer communications capability that enables transmission of data from wayside detection or onsite monitoring systems; thus supporting development and testing of communications-based train control applications.
- It is the only vendor with an operational system currently in use system-wide by a Class I railroad.
- It offers a demonstrated history of on-time, on-budget product delivery for a Class I customer.
- A Class I railroad selected it as the best solution after extensive review of available vendors and technologies. Recommended by a Class I railroad for implementation at TTC.

2.0 RECOMMENDATION

Based on the VTS comparison summarized in Table 2, and the strong differentiating features outline above, TTCI recommends procurement of the Meteorcomm FleetTrak™ system for implementation at TTC.

With concurrence from FRA, TTCI will request a proposed system design and firm quote from Meterocomm for a VTS that complies with the Concept of Operations and Systems Requirements Specification. With FRA approval of the quote, TTCI will contract for the system with Meteorcomm and proceed with system installation.

Table 2. Comparison of Vehicle Tracking Systems

Basic System Design Requirements for TTC VTS		NSR	GSC	SAIC	Meteorcom
1.	Developed by established vendor with a history of on-time, on-budget performance for implementation of VTS technology in the transportation industry.	No	No	No	**Yes**
2.	Uses GPS to generate location tracking data.	Yes	Yes	Yes	Yes
3.	Supports monitored-only (no display) vehicles.	Yes	Yes	Yes	Yes
4.	Provides for time synchronization among distributed test platforms, some of which are mobile (e.g., for measuring latency).	No	N/A	Yes	**Yes**
5.	Supports display-equipped vehicles.	No	Yes	Yes	Yes
6.	Supports optional interaction (sending and receiving message) with the VTS server for display equipped "smart" vehicles.	No	Yes	Yes	Yes
7.	Supports display of map and vehicle movement via the Internet.	Yes	Yes	Yes	Yes
8.	Provides at least 5-meter location accuracy.	No	Yes	Yes	Yes
9.	Robust communications protocol demonstrated in an operational railroad environment preferable.	No	No	No	**Yes**
10.	Leverages existing TTC communications infrastructure.	No	Yes	Yes	Yes
11.	VTS server uses off-the-shelf computer with real-time, multi-tasking operating system.	No	Yes	Yes	Yes
12.	Peer-to-peer communications capability required.	No	No	No	**Yes**
13.	Supports "no entry zones" with warnings to equipped vehicles entering/approaching them.	Yes	Yes	Yes	Yes
14.	Supports capability to assign specific identification parameters to monitored vehicles and selectively edit them in real time.	No	Yes	Yes	Yes
15.	Supports the ability to record and play back vehicle tracking data.	Yes	Yes	Yes	Yes
16.	Supports development/use of "portable" vehicle VTS hardware for rapid, temporary installation in monitored vehicles.	Yes	Yes	Yes	Yes
17.	Provides interchangeability of tracking system hardware and software with different communications platforms.	No	Yes	Yes	Yes
18.	Remote unit is single piece — GPS receiver, radio transceiver, and computer controller preferable.	Yes	Yes	Yes	Yes
19.	Remote unit, including display, operates on 12 VDC power with surge and reverse power protection.	Yes	Yes	Yes	Yes
20.	Remote unit operational within 30 seconds (warm start) and 3 minutes (cold start) from vehicle turn-on.	Yes	Yes	Yes	Yes
21.	Remote provides latitude, longitude, course, velocity, and altitude.	Yes	Yes	Yes	Yes
22.	Remote unit functions as stand-alone device providing positioning to the OCC base station as well as to other vehicles equipped with vehicle location display units.	No	Yes	Yes	Yes
23.	Remote unit has Mean Time Between Failure (MBTF) of at least 50,000 hours.	N/A	N/A	N/A	**Yes**
24.	Remote receives and displays alarm indications set by OCC.	No	Yes	Yes	Yes
25.	Remote unit supports RTCM SC-104 DGPS format.	Yes	Yes	Yes	Yes
26.	Remote unit supports connection to optional display.	Yes	Yes	Yes	Yes
27.	Remote unit contains GPS receiver, accepts DGPS corrections, and communicates via local RF link.	Yes	Yes	Yes	Yes
28.	In-vehicle display has variable screen intensity control.	No	Yes	Yes	Yes
29.	In-vehicle display has zoom and moving map capability.	No	Yes	Yes	Yes
30.	Proven, system-wide railroad implementation preferable.	No	No	No	**Yes**
31.	Can be cost-effectively implemented at TTC on or before December 31, 2002 (based on reviewers' judgment).	No	No	No	**Yes**

APPENDIX A:

VTS-Related Web Sites Reviewed

A&E Technologies - http://www.gpsmerchandise.com
GPS vehicle tracking hardware and software. Passive and active hardware solutions.

Aaron Gregory Spy Marketing, Ltd. - http://ggsmark.com/abvehtrac.html
Portable GPS units allowing to monitor where a car or vehicle has been, the speeds that it has traveled, and start/stop times.

Advanced Communications and Information Systems - http://www.acis.uk.com
Telematics including both GPS and radio-based solutions to the public transport sector for use in tracking buses.

Advanced Tracking Technologies, Inc. - http://www.traveleyes.com
Manufacture a personal GPS vehicle-tracking device used to monitor and report a vehicles daily route, mileage, and speed driven.

AirLink Tracking System (ATS) - http://www.airlinktracking.com
Vehicle tracking system that uses CDPD technology to transmit vehicle and location information to a control center.

American Millennium Corporation, Inc. - http://www.amc-wireless.com/
Global provider of wireless hardware and software solutions foe asset tracking and monitoring.

Ancor Engineering, Inc. - http://www.ancoreng.com
Vehicle location hardware using GPS and CDPD.

Applanix - http://www.applanix.com/
Position and Orientation Systems (POS) were developed specifically for surveying, mapping and robust positioning in dynamic environments.

ARIA-GLB - http://www.aria-glb.com/
Wireless solutions for automatic vehicle location (AVL) and mobile data for vehicle tracking, messaging, railroads, taxis, stolen vehicles and public safety applications.

Asian Navigation & Tracking Systems - http://www.ants.ph
Track your vehicle real-time on a complete Philippine map over the World Wide Web.

ASPU - http://www.aspu.cc/
Sales, installation and service of fleet, aviation, and marine GPS/AVL tracking/dispatch systems. Also offers third-party installations and service.

Automatic Vehicle Locating with GSM/GPS units - http://www.magnatec.de/
Vehicle tracking and monitoring with and without GPS. Special combined GSM / GPS antenna for security applications.

Automatic vehicle tracking with GSM and GPS - http://www.gsm-modem.de
AVL system for fleet management. GSM modem and GSM modules for wireless applications. Accessories like antennas, mobile data terminals and software for vehicle tracking.

AVeL-TECH Inc. - http://www.aveltech.ca/
Automatic vehicle location and associated systems. Includes product specifications, company history, and trade show information.

Cancom Tracking Solutions - http://www.cancom.ca/english/index.html

Car Bug - http://www.carbug.co.uk
Personal satellite vehicle tracking system that is entirely controlled by the owner.

Cellocator - Wireless Location Systems - http://www.cellocator.com
Location and positioning systems for security and fleet management applications.

Celtrak - http://www.celtrak.net/
Satellite-based vehicle-monitoring systems used in a broad range of fleet management applications.

Central Tracking Services, Inc. - http://www.centraltracking.com
Automatic vehicle location services.

CES Technologies Corp - http://www.cesusa.com/
Design, manufacture and implementation of mobile information systems, fleet management, internet convergence, systems integration and wireless signaling products.

Cimarron Technologies - http://www.cimtechcorp.com/
Manufactures ANI and real-time AVL systems

Cloudberry - http://www.cloudberry.com
Tracking and messaging system that allows the monitoring of fleet activity from a desktop PC.

Comtech Mobile Datacom Corp. - http://www.comtechmobile.com/
Two way data communication and GPS services.

Corp Ten International - http://www.corpten.com/
GPS tracking and data messaging systems including hardware and software .

Data Burst Technologies Inc. - http://www.databurst.com/
Vehicle location technology products and services.

Data Communications Romania - http://www.guardone.ro
Operating monitoring center.

DCS - http://www.dcs.com
Integrated hardware and software solution that tracks, monitors and manages mobile assets or vehicles

Distributed Networks,Inc. - http://www.wdso.net/
Wireless fleet communications systems. Products include mobile data terminals and AVL/GPS vehicle tracking systems.

Dynamic Mobile Data - http://www.dmdsys.com/
Wireless messaging and tracking applications that are accessed over the Internet .

Earth Trak - http://www.gpsvehicletracking.net
GPS vehicle management and asset tracking.

ESITrack - http://www.ESITrack.com/
Vehicle tracking system that combine GPS, GSM, and Compact Flash.

eTP Systems Inc. - http://www.etpsystems.com/
Onboard computer that uses GPS to provide automated compliance reporting data for trucking fleets.

FreshTrak - http://www.freshtrak.com
Truck tracking and load temperature monitoring.

Geollit - http://www.geollit.com
Communication solutions for global wireless M2M communication with Orbcomm, GPS and GSM

GEOTAB - http://www.geotab.ca
GPS monitoring of vehicle fleets.

Global Tech Marketing - http://www.globaltechmarketing.com/
Fleet Tracker is a management tool designed for ease of use and increasing profitability.

Global Tracking & Telemetry Services - http://www.globalwebtrack.com
Tracking and remote telemetry via the Internet. Track (and check the speed, position, temp) of vehicles.

Global Trak Vehicle Tracking and Control System - http://glotrak.com
GPS vehicle tracking system with Internet link to RF systems for individual or fleet applications. Can be accessed from any PC location.

GPS America - http://voicegps.com
Voice interactive vehicle navigation.

GPS fleet management solutions - http://www.bizgps.net
GPS vehicle tracking technology in use for small business.

GPS Fleet Solutions - http://www.gpsfleetsolutions.com/
Real-time and passive GPS systems for vehicle location, tracking, and dispatching.

GPS Global Positioning Systems Outpost - http://gps-global-positioning-systems-outpost.com
Wireless GPS systems and software for covert vehicle tracking and recording, Real-Time GPS mapping of routes, mileage, and speeds.

GPS Management Systems - http://www.gpsmanagement.com
Combined with the in-vehicle GPS receivers, our software makes it possible for you to track each vehicle and its operation.

GPS Tracking Systems - http://www.spysite.com/gps_tracking.html
Miniature vehicle and personal GPS Tracking Systems.

Grid Data Inc. - http://www.griddata.com/
Automatic vehicle location AVL and two-way data messaging services via GPS and wireless network technologies.

HeavyTrack.com - http://www.heavytrack.com
GPS fleet monitoring and theft detection system for heavy equipment and trucks.

HGI Inc. - http://www.hegyi.com/
Wireless automatic vehicle location technology solutions to the law enforcement, fleet management, and field service markets .

IDA Corp. - http://www.idaco.com/AVL.htm
Automatic vehicle location (AVL) systems for fleet management.

Immotrac Ltd - http://www.immotrac.com
Vehicle management, security, and tracking

Island Communications Limited - http://www.islandcomltd.com/index.htm
AVL systems and consultancy services for fleet operators.

Land, Air, Sea, Systems - http://www.landairsea.com
Small vehicle tracking and data storage systems.

Locarta - http://www.locarta.com
Vehicle tracking units. It works with either Microsoft MapPoint or ESRI's ArcView tracking analyst software.

Locate Networks - http://www.locatenetworks.com/
Combines GPS, wireless, and the Internet to enable the location of mobile assets and people.

Manning NavComp - http://www.navcomp.com/
Developers of RASTRAC software, and integrators of systems for management of mobile assets and vehicle tracking.

MARCUS - http://www.discretewireless.com
Discrete wireless vehicle tracking service, uses GPS technology, wireless data networks and the Internet to track vehicle's location, speed, movement and operational status.

Mentor Engineering - http://www.mentoreng.com
Wireless data and AVL solutions for commercial fleets.

Mobile Tracking Systems - http://www.mobiletrackingsystems.com/
GPS vehicle tracking systems including hardware and software.

MovSat - http://www.movsat.com.ar/
Logistics system and satellite tracking of vehicles and cargo.

mTrack - http://www.novogroup.com
Solution for tracking mobile objects.

Navtrak Inc. - http://www.navtrak.net/index.html
Web-based mobile data and vehicle tracking systems .

NeoMatrix Pty Ltd - http://www.neomatrix.com.au
Remote vehicle tracking, fleet management, GPS/GSM system. Automated reporting of vehicle movement or alarm activation, summary reporting of driving time and distance. Geofence boundary monitoring.

NeoTech - http://www.neotech.com
Mobile-Trak II is a modular vehicle tracking system. It ranges from a low-end, passive GPS logger to a high-end, real-time solution.

Numerex Technologies - http://www.nmrx.com/
Software and hardware solutions for remote equipment management, and shipping and vehicle tracking.

OmniTrack - http://www.omnitrack.com/
GPS Design Group offers vehicle tracking and the Spike Strategic Driver Information system for driver performance monitoring.

OuterLink Corporation - http://www.outerlink.com/
Real-time GPS tracking and two-way data messaging for fleets of vehicles, ships, and aircraft.

PacComm Packet Radio Systems - http://www.paccomm.com/main.html
GPS receiver, packet modem, and micro-controller device to control external RF transmitters.

PowerLOC Technologies Inc. - http://www.powerloc.com
Wireless and GPS satellite-based location tracking technology solutions.

Power-Trak - http://www.power-trak.com
Wireless, internet-based GPS vehicle tracking.

Quartix Ltd - http://www.quartix.net
A GPS vehicle tracking service based on internet tools and the GSM network.

Rosum Corporation - http://www.rosum.com
Mobile positioning technology will initially be used to locate cellular phones.

Satsafe - http://www.satsafe.com
Swedish-developed system for locating, controlling, signaling, and personal security. Based on both the GSM and the GPS systems.

Saturn Technologies - http://www.saturn-technologies.com
The SENTRY product ensure that communication costs between base and mobile asset remains efficient and cost effective.

Scoresoft Technologies - http://www.scoresoft.com
Using wireless technology to monitor, locate, and communicate with your mobile workforce and assets.

Signal Wireless - http://www.signalwireless.com
Delivers customized fleet tracking solutions to companies of all sizes.

SkyBitz - http://www.skybitz.com/
Tracking and communications services based on Global Locating System (GLS) technology.

SkyTrackers Inc. - http://www.skytrackers.com/
Supply automatic vehicle location systems and related equipment.

Strategic Fleet Measurement - http://vigilsystems.com.au
Requires measurement of operational parameters whether it is speed, location, driver performance, vehicle performance or payload monitoring.

Sunninghill Systems - http://www.gpss.co.uk
GPS Software for automatic vehicle location and tracking via radio, cell phone, or satellite.

Technocom Wireless - http://www.wireless-e911.com
Solutions for mobile applications such as vehicle tracking, telematics, public safety, fleet management, asset tracking, and Intelligent Transportation Systems (ITS).

Tecnocon - http://www.tecnocon.com
Produces, markets, and services the *Retreever* system for vehicle recovery after theft.

TekniREP - http://www.teknirep.com
GPS tracking solutions, onboard computers (black box), and vehicle dispatch systems. Serving Ontario and Quebec, Canada.

Teletrac - http://www.teletrac.net/
Vehicle location and fleet management services.

Telogis - http://www.telogis.com
Vehicle tracking via the Internet and mobile wireless information systems.

Terion - http://www.terion.com/
Mobile tracking services and systems.

Titanstategic - http://www.titanstrategic.com
provides products and services to track your equipment, trucks, boats, and automobiles.

Track Communications, Inc. - http://www.highwaymaster.com/
Operates wireless enhanced communications services network with both voice and data capabilities.

Tracker International - GPS Asset Management - http://www.tracker-international.com/
Integrated systems to control mobile assets by providing selective use access, tracking, monitoring, location, and recovery of the asset on demand.

Trackstar - http://www.trackstar.com
GPS Vehicle Tracking for AVL markets to enhance ve hicle monitoring, trailer tracking, cargo control, fleet management, driver safety, and truck security.

TrakM8 - http://www.trakm8.com
Tracks your vehicle using your normal GSM mobile phone.

Trimble Navigation Limited - http://www.trimble.com/mpc/index.htm
Fleet management and mobile asset tracking systems.

Universal Tracking Technologies, Inc. GPS based fleet management solutions -http://universaltracking.com
Product is designed to reduce operating costs for busing, waste management, delivery, maintenance, and vehicle fleets of every kind.

U-Track Satellite vehicle tracking system - http://www.u-track.co.uk
A tracking system that offers access to vehicle's location. Uses satellite navigation technology to pinpoint the location of a lost vehicle

Vehicle Tracking - http://www.thespystore.com/vehicletracking.htm
Real-time GPS vehicle tracking and GPS vehicle logging equipment with cellular phone.

VehicleTrak Technologies - http://www.vetrak.com
Offering portable/covert/compact GPS Tracking products.

Vetronix Corp. - http://invehicleproducts.com/
Mobile computing products and services for fleet managers, business professionals, and automotive consumers.

Vistar Telecommunications Inc. - http://www.vistar.ca/
Offers a satellite, two-way asset tracking, monitoring, and management system. Operational throughout the United States .

Visual Dispatcher by Apollo Systems - http://www.apollo-systems.com
Dispatching and tracking software that allow a service company to track and manage their mobile service fleet.

V-Sol - http://www.v-sol.co.uk
Developers and suppliers of GPS vehicle tracking systems using satellite technology.

WebTech Wireless - http://www.webtechwireless.com
Vehicle location services provider delivering GPS tracking and two-way messaging services for wireless carriers, private and trucking fleets, and vehicle owners.

Where Is My Bus? - http://www.whereismybus.com
Web-based, live, real-time vehicle tracking solution.

Wherify Wireless - http://www.wherifywireless.com/
Products and services using GPS and cellular technologies to locate people or property through the Internet or phone.

Wireless Concepts LLC - http://www.wirelessconcepts.net/
Automatic vehicle location systems for stolen vehicle recovery, fleet control, mobile data terminals, and computer aided dispatch systems.

APPENDIX B:

Vendor Materials

- **B1: Galaxy Scientific Corporation (GSC), Warminster, Pennsylvania**
- **B2: Meteorcomm, Meteor Communications Corp, Kent, Washington**
- **B3: National Systems & Research (NSR), Colorado Springs, Colorado**
- **B4: Science Applications International Corp. (SAIC), Albuquerque, New Mexico**

B1: Galaxy Scientific Corporation (GSC)
Warminster, Pennsylvania

B2: Meteorcomm, Meteor Communications Corp
Kent, Washington

B3: National Systems & Research (NSR)
Colorado Springs, Colorado

B4: Science Applications International Corp. (SAIC)
Albuquerque, New Mexico

U.S. Department
of Transportation
**Federal Railroad
Administration**

TASK ORDER #115: REVISED TANK CAR DAMAGE ASSESSMENT GUIDELINES

Office of Research and
Development
Washington, D.C. 20590

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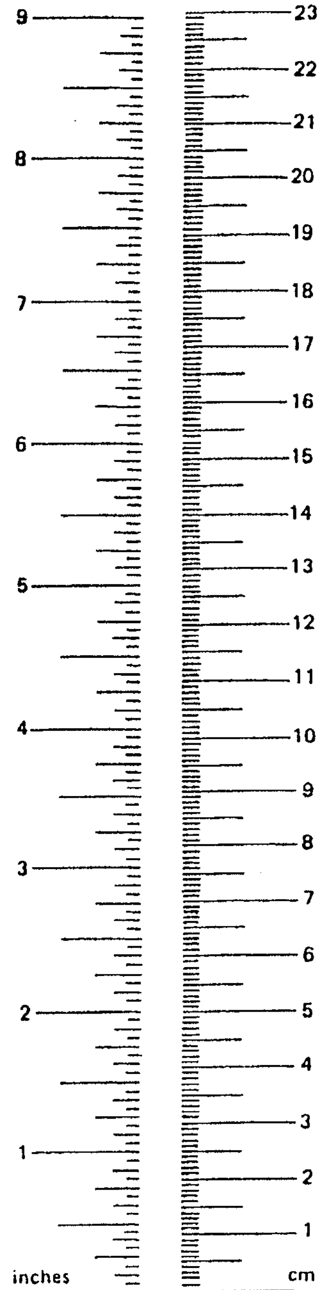
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

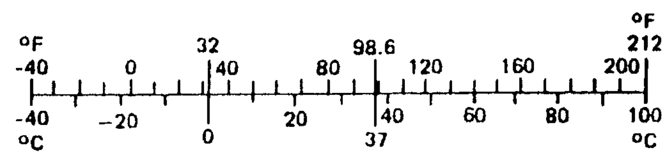
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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16. Abstract
Under Federal Railroad Administration (FRA) Contract No. DTFR 53-93-C-00001, Task Order Number 115, the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), has conducted a multi-phase research project focusing on the field assessment of damage to tank cars that have been involved in accidents. (after first sentence, substitute the following) Phase I of the project focused on evaluating the technical foundations for the current tank car damage assessment guidelines developed by the AAR in the 1980's. A formal technical literature search conducted by Stanford Research Institute (SRI) identified which guidelines could be validated and which required additional modeling and validation in the project's Phase II effort.

The Phase II effort of this research project was intended to accomplish the following:

- Assess the validity of the existing guidelines using laboratory experiments and computer modeling
- Estimate their margin of safety
- Develop an analysis method for generating a damage assessment handbook

This report uses the results of the Phase I and Phase II results to generate new guidelines.

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The objective of this report is to validate those guidelines where possible and to document the process carefully in order that those that follow us may see how we arrived at our conclusions. Where our research did not agree with the existing guidelines, we have let the research drive the conclusions. To the extent possible, subjectivity is avoided in drawing conclusions

Special thanks and recognition to Dr. Richard Klopp and Dr. Steve Fitzpatrick formerly of Stanford Research Institute (SRI) for the integrity of their research, and Mr. Norman Smith of Hulcher Resources, Inc. for donating his time, insight, and personal knowledge of the incidents in this report.

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EXECUTIVE SUMMARY

Under Federal Railroad Administration (FRA) Contract No. DTFR 53-93-C-00001, Task Order 115, the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), has conducted a multi-phase research project focusing on the field assessment of damage to tank cars that have been involved in accidents. Phase I of the project focused on evaluating the technical foundation for the current tank car damage assessment guidelines developed by the AAR in the early 1980's. A formal technical literature review conducted by Stanford Research Institute (SRI) identified which guidelines could be validated and which required additional modeling and validation in the project's Phase II effort.

Recently, the original guidelines were reviewed to determine how or if they could be validated. After consulting with experts in the tank car, railroad, and chemical industries it was determined that the individuals who developed the damage assessment guidelines are no longer available to substantiate them. The formal literature review did not specifically mention the establishment of the guidelines or the basis on which they were established. Subsequent to SRI's review it was discovered that a document titled *Container Integrity Assessment* was used during mid-1980 as a student handout by TTCI's Emergency Response Training Center at the FRA's Transportation Technology Center, Pueblo, Colorado. This handout provided the rationale for some of the recommendations made in the guidelines.

Since 1983, many new engineering tools have been developed that can be readily adapted to examine the validity of guidelines, their built-in safety factors, and the methodology on which these conclusions are based.

From the recommendations of the Phase I program, a Phase II effort was designed and performed to address the highest priority issues. This Phase II effort was intended to accomplish the following:

- Assess the validity of the existing guidelines using laboratory experiments and computer modeling

- Estimate their margin of safety
- Develop an analysis method for generating a damage assessment handbook

The following conclusions can be drawn from the research conducted during Phase I and II:

- The existing guidelines involving cracks are valid, for the most part, because they require tank unloading for almost any crack. The existing guidelines are also valid for cases in which a crack occurs in an attachment weld -- unless the crack is accompanied by other damage or is extraordinarily long, such cracks will result in leaks instead of extending catastrophically.
- The existing guidelines for base-metal scores and gouges are valid, with safety factors ranging from 1.3 to 2.1. The guidelines for scores or gouges removing only weld bead reinforcement are valid because of the extra strength of the weld filler metal and because, even if the weld contains an undetected crack, the crack is unlikely to extend catastrophically in the absence of other damage such as a dent.
- The existing guidelines for wheel burns are valid with a safety factor of roughly 1.4 to 1.7.
- The existing guidelines for otherwise undamaged dents should be modified to remove dependence on dent radius of curvature. New research has revealed that radius of curvature has little bearing on propensity for failure. At pressures near and above 100 psi, dents are forced back out to yield large radii of curvature and can almost disappear at relief valve discharge pressures.
- Recent research has also shown dents that have no other damage (i.e., cracks, scores, or gouges) and do not involve welds appear unlikely to crack no matter what the radius of curvature. Comparatively, dents with cracks are dangerous because cracks at dent roots can easily extend when driven by the pressure-induced bending moment. Thus existing dent guidelines should be reformulated and based on an assessment of the likelihood that a dent contains a hidden crack.
- As demonstrated in this work, stresses in an undamaged tank are primarily due to internal pressure and not gravity loads induced by the lading. Thus, re-railing operations on undamaged tank cars will generate stresses that are negligible in magnitude compared with the pressure stresses.

Accordingly, the revised guidelines will stress the following:

- The contents of the tank should be verified with the shipping papers before proceeding any further in the decision-making process.
- If the tank fails ANY of the guidelines, it should be unloaded OR have the pressure reduced as soon as possible.
- If the tank passes all the guidelines, it can be safely lifted.
- Catastrophic failure is not likely without a 7-foot or longer longitudinal dent.
- These guidelines do not apply to a tank that has suffered fire damage.
- Determining tank pressure and temperature are vital first steps in the damage assessment process.
- Risk of tank failure is a function of pressure and tank damage. A change in either constitutes a variable that must be considered (i.e., increase in ambient temperature).
- Venting product vapors is a much faster method of reducing pressure than transferring liquid. It is also a safer method if done properly; thus, reducing risk.
- Based on new research, the "Tank Car Dent Gauge" is obsolete, and any reference to it is deleted in the revised guidelines.
- Temperature and Pressure Tables for 22 of the most commonly transported flammable compressed gases transported by rail have been added to this tank car damage assessment handbook for easy reference by the responder.

To better ensure the safety of emergency response personnel and the public at large, it is necessary to provide those who are assessing tank car damage in the field with sound, qualitative evaluation techniques that they can use safely and reliably. Compiling this information into a clear, practical handbook will help emergency response personnel make critical decisions. This is an important effort that will significantly improve the safety of such operations.

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1.0 INTRODUCTION

Under Federal Railroad Administration (FRA) Contract No. DTFR 53-93-C-00001, Task Order 115, the Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), has conducted a multi-phase research project focusing on the field assessment of damage to tank cars that have been involved in accidents. Phase I of the project focused on evaluating the technical foundation for the current tank car damage assessment guidelines developed by the AAR in the early 1980's. A formal technical literature review was conducted by Stanford Research Institute (SRI) and evaluated to identify which guidelines could be validated and which required additional modeling and validation in the project's Phase II effort.

2.0 BACKGROUND

In February 1993, the TTCI produced *Field Product Removal Methods for Tank Cars*, an emergency response handbook. It was developed for the FRA under contract DTFR 53-82-C-00282, Task Order 31 and was produced for emergency response personnel who deal with tank cars that have been damaged in accidents and carry hazardous materials. Since its publication and subsequent use, a need has arisen for a companion handbook identifying proven and reliable damage assessment guidelines.

Since 1985, TTCI and other organizations have used a set of guidelines that were developed by the AAR in the late 1970's to teach emergency response personnel how to make judgements in the field as to the severity of damage to tank cars involved in accidents. These guidelines were developed to help emergency responders decide whether tank cars carrying hazardous materials shipped under pressure can be safely re-railed, should be unloaded in place, or whether nature should be left to take its course.

Recently, the guidelines were reviewed to determine how, or if, they could be validated. After consulting with experts in the tank car, railroad, and chemical industries, it has been determined that several individuals developed the guidelines but are no longer available to substantiate them. To better ensure the safety of emergency response personnel and the public-at-large, responders need sound, qualitative evaluation techniques that can be safely and reliably used to make these decisions. Compiling this information in a clear and concise handbook that will help emergency response personnel make critical decisions is an important effort that will significantly improve the safety of such operations.

The literature reviewed did not specifically mention the establishment of the guidelines or indicate the basis on which they were established. After SRI's formal literature search it was found that a document titled *Container Integrity Assessment* had been used as a student handout at TTCI's Emergency Response Training Center (ERTC) in the mid-1980's. This document provides the rationale for some of the recommendations made in the guidelines.

According to AAR personnel, the guidelines were developed by Roy Holden, a former AAR engineer with the Bureau of Explosives, and were based on experienced gained while attending derailments and inspecting specimens from damaged or failed tank cars. Most of the available fracture analyses for tank cars are based on the work of William S. Pellini, who after a career at the Naval Research Laboratory, acted as a consultant to the AAR for many years. Mr. Holden reportedly interacted extensively with Mr. Pellini during the drafting of the guidelines, and the guidelines appear to be based, in part, on Pellini's work.

From the recommendations of the Phase I program, a Phase II effort was designed and performed to address the highest priority issues. This Phase II effort was intended to accomplish the following:

- Assess the validity of the guidelines using laboratory experiments and computer modeling
- Estimate their margin of safety
- Develop an analysis method for generating a damage assessment handbook

3.0 APPROACH

In order to provide the reader with the basis for the recommended changes to the guidelines, the research of this project are presented in this report in the following manner:

- Summarize the results and conclusions of the laboratory testing and modeling performed by SRI.
- Present the results and conclusions of the research performed by TTCI, including the laboratory testing done on ACFX 80417 (delayed rupture at Flomaton, AL).
- Highlight the recommended changes to each of the guidelines and the rationale for making those changes.
- Develop a listing of the margins of safety for each of the guidelines.
- Provide recommendations for further research.
- Develop a revised set of guidelines and inspection procedures that can be readily understood and used by emergency responders.

This approach is essential in providing the reader with an understanding of why changes were or were not made in particular guidelines, the margin of safety they provide, and where additional research needs to be done to conclusively validate the guidelines.

4.0 RESULTS OF VALIDATION RESEARCH

A summary of the research project's findings with respect to the validity of the individual guidelines is presented. A copy of the Tank Car Damage Assessment Guidelines is provided in Appendix A.

4.1 GUIDELINES FOR CRACKS

The guidelines for cracks require unloading if any cracks are visible, with the exception that cracks in welds used to attach brackets or reinforcement plates are not critical unless the crack extends into the base metal. (Existing guidelines are presented in italics.)

"A crack in the tank metal indicates serious damage. Cracks in welds, used to attach brackets or reinforcement plates, are not critical unless the crack extends into the base metal.

Welds securing reinforcement pads on the tank are designed to fail, allowing the attachment to break away without damage to the tank.

Any crack found in the base metal of a tank, no matter how small, justifies unloading the tank as soon as possible. However, if in a yard, the car may be carefully moved to a designated remote location in the yard for transfer.

When a crack is in conjunction with a dent, score or gouge, the tank should be unloaded as soon as possible without moving it."

Pellini reports that there has been at least one rupture (not a delayed rupture) originating from a crack in an attachment fillet weld (Austin, Manitoba). The weld in question was used to attach an eduction tube guide to the inside of the shell. The rupture occurred during a derailment as the result of denting which caused a stress concentration at the change in stiffness between the base metal and the attachment. In cases where there is no other damage associated with the attachment weld crack, the effect of the stress concentration is much less critical. Since attachment welds are usually lightly stressed, a crack should not extend in an unstable fashion even if it reaches base metal.

Validation:

The research and history of delayed ruptures validates this guideline with a cautionary note that several instances of cracking in tank heads on cars equipped with head blocks occurred in Canada during 1998 and 1999.

4.1.1 Revision to Guideline on Cracks

It should be noted that instances of base metal cracking underneath cracked sill pads have been documented in the past several years. There have been no cases of delayed rupture attributed to these cracks.

The part of the existing guidelines stating that a tank with a crack in it may be moved if the crack is not in conjunction with a weld nor any other form of damage appears to be valid as well. The research indicates that such cracks are not able to initiate, much less run, even under the lowest temperatures likely to be encountered in the field.

4.2 GUIDELINES FOR GOUGES

4.2.1 Guidelines Affecting Weld Reinforcements Only

The guidelines for scores imply that scores affecting only the weld bead above the base metal are benign:

> *"Scores or gouges crossing a weld and removing only the weld reinforcement are not critical."*

Two pieces of evidence tend to validate this guideline:

- Even if such a score caused an undetected crack completely through the weld, the SRI research shows that the situation is relatively safe.
- Experiments done by Pellini following the Waverly TN accident showed that very low temperatures or high dynamic loads had to be applied to cause fracture propagation.

4.2.2 Base Metal Gouges: Validation of Guideline, Depth versus Pressure Table for 340W Tanks

The guidelines for base metal gouges require unloading when the gouge depth exceeds half the pressure limits given in the guidelines. (Tables are included in the guidelines but omitted here.)

> *"Tanks having scores or gouges should be unloaded in place when the internal pressure exceeds 1/2 of the allowable internal pressure listed in the tables below. Tables 1 and 2 show the allowable score depths and allowable pressures for 340W and 400W tanks, respectively."*

Laboratory experiments and finite element modeling validated this Guideline, showing the most serious gouge allowed (1/4 inch) at the corresponding internal pressure, still gives a safety factor of almost 4 for cleavage fracture and 1.3 for complete root yielding.

4.2.2.1 Revision to Guideline and Rationale

This Guideline is overly conservative and in fact, documentation recently discovered indicates that the intent of the original guidelines was to provide a safety factor of 2. Accordingly, the guidelines will be revised to reflect this, and the reference specifying that "...when the gouge depth exceeds one-half the pressure limits given in the Table" will be deleted. This still gives a margin of safety of 2:1.

4.3 GUIDELINE FOR WHEEL BURNS

The guidelines state that wheel burns do not induce a high probability of failure:

> *"If the maximum depth of the wheel burn exceeds 1/8", the tank should be unloaded as soon as possible. If the depth of the wheel burn is less than 1/8", the tank should be emptied at the nearest loading facility, provided it is moved with care; not in ordinary train service."*

Inasmuch as wheel burns are very similar to scores and gouges, the work done to validate those guidelines is applicable here. The only caveat being that wheel burns may exhibit metallurgical effects due to frictional heating. Pellini concluded, however, that, for the most part, these changes are superficial in nature and not of any consequence. Reference 17 in the Phase I report also showed that although cross sections of wheel burns sometimes contained cracks, they arrested without extending out of the heat affected zone.

4.3.1 Revision to Wheel Burn Guideline and Rationale

This will be revised to clear up the existing ambiguity, as the current guideline can be confusing to the responder. The revised Guideline will read as follows:

> "If the car is loaded, and the depth of the burn is 1/8 inch or less, the car may be transported to the closest unloading point. If the depth exceeds 1/8 inch, the load should be transferred without further transportation. If the depth exceeds 1/4 inch, the car should be transferred immediately. In the latter case, the responder should consider off-loading the car by pump (see *Emergency Product Removal Techniques for Tank Cars* for procedures) rather than pressure, to avoid raising the internal pressure of the car."

4.4 GUIDELINE FOR DENTS

4.4.1 Validity of 50-Percent Rating Reduction

The guidelines state that a long rail burn dent reduces the rating of a tank by 50 percent:

> *"Sharp dents in the shell of a tank (cylindrical section) which are parallel to the long axis are the most serious as these dents drop the rating of the tank by 50 percent."*

The research done by SRI calls into question the validity of this guideline. A simple linear elastic fracture mechanics analysis indicates that long dents, parallel to the long axis of the tank, may develop stress intensities that are at or above the measured fracture toughness of A515-70 steel. Additionally, finite element analysis calculations and intuition indicate that the bottom of the dent has experienced a reversed cycle of plastic straining which may significantly reduce the fracture toughness for ductile rupture. Apparently, if there is a crack with applied bending moment, the crack will propagate (if there is sufficient internal pressure to drive the crack). Without a dent there can be no moment.

The validity of this Guideline is also called into question by the fact that long rail burn dents have resulted in delayed fracture at pressures around 200 psi (see Texarkana incident). Also Waverly, TN (LPG: 126 F at 68°F, failure occurred at 50°F) and Cuming, IA (anhydrous ammonia: 147 psi at 78.3°F, failure occurred at 55-60°F).

4.4.1.1 History of Delayed Failures

TTCI has documented eight cases of tank cars that failed from delayed fracture attributable to long dents:

- Two cases of delayed fracture that developed approximately 40 hours following a derailment (Waverly, TN and Cuming, IA).
- One leakage type failure (arrested brittle fracture) that developed while the car was being loaded with LPG (Sarnia, ON).
- One leakage type failure that occurred while the car was being moved during re-railing operations (Flomaton, AL).
- Four arrested brittle fractures that developed during hydrostatic reforming to pop-out dents (one in Texarkana, TX and three others at another tank car shop).

All but one of these cases (Flomaton, AL) involved long dents more or less parallel to the long axis of the tank. The Flomaton car involved a long circumferential dent on the bottom of the car (50+ inches).

Delayed failures after derailments:

1. Waverly, TN, 1978. UTLX 83013, 112A400W, as-rolled 212B steel. Fracture occurred approximately 40 hours after the derailment resulting in catastrophic failure of the tank. Fracture initiation was at the point where a 12-foot long rail burn dent 3 inches deep crossed a girth weld. Lading was LPG. Failure occurred after the ambient temperature increased from 30°F to 50°F.

2. Cuming, IA, 1963. GATX 84429, 112A340W, dual diameter car built in 1963, as-rolled A-212B steel. Fracture occurred approximately 40 hours after the derailment, resulting in catastrophic failure of the tank. Fracture initiation point was at the point where a 15-foot long rail burn crossed a girth weld at the tank diameter transition point. Lading was Anhydrous Ammonia. The reason for failure is not entirely clear, but it is believed that the small increase in ambient temperature after the derailment was sufficient for fracture initiation.

Tank failures during shop-reforming procedures:

Shop reforming involves applying hydrostatic pressure to a damaged tank car in order to "pop-out" a dent. TTCI has no formal data on how many cars this procedure has been successfully performed. Pellini documented four cases of tanks failing during this process.

1. Texarkana, TX, 1980. ACTX 32001, 112J340W, dual diameter car built in 1963, A212B as-rolled steel. This failure occurred at a tank car shop while trying to pop-out a head dent. During this process, the tank fractured at the location of an old rail dent on the underside of the tank. The tank fractured at approximately 200 psi (hydrostatic). The fracture initiation site was at the point where an old wheel burn dent approximately 10 feet long crossed a girth weld at the tank diameter transition weld.

2. Tank car shop. AMOX 33424, 112A400W, as-rolled TC-128B steel, fracture initiated at the site where a 15-foot long burn dent crossed a girth weld (approximate center of the car). Pressure at time of failure unknown (below pressure relief valve setting).

3. Tank car shop. UTLX 83069, 112A400W, as-rolled A-212B steel, fracture initiated at the point where a burn dent 20-foot long, 2 inches deep crossed a girth weld. Pressure at failure unknown (below pressure relief valve setting).

4. Tank car shop. UTLX 83649, 112A340W, as-rolled A-212B steel. Fracture initiated at the point where a rail burn dent 36-foot long, 5 inches deep crossed a girth weld. Hydrostatic pressure at the time of failure was between 200-250 psi.

Delayed fracture during LPG loading:

Pellini documented the following:

1. Sarnia, ON, 1979. NATX 32044, 112J340W, dual diameter car, A212B as-rolled steel. This failure occurred while the car was being loaded with LPG. Tank pressure at the time of the fracture is unknown. **The fracture initiation site was at the point where an old wheel burn dent approximately 7 feet long, 1 inch deep crossed a girth weld at the tank diameter transition weld.** The fracture arrested at 7 feet resulting in LPG leakage.

Delayed fracture during re-railing:

TTCI documented the following:

1. Flomaton, AL, 1996. ACFX 80417, 112T340W, TC128B as-rolled steel. This failure occurred during re-railing operations. This car sustained a dent 57 inches in diameter, 11 inches deep in the "A" end head that resulted in a ductile tear at the weld near the bottom of the dent. After this leak was patched, the car was being rolled to facilitate product transfer when another fracture developed on the bottom lower side of the car, 55 inches inboard from the circumferential head weld.

The fracture initiated at the point where the dent on the bottom of the car intersected a weld defect, apparently a field repair weld on a placard holder weld. The fracture was 35 inches long and arrested, resulting in product leakage (vinyl chloride). Given the relatively low vapor pressure of vinyl chloride at 49.9 pounds per square inch absolute (psia) at 68°F and the fact that the car had a pre-existing hole in it, one would not expect the internal pressure to have been much over 50 pounds per square inch absolute (psia) at the time of the long dent failure.

The following is a list of built dates for the cars discussed:

Intl.	Number	Built date	Steel	Cert. of Construction
ACFX	80417	1975	128B	F741008-C
NATX	32044	1966	212B	166722
UTLX	83649	1962	212B	16696
UTLX	83069	1962	212B	15189
AMOX	33424	1972	128B	26237
ACTX	32001	--	--	--

4.4.1.2 Conclusions

Post-accident analysis of these cases revealed the following:

- **In all cases (except the Flomaton car), the fracture initiated at crack-like defects in girth welds, at the point where the wheel or rail burn crossed the weld**. The fracture on the Flomaton car initiated at the point where the circumferential dent intersected a defective weld on the placard holder bracket weld (probably a field weld).
- Delayed fractures tend to propagate in both directions from the initiation site. As in the Flomaton car , the fracture often travels almost equidistant from the initiation site in each direction,.
- The steels were close to, but above, the NDT of the plate in all cases.
- Six of the eight cases were of as-rolled A-212 steel. The other two involved as-rolled TC-128B.
- **In all cases, the dent length exceeded 7 feet.**

4.4.1.3 Revision to Rail Dent Guideline and Rationale

Inasmuch as all the failures referred to above involved fracture initiation at the juncture of a dent and a weld, this guideline will be revised as follows:

> "Long, sharp dents in the shell of a tank (cylindrical section) which are parallel to the long axis, and which cross a weld or extend to within one inch of a weld are the most serious as these drop the rating of the tank by 75 percent or more. Reduce pressure as soon as it is practical to do so safely and unload contents."

4.4.2 Validity of Other Dent Guidelines

The guidelines state:

"For dents in the shell of tank cars built prior to 1967, the tank should be unloaded without moving it under the following conditions:

- *A minimum radius of curvature of 4 inches or less;*
- *Have a crack anywhere;*
- *Cross a weld;*
- *Include a score or gouge."*

Dents with a radius of curvature more than 4 inches are not a problem by themselves.

"For dents in the shells of tank cars built since 1967, the tank should be unloaded without moving it under the following conditions:

- *A minimum radius of curvature of 2 inches or less;*
- *Have a crack anywhere;*
- *Cross a weld;*
- *Include a score or gouge; or*
- *Show evidence of cold work*
- *Dents with a radius of curvature more than 2 inches are not a problem by themselves."*

Validation of the other guidelines in these groups:

The guidelines state that a crack in a dent of otherwise undamaged metal, i.e., away from a score or weld, is unlikely unless the dent is creased sharper than a 4-inch radius for A212B, or 2-inch radius for TC-128B.

SRI conducted laboratory tests in which A515-70 plates were bent welded sharper than a 1-inch radius at room temperature. Similar tests were conducted on TC128B as-rolled specimens at -112°F. Neither test resulted in failure. When either steel was cooled to -238°F, cleavage failure did result when the specimens were bent at 30-inch radii. Hence the conclusion that dent formation would always result in rupture during an accident if the tank steel were on the lower shelf. As a practical matter however, lower shelf conditions could never be reached in the real world (i.e. in service conditions); thus, ruling out cleavage fracture.

For the case of ductile fracture, simple strain-to-failure considerations coupled with equations relating bend radius of curvature to surface strain suggest the 2-inch and 4-inch limits are conservative. However, these equations do not take into account the prior inward bending of the dent. This guideline needs further research before it can be validated since there is no way of knowing the effects of this reversed plastic deformation on the propensity of ductile failure.

4.4.3 <u>Delayed Fracture of ACFX 80417 (Flomaton, AL)</u>

This case of delayed rupture occurred during re-railing operations in 1996. Tank car ACFX 80417, a 112T340W constructed in 1974 of as-rolled TC128B steel, experienced a delayed rupture approximately 20 to 30 hours after being derailed and while being rolled over to facilitate product transfer. This car sustained a 57-inch diameter dent, 11 inches deep in the "A" end head resulting in a ductile tear at the head weld near the bottom of the dent. After this leak was patched, the car was being rolled to facilitate product transfer when another fracture developed on the lower side of the car 55 inches inboard from the head weld. The initiation site of the crack was the heat affected zone of a 2-inch placard holder bracket weld, about midway in the valley of a circumferential dent 8 feet 3 inches long, on the bottom of the tank, about 7 inches deep. The radius of this dent was at least 6 inches. The fracture reached 35 inches long and arrested, resulting in product leakage (vinyl chloride). Given the relatively low vapor pressure of vinyl chloride (49.9 psia at 68°F), and the fact that the car had a pre-existing hole in it, it is not expected that the internal pressure was over 50 psia at the time of the long dent failure

TTCI performed metallurgical tests on this car's tank steel and determined the following:

1. Crack initiation site was at the juncture of the dent and a defect in the weld, which secured the placard holder to the "R" side of the car.
2. The crack was not pre-existing, but was initiated at the time of the dent formation.
3. Spectrographic testing indicated the tank's steel met the as-rolled TC- 128B specification (although on the lower shelf of the specification).

4. Charpy V-notch testing indicated that the steel was at the lower shelf of other TC-128B steels in the data base

It is concluded that the internal pressure of the product, combined with the dent and possibly reverse bending forces experienced during the derailment and the rolling maneuver caused the crack to run. The fact that the crack arrested at 35 inches rather than running the full length of the dent is attributable to the sudden loss of an already relatively low internal pressure. **It is important to note that the crack ran the full length of the bend.**

This incident points to the potential critical nature of dents in welds or heat-affected zones. Even relatively large radii dents in the area of very short welds can cause failure provided other conditions are present.

In view of the results TTCI's examination of the Flomaton, AL delayed rupture, this Guideline will be revised to stress the criticality of even a circumferential dent of relatively large radius affecting the heat affected zone of a weld. **More emphasis must be placed on the criticality of dents in heat affected zones, and on the importance of long dents.**

4.4.3.1 Revision to Guideline and Rationale

TTCI's research on the Flomaton, AL car suggests that a dent (even a circumferential dent) that touches a weld or a heat affected zone is potentially critical. Accordingly, this guideline will be revised as follows:

"1. For dents in the shells of tank cars, the tank pressure should be reduced or the contents transferred without moving it under the following conditions:

- Has a crack anywhere (except attachment or re-enforcement pads); or
- Crosses a weld; or touches the heat-affected zone of a weld (1 inch on either side of the weld bead); or
- Includes a score or gouge.

Dents without other associated damage are not a problem by themselves, unless they cross a weld or touch the heat-affected zone of a weld.

2. For dents on the shell of tank cars built since 1967, the tank should be unloaded without moving it under the following conditions:
   - Has a crack anywhere; or
   - Crosses a weld, touches the heat affected zone of a weld; or
   - Includes a score or gouge.

4.4.4 Short or Broad Area Dents

The guidelines imply that broad area dents in heads are benign unless combined with other damage or if bends are particularly sharp:

> *"Massive dents in heads of the tank are generally not serious unless gouges or cracks are present with the dents.*
>
> *Small dents in heads not exceeding 12 inches in diameter in conjunction with cold work in the bottom of the dent are marginal if they show a radius of curvature less than 4 inches for tanks built prior to 1967 or less than 2 inches for tanks built since 1967. If at all possible, such tanks should be unloaded in place. In any case the tank should be moved as little as possible and promptly unloaded."*

The research conducted by SRI failed to validate this guideline for the same reasons the rail dent guidelines were called into question: there is simply no way to know how much the dent has been pushed back out when the loading was removed, nor the effect on the metal of this reverse bending. However, in the case of head dents, the situation is mitigated by the following facts:

- The bending moment and tensile stresses for head dents are likely to be lower because head stresses are always lower than shell hoop stresses.
- The distance a crack could run is shorter.
- Head metal is often thicker than shell metal due to the way the head is formed.

In view of this, and the fact that there has never been a documented case of delayed failure attributable to a head dent, this guideline will stand as is until further research can be done to validate it.

There is some concern with respect to the issue of long dents. There have been two instances of pressure cars that have suffered long dents catastrophically rupturing approximately 40-hours after being derailed (Waverly and Cumming). In fact, every delayed failure on record, with the exception of the case of Sarnia, ON LPG loading, is attributable to a long dent.

5.0 SAFETY FACTORS OF THE GUIDELINES

5.1 DEPTH OF SCORE VERSUS ALLOWABLE INTERNAL PRESSURE TABLES

The tables in the guidelines give a safety factor of 4. The guidelines will be revised to give a safety factor of 2, which was the intent of the original guidelines (see reference 5). The validity of this safety factor is confirmed by the calculations in the revised guidelines and by the laboratory experiments performed by SRI.

5.2 CIRCUMFERENTIAL DENTS

In view of the results of TTCI's examination of the car involved in the Flomaton, AL derailment, the guidelines will be revised to stress the potential criticality of even a circumferential dent when it crosses a weld of any length or the heat affected zone of any weld. Thus, it is believed the safety of the guidelines is enhanced.

5.3 CRACKS IN REINFORCEMENT PLATES

The instances of cracks in base metal beneath cracked pads adjacent to stub sills found recently in Canada indicate the need for a cautionary note in this guideline. While the intent of the guideline is clearly to make the differentiation in the responder's mind between base metal and pads, these recent discoveries of cracks behind head reinforcement pads are an indication that tanks may be cracking due to tank stiffening in the head area.

5.4 REVERSE DENTING

The Phase II work done by SRI shows that under certain conditions, the pressure in a tank car can push out the dent such that the final dent shape shows little evidence of the full extent of deformation in the tank wall. The SRI reservations regarding the unknown amount of "reverse denting" that occurs immediately after the damage is sustained due to internal pressure warrants a cautionary note in the revised guidelines. This phenomenon is also a candidate for future research to completely validate the dent guidelines.

5.5 LONG DENTS

The statement in the guidelines that a long dent th s longitudinal to the long axis of the car may reduce the tank's rating by 50 percent ncorrect. Such a dent in fact, ***will*** reduce the rating of the tank by ***at least*** 50 percent fore any other damage, and possibly 75 percent after damage because the hoop esses are twice as great as those for circumferential or head dents. Further, long de have resulted in tank failure at pressures as low as 25 percent of burst pressure.

6.0 OVERVIEW OF DAMAGE ASSESSMENT G ELINES

Pressure tank cars may sustain massive damage w out losing their contents. Of concern to the responder and those involved with ck clearing operations, however, is the phenomenon of delayed rupture. There hav en at least three cases (Cuming, IA; Waverly, TN; and Flomaton, AL) of pressure ta cars damaged in derailments rupturing hours after the derailment.

The Cuming and Waverly cases involved catas phic rupture with tank fragmentation and explosion. The Flomaton case the only instance TTCI is aware of where a pressure car being handled during re-ra g operations sustained an arrested fracture and lost product (no fire or explo was involved). Delayed rupture is particularly dangerous because response person and others are likely to be involved in wreck clearing operations during this e.

Although these guidelines have been used succ ully for over 15 years, it should be recognized that judgements made in the field m not be exact. In addition, there are many factors that are not apparent to the emer y responder making the assessment. Conditions such as pre-existing cracks visible to the responder, defects in material or workmanship of the tank and its wel jackets, and thermal protection or other unknowns (such as pre-existing or accident-c ed damage not visible to the responder) make tank car damage assessment inhe tly dangerous. With this in mind, it is always prudent to limit access to an accident si nvolving damaged compressed gas cars until a thorough damage assessment has b made.

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Glossary of Key Terms

- **Arrested fracture:** A fracture that stops before a flap is formed and catastrophic failure of the tank occurs.
- **Catastrophic failure:** (see total delayed fracture)
- **Cold work:** The deformation of steel when it is bent at ambient temperatures without benefit of heat treatment or suffers an impact or static load (i.e., a tank sliding over a solid object with a rounded point).
- **Crack:** A narrow split or break in the tank metal which may or may not penetrate through the tank metal.
- **Delayed fracture:** The time period between initiation of a crack and the propagation of that crack to failure. This time period may range from hours to years. As opposed to more or less instantaneous failure during the dynamics of the derailment.
- **Dent:** A deformation that changes the tank contour from that of the original manufacture as a result of impact with a relatively blunt object (coupler or end of adjacent car).
- **Ductility:** The relative ability of a metal to bend or stretch without cracking.
- **Flap formation:** The phenomenon whereby a fracture follows a dent until the internal pressure pushes out the tank metal in a lateral direction. This action normally occurs when the fracture reaches a critical length of 9 to 15 feet (3-5 m). When the critical length is reached, the ends of the fracture turn 90 degrees and extend in a circumferential direction. Flap development results in total rupture of the tank car.
- **Girth weld:** The circumferential weld that joins the plates of a tank car tank.
- **Gouge:** The removal of the tank metal along the line of contact with another object. This causes a reduction in tank metal thickness.
- **Hoop stress:** Refers to the fact that the stress on the longitudinal part of the tank is twice as great as the stress on the circumferential part of the tank.
- **Heat-affected zone (HAZ):** The area in the undisturbed tank metal next to the actual weld material. This zone is less ductile than either the weld or the plate due to the effect of the heat of the welding process. The width of the HAZ is approximately the width of the weld bead on each side of the bead.

Glossary of Key Terms (continued)

- **Internal pressure:** The force against the internal surfaces of the tank caused by the vapor pressure of the contents.
- **Jacket**: The thin metal (approximately 1/8") covering that holds the insulation and/or thermal protection in place and protects them from the elements. *Not* an outer tank!
- **Long dent**: A dent 7 feet or longer (2.3 meters). Long dents are serious for two reasons: Historically, catastrophic failures have involved a dent 7′ long, and; A 7′ long dent will almost invariably cross a weld or heat affected zone.
- **Lower Shelf**: The approximately horizontal line of energy versus temperature where notched bar impact tests demonstrate a fully brittle or cleavage fracture surface. The lower ends when the steel's transition temperature is reached.
- **Macrocrack:** A crack that can be seen with the naked eye.
- **Microcrack:** A crack requiring a magnifying device to see.
- **NDT (nil ductility temperature):** The temperature at which a particular type of steel is entirely brittle.
- **Normalize**: The process of heating steel plates to approximately 1,400 degrees F., and then air cooling it after forming, but before fabrication, in order to heat treat the steel.
- **Partial delayed fracture:** A delayed fracture resulting in tank leakage rather than total or catastrophic failure of the tank. Such a fracture arrests before flap formation and allows the pressure in the tank to dissipate.
- **Radius of curvature**: Used to describe the sharpness of a curve (dent). A small radius of curvature indicates a small circle and a sharp bend; whereas, a larger radius of curvature indicates a larger circle and a gentler bend.
- **Rail burn:** A long dent, usually parallel to the length of the tank, which crosses a weld and causes cold work. The tank passing over a section of rail may cause rail burn.
- **Rail dent**: A long narrow dent caused by the tank dropping on the rail without relative sliding motion between the rail and the tank.
- **Score:** A relocation of tank or weld metals so that the metal is pushed aside along the lines of contact with another object. This causes a reduction in tank metal thickness.

Glossary of Key Terms (continued)

- **Short dent**: A dent less than 7 feet in length (2.3 meters).
- **Tank**: "Tank" in this document refers to the actual tank car tank. It is comprised of shell plates welded together to form a cylinder. Formed heads are then welded on each end of the cylinder. Pressure tank car tanks are a minimum 9/16" thick after forming.
- **Total delayed fracture (catastrophic failure)**: A delayed fracture that extends along a long dent until it turns 90 degrees forming a flap. Such total delayed fractures have historically involved an explosion and ejection of the end tubs of the tank car over a long distance, and fragmentation of the center region of the tank.
- **Transition temperature**: The point where the properties of a steel change from ductile to brittle.
- **Wheel burn:** The removal of tank metal due to the tank coming into prolonged contact with a revolving wheel. Wheel burns often occur during the initial phases of a derailment after the car has left the tracks, but before the car overturns. In such a case, the tank center plate comes out of the truck bolster and rides on the rotating wheel, gouging out metal from the tank. Wheel burns often are preceded by a dent as the tank drops onto the flange of the wheel.

List of Acronyms

AAR	Association of American Railroads
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BOE	AAR Bureau of Explosives
ERTC	Emergency Response Training Center
FRA	Federal Railroad Administration
HAZ	Heat Affected Zone
LPG	Liquefied Petroleum Gas
NDT	Nil Ductility Temperature
NTIS	National Technical Information Service
PSIA	Pounds per square inch absolute
PSIG	Pounds per square inch gauge
SRI	Stanford Research Institute
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc

APPENDIX A:

REVISED TANK CAR DAMAGE ASSESSMENT GUIDELINES

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1.0 SCOPE AND PURPOSE

These guidelines are intended to provide the emergency responder with some reliable criteria with which to make "go/no go" decisions when interpreting damage to pressure tank cars involved in derailments or accidents. In particular, they are intended to avoid exposing personnel to the phenomenon of delayed fracture of the tank car tank. This document is intended to be a handbook of damage assessment guidelines for pressure tank cars, to be used in conjunction with *The Handbook for Field Product Removal Methods for Tank Cars*, also available from the National Technical Information Service, Springfield, VA.

Occasionally, tank cars may be so badly damaged that a conventional transfer operation may not be an option. Unloading valves may be damaged, sheared-off, or inaccessible. Eduction pipes may be broken or cracked, excess flow valves may be seated, or the tank may be so badly damaged that re-orienting it to facilitate a transfer is inadvisable.

In such cases, *The Handbook for Field Product Removal Methods for Tank Cars* provides the responder with viable options such as flaring, or vent and burn. These damage assessment guidelines provide the following information for the responder and those responsible for dealing with railroad accidents:

- An explanation of delayed fracture
- A list of safety precautions that should be followed in order to minimize the hazards of performing tank car damage assessment
- A process to follow in inspecting a damaged tank car
- A form to use when inspecting a car for damage
- Factors that affect the severity of tank damage
- The type of tank car construction information required to interpret damage and how to obtain that information
- An explanation of the significant types of damage
- Guidelines for interpreting the severity of that damage
- A list of equipment required for damage assessment

This document also recognizes the dangers inherent in operations such as field transfers of compressed gases, an alternative often chosen when damage to a tank car is deemed too serious to allow rerailing. The decision to transfer a car is often made because those in authority believe it is the safest option available without recognizing that the operation always involves the potential for hose or pump failure or other unanticipated events.

The fact that a tank car has derailed and is lying on its side is in itself no reason to mandate unloading the car in place. Unloading operations and other emergency product removal techniques carry with them inherent hazards that should be recognized and taken into consideration before such decisions are made.

2.0 SAFETY PRECAUTIONS

Response personnel must take the following precautions before inspecting pressure tank cars involved in a derailment:

- Control access to the emergency scene to minimize exposure to unauthorized personnel.
- Obtain a copy of the train consist (shipping papers) in order to determine whether hazardous materials are in the train. The consist will list the cars in the train from back to front (or front to back, depending on the railroad) by initials and number, and give an indication of the hazardous material contained in each car. Although the forces of the derailment may have affected the order of the cars in the train, the location of particular cars can sometimes be determined through a process of elimination.
- Wear personal protective equipment appropriate for the hazardous materials present (until it has been determined there are no leaks). Dress "down" only when it is appropriate to do so.
- Keep fire, lights, internal combustion engines, smoking materials, and other sources of ignition away from the area if there is a flammability hazard.

- If hazardous materials are present, determine if packages or tank cars are leaking by surveying the area with the appropriate monitoring instruments.
- Identify any tank cars in the train and determine whether they are pressure cars or general service cars.
- Secure the assistance of someone with experience and training to perform a damage assessment of any pressure cars in the derailment. Potential sources of this expertise are Bureau of Explosives Inspectors, railroad hazardous materials specialists, shipper representatives, and tank car manufacturers or repair personnel.
- Secure the assistance/advice of the shipper of the hazardous materials involved for detailed information on the characteristics and behavior of the material(s).

3.0 FACTORS AFFECTING THE SEVERITY OF TANK DAMAGE

3.1 DUCTILITY OF TANK METAL

Ductility is the relative ability of a metal to bend or stretch without cracking. Ductile materials tend to bend but not crack. Brittle materials tend to crack rather than bend. When a ductile steel tank does crack, it tends to be small; whereas, the crack in a brittle steel tank tends to run linearly and causes the tank to fail.

Four factors affect the ductility of tank steel:

- Specification of the steel
- Temperature of the steel
- Damage to the tank
- Heat affected zone

3.2 TANK CAR STEEL SPECIFICATIONS

From 1937 to 1966, pressure tank car tanks were constructed of as-rolled ASTM A-212 grade B, AAR M-115, ASTM A-285 grade C, and ASTM A-515 grade 70. From 1967 to 1986, pressure tank cars were constructed of as-rolled TC-128 B steels. Compared to the steel used after 1966, these were relatively coarse grained. The TC-128 B has a transition temperature that is considerably lower than the previously used steels, and tends to bend rather than crack at normal operating temperatures.

Table 1. Comparison of Tank Car Steel Properties

Steel	Yield (min. ksi)	Ultimate (ksi)	Elongation (% in 8 in)	C Content (max. Wt %)	Mn Content (max. Wt %)
A212B /A515 Gr 70	48	70-85	27	0.31	0.9
TC-128B	50	81-101	16	0.25	1.35

Note: As of November 1999, there were approximately 7,000 of these pre-1967 cars still in service)

In 1986, requirements mandated that pressure tank cars be constructed of TC-128B normalized steel. Normalized TC-128B steel is much more damage tolerant than the previous steels used in tank car construction, primarily because it has a nil ductility temperature (NDT) that is about 40° F lower than the other steels. This lower NDT basically means that the car is less subject to brittle fracture over a wider range of temperatures. That is, the tank will tend to bend, rather than break. The following breakdown gives an indication of the percentage of cars constructed of each type of steel that are still in service as of 1998.

Percentage of pressure cars by built date and steel type:

- 15 percent built prior to 1966 (A212B or A515-70 or equivalent)
- 65 percent built between 1967 and 1985 (as-rolled TC-128B)
- 20 percent built since 1986 (normalized TC-128B)

3.3 TEMPERATURE OF THE STEEL

The temperature of the steel affects its ductility. The higher the temperature of the steel at the time it is damaged, the more ductile it will be and the less risk there is for failure. This benefit is offset by the fact that the higher the ambient temperature, the higher the vapor pressure of the product in the tank.

If the tank is warm to the touch (100°F) the tank will be entirely ductile, regardless of the type of steel of which it is constructed.

3.4 COLD WORK

Cold work is deformation of steel when it is bent at ambient temperatures or suffers an impact or static load; i.e., a tank sliding over a solid object with a round point. Any damage to a tank (other than that caused by fire) is by definition "cold work." Cold work reduces the ductility of the steel.

The transition temperature of the steel is raised sharply as a result of cold work. That is, the steel becomes more brittle at the point where the cold work takes place.

3.5 HEAT AFFECTED ZONE

The heat affected zone (HAZ), is an area in the undisturbed tank metal on both sides of the actual weld bead (see Figure 1). The width of each zone is approximately the same as the width of the bead itself. This zone is less ductile than either the weld or the plate due to the deleterious effect of the heat generated by the welding process on the steel. The HAZ is most vulnerable to damage, as cracks are most likely to initiate there. This was the case with the Flomaton, AL car.

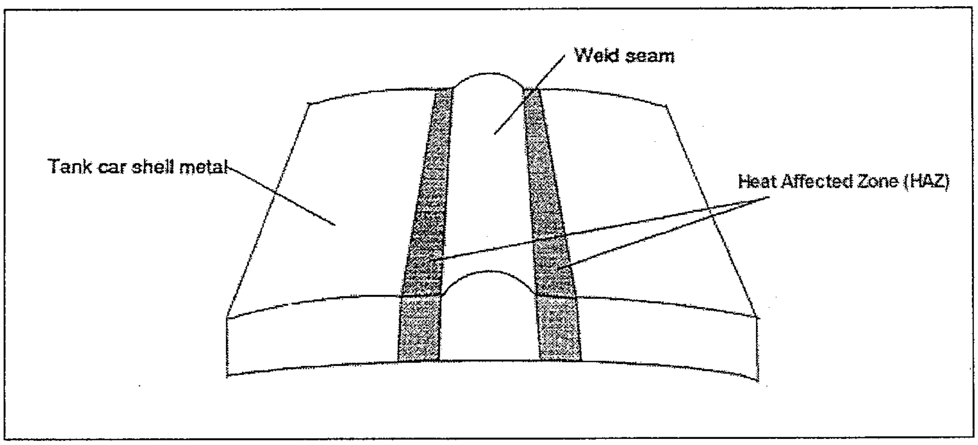


Figure 1. Heat Affected Zone

4.0 TOOLS REQUIRED FOR TANK CAR DAMAGE ASSESSMENT

- Depth gauge
- Magnifying glass
- Pressure gauges (up to 400 psi suitable for ammonia, LPG, and chlorine)
- Thermometer (for tank metal)
- Thermometer (for lading)
- Reducers from both 1 and 1/2 inches and 1 inch to 1/4 inch
- Teflon or other thread tape
- Tape measure
- Compressed gas handbook

5.0 UNDERSTANDING DELAYED FRACTURE

In order for delayed fracture to occur, there must be a pre-existing crack in the tank metal. This crack may be microscopic or large, depending on the forces the tank has encountered. Such a crack may be caused by the tank striking or being struck by another object (e.g., a rail) during the dynamics of a derailment. Analysis of the cases above suggest that this crack will initiate where the dent crosses a weld (most often, a girth weld). In order for a micro-crack to become unstable and propagate, a critical stress level must be reached. Stress tends to make cracks grow. In the case of a tank damaged in a derailment, the principal cause of increased stress will be a rise in internal pressure. This pressure rise may be caused by a rise in the ambient temperature, fire impingement, or radiant heat. As the critical stress level is reached, the crack will start to grow, become unstable, and propagate. In essence, the crack "waits" for the necessary conditions of temperature, loading rate, and stress to develop. In the case of a long, straight dent, the crack will follow the line of the dent.

Depending on the length of the dent, the crack will either be arrested (if a short dent), or progress along the dent until a flap is formed and the tank totally fails (if a long dent).

While the primary cause of this increased stress is a rise in internal pressure, dynamic loadings incurred during re-railing operations (such as dropping or twisting the car) could induce stresses sufficient to cause crack propagation. Computer modeling suggests that normal lifting, in and of itself, is generally not a critical factor.

6.0 INSPECTING A TANK CAR FOR DAMAGE

Before wreck clearing operations begin, it is imperative that all pressure tank cars be inspected for damage whether they are loaded or empty (many "empty" cars are shipped with relatively high vapor pressures). The following steps should be taken when inspecting damaged tank cars:

- Inspect all accessible areas of the tank for cracks, scores, gouges, wheel burns, dents, and rail burns. Be certain to record the location, size, and other discerning information on the worksheet provided, so that details are not forgotten or overlooked. Any damage that runs in the longitudinal direction (parallel to the long axis of the car) is potentially serious because of hoop stresses. Since that portion of the tank that is lying on the ground may have sustained the most serious damage, it is advisable to have the car lifted in order to properly inspect the underneath portion of the tank. This is particularly advisable if the terrain is rough or if there is reason to believe the tank may have slid across a rail or other obstruction.

  Since many pressure cars are jacketed, it is important to differentiate between superficial damage and actual tank damage. Minor dents, scores, or gouges on the tank jacket are not a concern. However, when the jacket is torn or dented for several inches or more, it may be a cause for concern. A rough estimate of the depth of a dent in a jacketed car can be made if one knows the thickness of the jacket material plus the thickness of the insulation and/or thermal protection. If in doubt, the jacket material can be cut away by mechanical means (e.g., air chisel) if it has been determined that there is not a flammable atmosphere present. Some cars are equipped with as much as 4 inches of insulation while others have as little as 1 or 2 inches. The tank car jacket is about 1/8 inch thick.

- Measure the depth of each score, gouge, or wheel burn on the tank.

- Identify the location where each score, gouge, or wheel burn crosses a weld.

- Where a score, gouge, or wheel burn crosses a weld, measure the depth of weld metal removed. If only the crown of the weld reinforcement is removed, the damage is not serious.

- Where a score, gouge, or wheel burn crosses a weld, determine if the heat affected zone has been damaged. If a score or gouge damages the heat affected zone, the damage is potentially critical.

Note: Dents 7 feet or longer that run longitudinally and cross a circumferential weld (girth weld), are particularly critical.

- Identify those dents which have scores or gouges associated with them and those crossing a weld.

Note: Dents in combination with scores or gouges and/or dents that cross welds are the most dangerous.

- Examine each dent or rail burn for cracks and record any found, regardless of size. Relatively large cracks (macro-cracks) are visible to the naked eye. To find smaller cracks (micro-cracks) a magnifying glass will be required. Often, the lading will weep through even a small crack, so look for signs of frosting or clear liquid near the damaged area.

- Determine the temperature of the tank metal.

Note: **This can be accomplished by attaching a thermometer to the shell of the tank. Ensure that the thermometer is attached to the tank and not the jacket.**

- If any potentially serious damage is found, determine the internal pressure of the car. This is essential for deciding whether the tank should be picked up, unloaded where it is, or another emergency product removal method should be employed.

  The pressure may be obtained by either:

  - Attaching a pressure gauge to the sample line or spew-type gauging device (both these fittings are usually 1/4 inch and will not require reducers). If the car is not equipped with a sample line or gauging device (e.g., a chlorine car), reducers must be used to accommodate the differential between the liquid or vapor valve to the gauge. Depending on the orientation of the car, it is often helpful to attach a long hose of appropriate pressure rating to the gauge so that the gauge hangs down the side of the car. This eliminates the need to climb up and down each time a reading is required.
  - Taking the temperature of the contents and referring to the vapor pressure/temperature graphs for the particular product.

Notes:

- Graphs are available from the Compressed Gas handbook (see Appendix C), the shipper, or the manufacturer of the commodity.

- Most pressures are shown as pounds per square inch absolute; therefore, 14.7 must be subtracted to obtain gauge pressure.

- In the event that neither temperature nor pressure can be measured, a rough estimate of the temperature of the product can be made from ambient temperature. The temperature of the tank's contents may lag ambient temperature by about 6 hours (for a non-insulated or thermally protected car).

Since the contents of a tank car may stratify by temperature, taking a direct pressure reading is the preferred method.

- Keep in mind that the internal pressure of "residue" tank cars containing the vapors of residual products may be equal to or higher than that in loaded cars.
- If any potentially serious damage to the car is found, the next step is to determine the year the car was built in order to identify what the material of construction is. The built date of a tank car can be determined from the consolidated stencil located on the right end of the car toward the bottom while one is facing the car. The abbreviation "BLT" followed by a year generally denotes the built date (example: BLT '67). This information is helpful because post-1967 cars are built of better steel. The type of steel used to construct the tank is also stamped into the head of the tank car.

7.0 REVISED DAMAGE ASSESSMENT GUIDELINES

When inspecting a damaged tank car, the inspector must be able to identify and categorize various types of tank damage. This section defines, illustrates, and explains how to interpret the seriousness of the following types of damage:

- Cracks
- Scores
- Gouges
- Wheel burns
- Dents
- Rail burns
- Long dents (7 feet or longer)

Accurate assessment of damage on jacketed tanks is difficult without removing the jacket and thermal protection/insulation. There is often great reluctance to use mechanical means to cut away the jacket of a damaged car for fear of explosion. However, this procedure can be performed safely if the area is carefully monitored for combustible gases.

Note: Tank cars in classes 105, 112J, 114J, and 120 are jacketed. Tank cars in classes 112A, 112S, 112T, 114A, 114S, and 114T are not jacketed cars.

Although damage to the jacket of a car is of no consequence, serious jacket damage may be an indication of tank damage behind the jacket.

7.1 CRACKS

As illustrated in Figure 2, a crack is a narrow split or break in the tank metal, which may or may not penetrate through the tank metal. Cracks may be microscopic or macroscopic (visible to the naked eye).

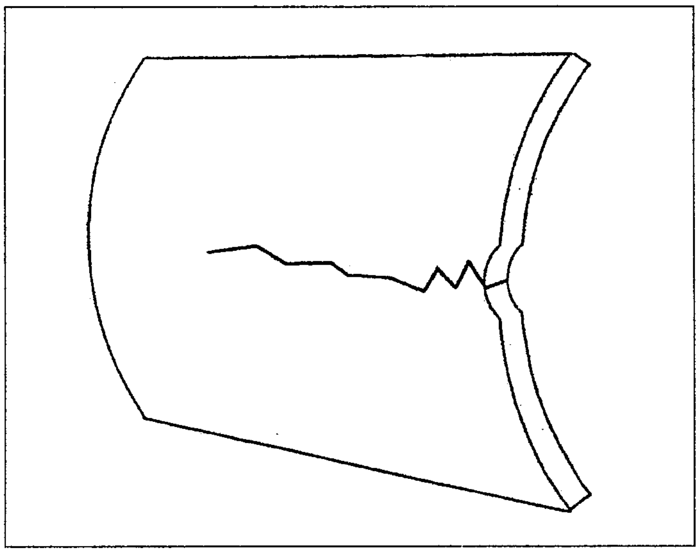


Figure 2. Illustration: Crack in the Tank Metal

- Since there is no way to detect a crack that has become critical, a crack found anywhere in the base metal or weld of a tank is justification for unloading the car in place.
- Cracks in attachment pads or the welds of these pads are not serious unless they extend into the base metal of the tank. **Caution:** Cracks have been found recently in heads of certain tanks equipped with head blocks.
- Cracks, which run longitudinally to the long axis of the car, are at least 50-75 percent more serious than those that are perpendicular to the long axis.
- Cracks in conjunction with other types of damage are more serious than if found alone (e.g., a crack in the valley of a dent).

7.2 SCORES

A score is a relocation of tank or weld metal so that the metal is pushed aside along the track of contact with another object. This causes a reduction in tank metal thickness. Scores and gouges in conjunction with dents are discussed in Section

Scores or gouges crossing a weld and removing only the weld reinforcement (crown) are not critical (see Figure 3).

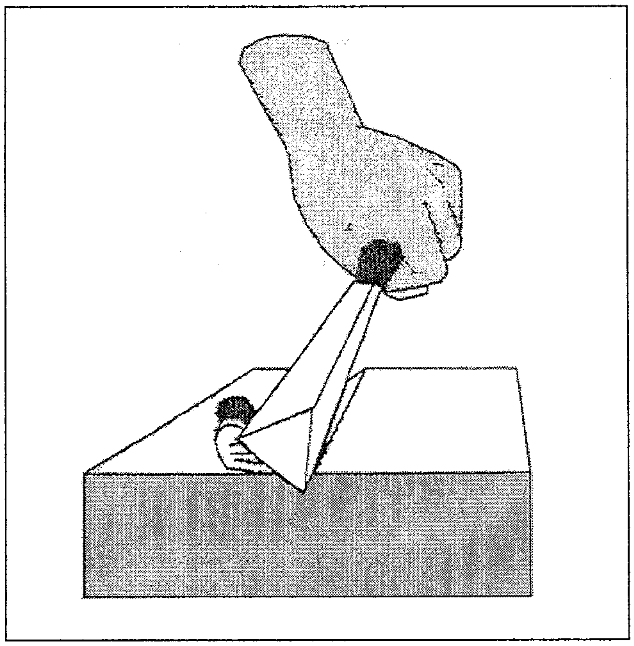


Figure 3. Illustration: Score

Longitudinal scores are the most dangerous. However, circumferential scores cannot be ignored for at any given section such scores also constitute a longitudinal notch.

As shown in Figure 4, longitudinal scores or gouges crossing welds and damaging the heat affected zone(s) are critical and the contents of the tank should be transferred immediately without raising the internal pressure of the tank (see various transfer methods in *Field Product Removal Methods For Tank Cars*).

Tanks having scores or gouges should have their internal pressure reduced or be unloaded in place when the internal pressure exceeds the pressure listed in Tables 2 and 3. The tables provide the allowable score depths and allowable pressures for 340W and 400W tanks, respectively. These tables incorporate a 2:1 safety factor; that is, the calculated burst pressure is actually twice the value shown in the tables.

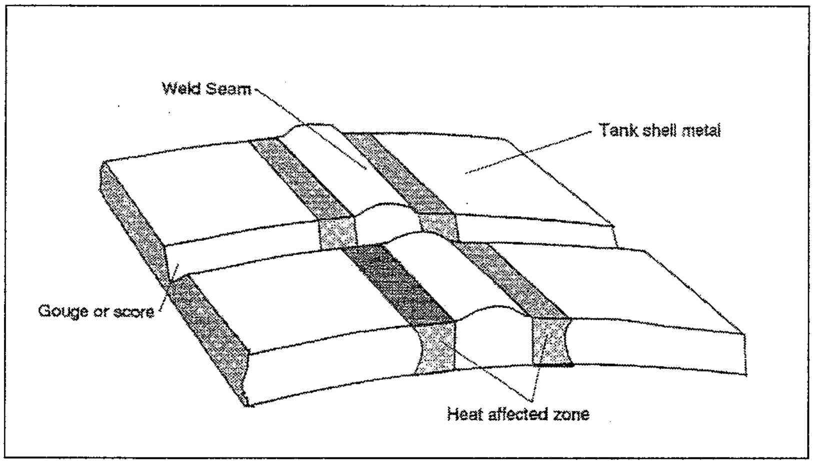


Figure 4. Illustration of Gouge Crossing the HAZ

Table 2. Limiting Score Depths for 340W Tanks

PSIG = pounds per square inch gauge

Depth of Score	Maximum Safe Internal Pressure,
1/16 inch	191 PSIG
1/8 inch	170 PSIG
3/16 inch	149 PSIG
1/4 inch	127 PSIG

Note: The bursting pressure for a 340W tank is 850 psi (in the newly constructed, undamaged condition.)

Table 3. Limiting Score Depths for 400 W Tanks

PSIG = pounds per square inch gauge

Depth of Score	Maximum Safe Internal Pressure, PSIG
1/16 inch	228 PSIG
1/8 inch	205 PSIG
3/16 inch	188 PSIG
1/4 inch	162 PSIG

Note: The bursting pressure for a 400W tank is 1,000 psi (in the newly constructed, undamaged condition.)

Both tables above assume the minimum tank thickness prescribed by current Federal regulations.

The decision to immediately reduce internal pressure or unload the car in place must be based upon the internal pressure of the tank and relating that number to the maximum safe internal pressures in the tables above. For example, if a 400W tank has a

1/4-inch deep score, and the internal pressure is 160 psi (after correcting for gauge pressure), the tank car can be safely moved. It is important to remember that this guideline assumes no other damage associated with the score.

7.2.1 Calculating Minimum Tank Thickness

CFR 49, Section 179.100-6 (a), sets the minimum thickness for pressure tank car tanks. The formula for calculating tank thickness is as follows:

$$T = \frac{PD}{2SE}$$

Where:

T = Minimum Thickness of Plates After Forming
P = Pressure (Burst)
D = Diameter
S = Minimum Tensile Strength of plate material
E = Welded Joint Efficiency = 1.0

Therefore, the following is the equation that would be used to determine the minimum required thickness for a DOT 112J340W tank car with an interior diameter of 118 1/4 inches, constructed of TC-128B steel, of 81,000 psi tensile strength:

$$T = \frac{PD}{2SE} \quad \frac{850 \times 118.25}{2 \times 81{,}000 \times 1.00} = .6204$$

The minimum thickness of this tank will be .6204 inch

7.2.2 Calculating Safe Internal Pressure

To calculate the safe internal pressure of a car with a longitudinal gouge 1/4 inch deep, we rearrange the formula in this manner.

$$P = \frac{T2SE}{D} = \frac{.3704 \times 2 \times 81{,}000 \times 1}{118.25} = 507 \text{ (bursting pressure)}$$

To maintain a safety factor of 2, divide the calculated burst pressure by two:

507 divided by 2 = 253.5 (maximum safe internal pressure)

Note that this calculation assumes no damage other than reduced thickness of the tank.

7.3 GOUGES

A gouge is a removal of the tank or weld metal along the track of contact with another object (Figure 5). This causes a reduction in tank metal thickness.

For the purpose of this report, gouges are treated in the same manner as scores. That is, unless associated with other types of damage, a gouge just reduces the thickness of the tank, and the same evaluation process is used.

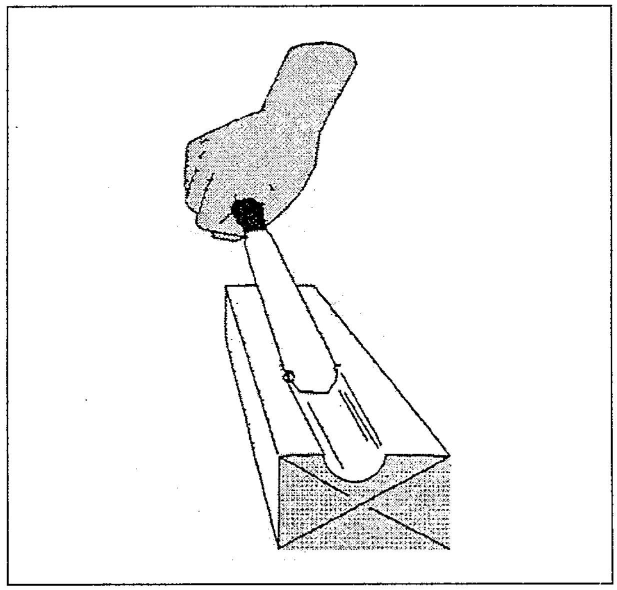


Figure 5. Illustration: Gouge

7.4 WHEEL BURNS

As shown in Figure 6, a wheel burn is similar to a gouge but is caused by prolonged wheel contact with the tank, which often causes metal discoloration and potential metallurgical damage. The discoloration itself does not cause serious damage.

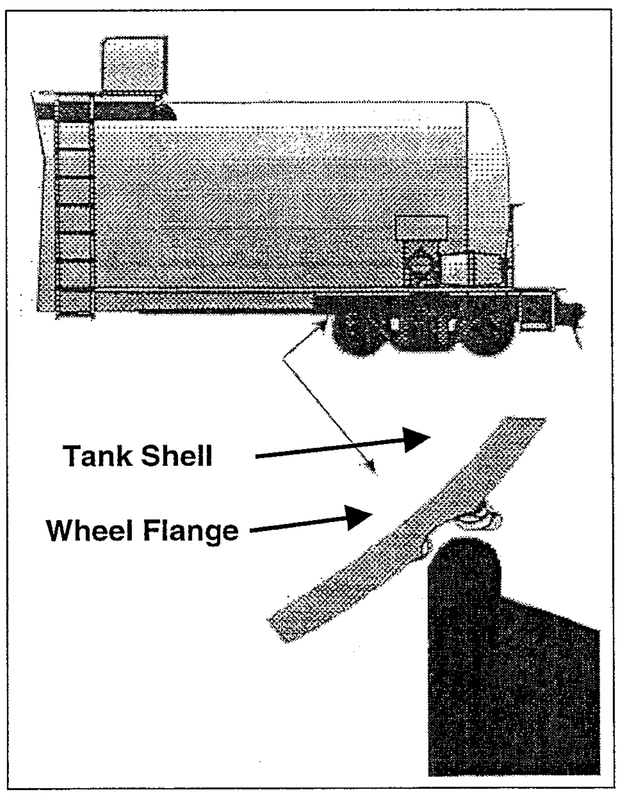


Figure 6. Illustration: Wheel Burn

7.5 DENTS

Figure 7 depicts a dent, which is a deformation that changes the tank's contour from that of original manufacture as a result of impact with a relatively blunt object (coupler, draft sill, or the end of an adjacent car).

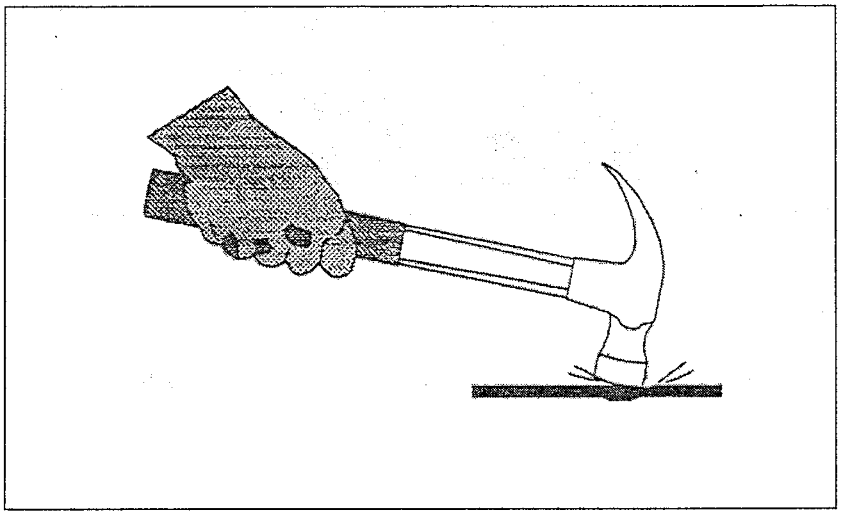


Figure 7. Illustration: Dent

7.5.1 Rail Dents

A rail dent is a long dent, usually parallel to the length of the tank (i.e., parallel to the longitudinal axis of the tank) that crosses a weld and causes cold work (Figure 8). The tank falling on, or passing over a stationary object such as a rail generally causes it. Rail dents are sometimes referred to as rail burns when the sliding action of the tank over the rail produces a discoloration of the surface metal. This surface discoloration (burn) is superficial and is not serious.

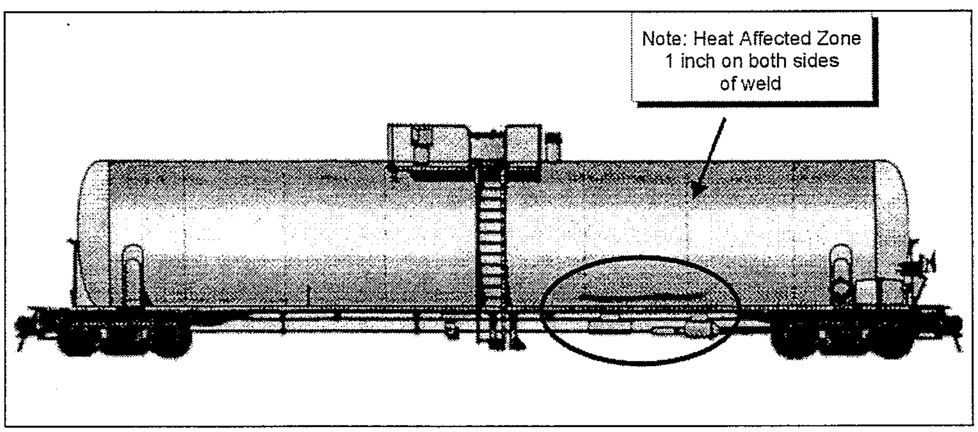


Figure 8. Rail Dent

The guidelines give a safety factor of 3 (i.e., the maximum strain allowed by the guidelines is one-third of the minimum value for that material).

In considering the severity of dents, the following factors need to be addressed:

- The internal pressure of the tank.
- The length of the dent -- long dents are more serious than short dents. Catastrophic failure has never occurred unless the dent was 7 feet or longer.
- The location of the dent -- dents that cross welds of any kind or touch the heat-affected zone of any weld are the most serious. Note: for the purposes of this report, the heat-affected zone is defined as within 1 inch of either side of a weld bead.
  - Sharp dents in the cylindrical portion of the tank which are parallel to the long axis and cross a weld are the most serious as they can drop the rated burst pressure of the tank by 75 percent (from 850 psi to 212 psi) for a 340-psi tank.

  Note: Every catastrophic delayed failure of a pressure car has been associated with dents of this type that were 7 feet in length or longer. The longer the dent, the more serious it is.

7.5.2 Dents in the Shell of Tank Cars Built Before 1967

The tank should be unloaded without moving if it meets any of the following conditions:

- Has a crack anywhere
- Crosses a weld; or touches a heat affected zone
- Includes a score or gouge

Dents which do not cross a weld, touch a heat affected zone, and are not associated with any other damage are not a problem by themselves.

7.5.3 Dents in the Shell of Tank Cars built in 1967 and After

The tank should be unloaded without moving if it meets any of the following conditions:

- Has a crack anywhere
- Crosses a weld or touches a heat affected zone
- Includes a score or gouge
- Shows evidence of cold work

7.5.4 Massive Dents

Massive dents in heads of the tank are generally not serious unless gouges or cracks are present with the dent.

7.5.5 Small Dents

Small dents in heads, in conjunction with other damage in the bottom of the dent, are marginal. If at all possible, such tanks should be unloaded in place. In any case, the tank should be moved as little as possible and promptly unloaded.

8.0 DISCUSSION OF RE-RAILING PROCEDURES

Computer modeling studies indicate that when a tank car is lifted properly (i.e., a straight lift from the body bolster or stub sill) the lifting loads imparted into the tank structure will not significantly reduce the safety factors used in evaluating a damaged car. These loads are relatively small relative to the stresses imparted by the internal pressure on the tank exerted by the lading. There are two possible exceptions: 1) when it is a car with critical damage in the area adjacent to the stub sill or bolster; or when a car with a deep (6″or more in this case), long dent is lifted in a way that would cause the dent to flex (Figure 9). This is one case where a circumferential dent can be critical, even when it does not cross a weld.

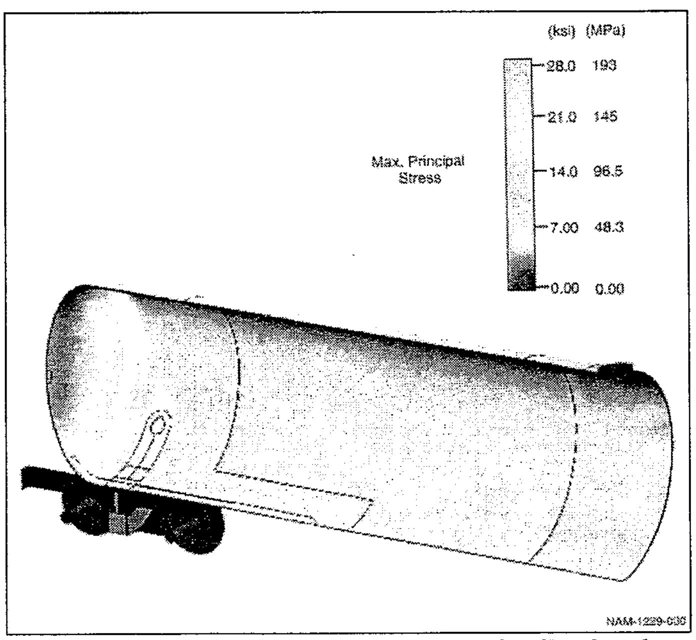


Figure 9. Maximum Principal Stress Distribution from 130-psi Internal Pressure and Lading

Lifting a car in this manner tends to:

- Flex the metal making the bend open up more (if the car is sitting upright and the bend runs circumferentially causing across the bottom of the tank), or
- Flex the metal the other direction causing the bend radius to become sharper (if the bend is on the top of the tank).

In either case, the effect is much like that when a metal can is bent into a "V" shape and then bent backwards. It only takes several instances of flex before the can fails, even with no internal pressure.

Care should be exercised when "rolling" severely damaged cars that a "torquing" effect is not created.

APPENDIX B:

TANK CAR DAMAGE ASSESSMENT WORKSHEET

(blank)

TANK CAR DAMAGE ASSESSMENT RECORD

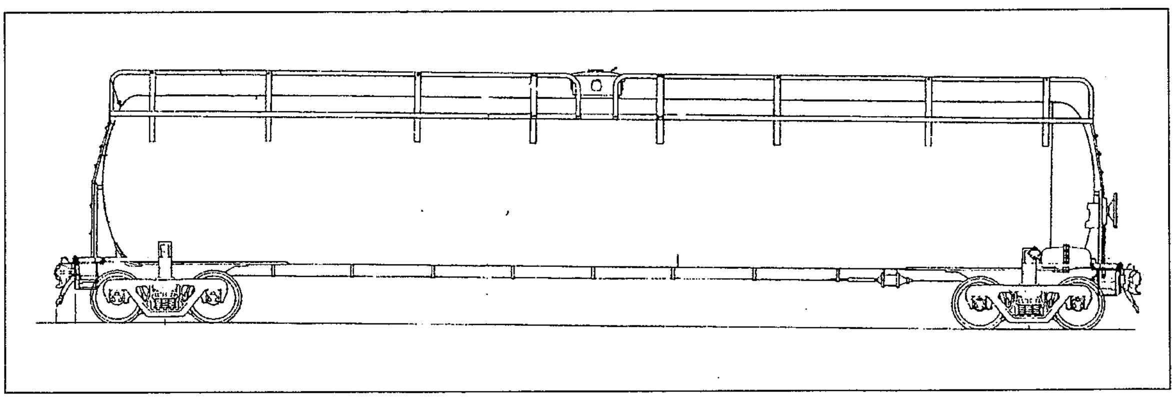
Reporting marks:_______________ **Built Date:**_______________

Specification:_______________

Load / Empty:_______________ **Product:**_______________

Internal Pressure:_______________ **Ambient Temp. At Time of Derailment** _______________

Damage Type	Length	Depth	In Conjunction with:	Cross a Weld or HAZ? (Y/N)
Crack				
Score				
Gouge				
Wheel Burn				
Dent				
Rail Dent				



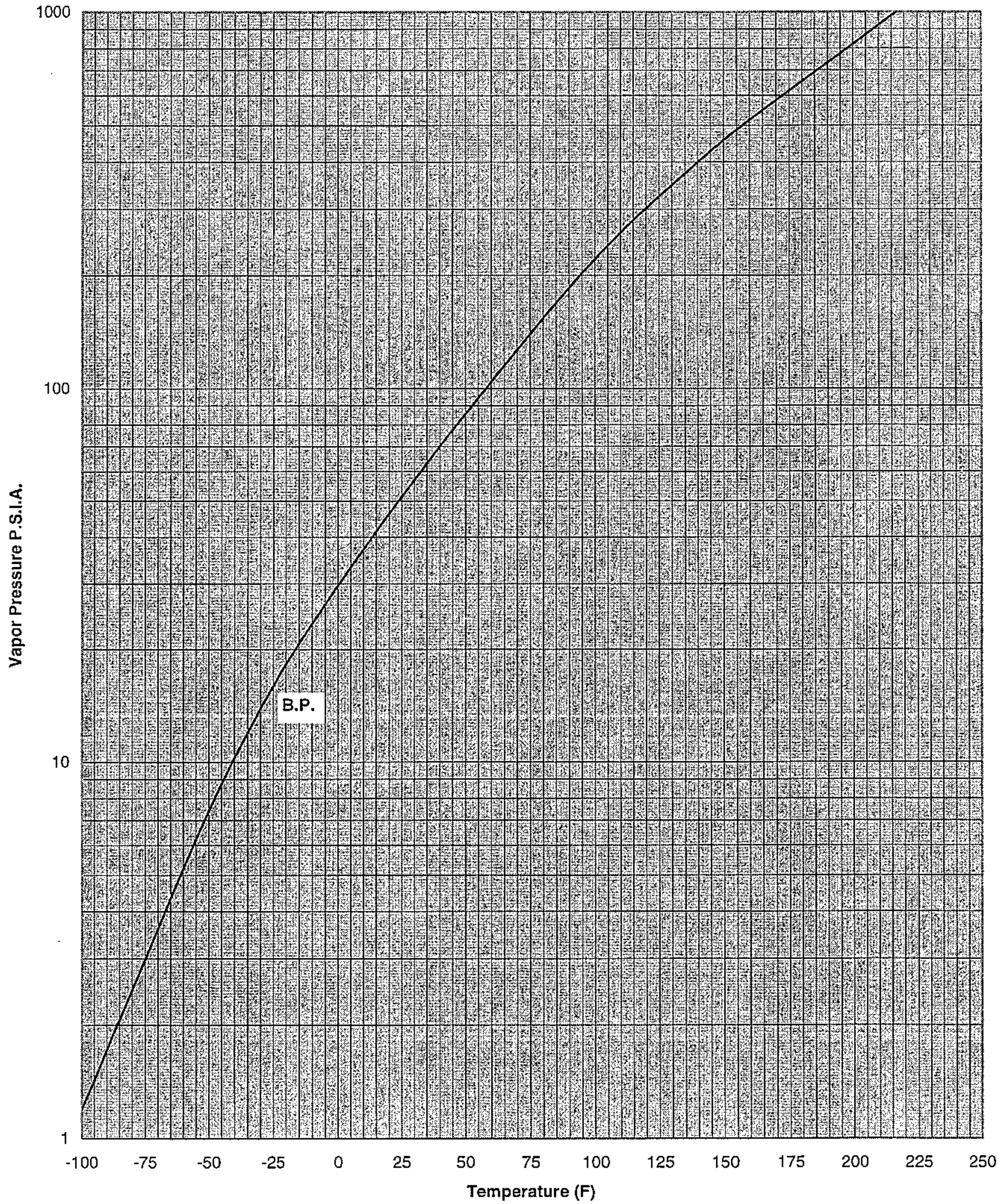
Pressure Car

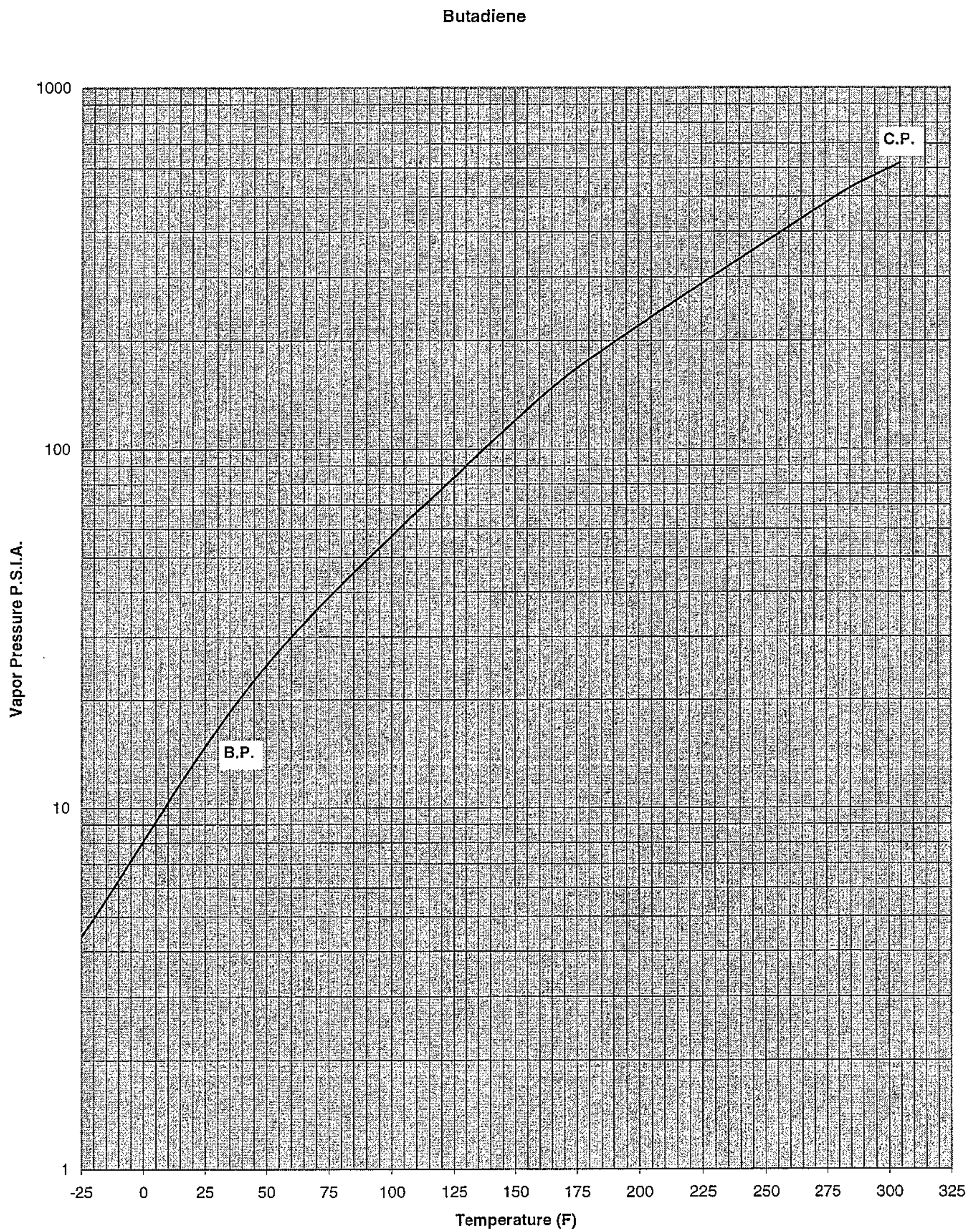
(blank)

APPENDIX C:
COMPRESSED GAS TABLES (22)

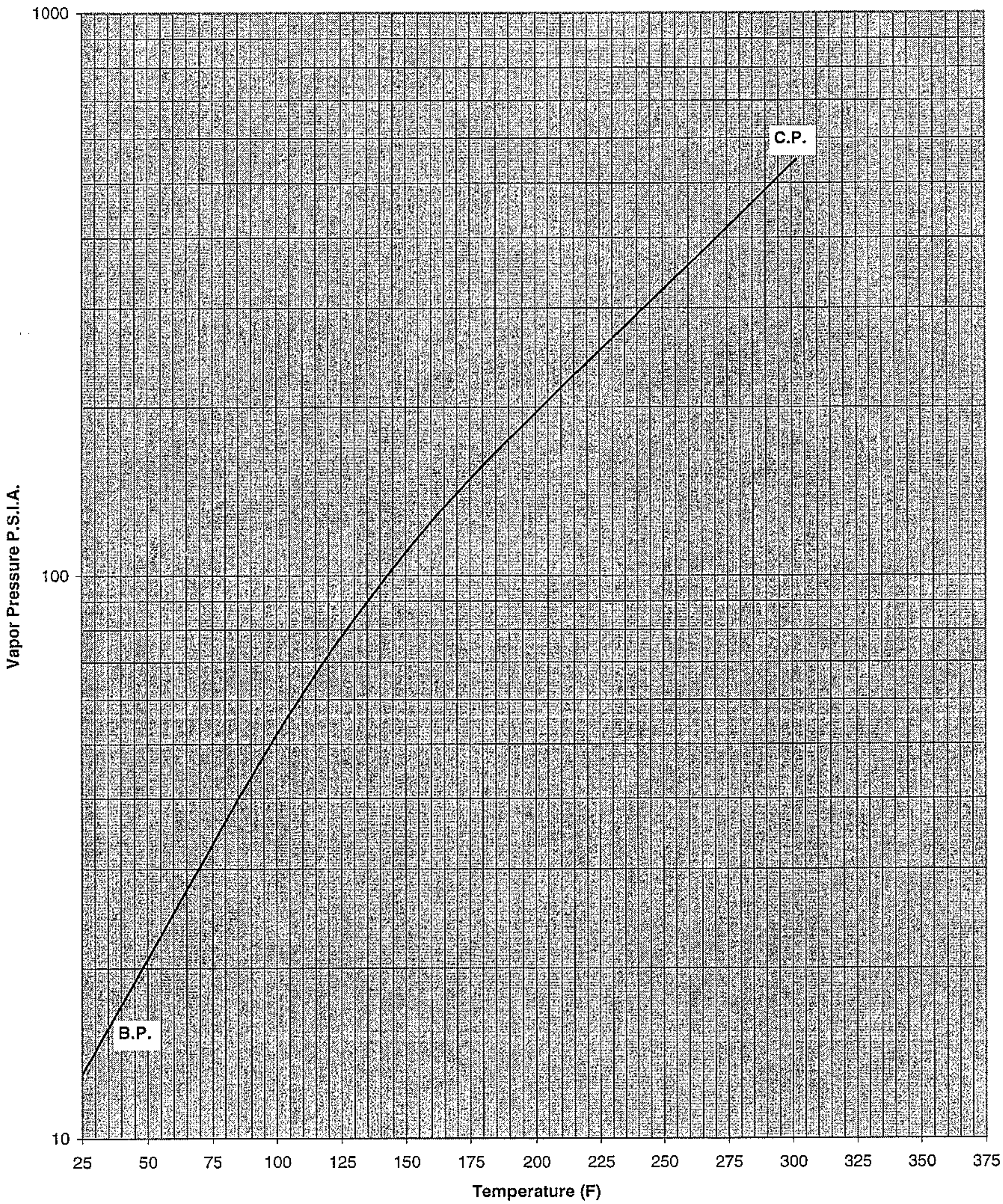
(blank)

Ammonia

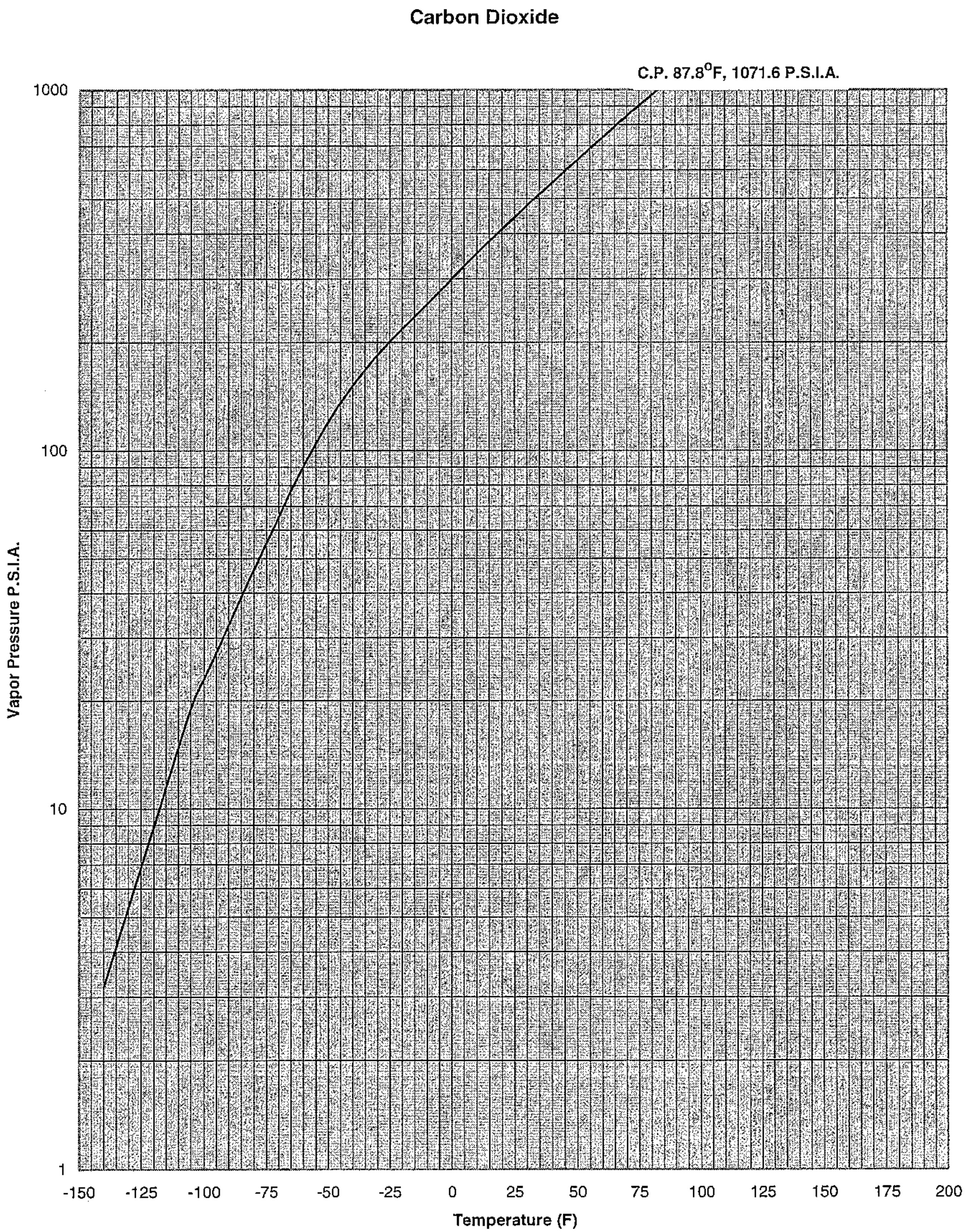

1000
100
10
1
Vapor Pressure P.S.I.A.
B.P.
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
225
250
Temperature (F)


Butadiene
1000
100
10
1
Vapor Pressure P.S.I.A.
C.P.
B.P.
-25
0
25
50
75
100
125
150
175
200
225
250
275
300
325
Temperature (F)

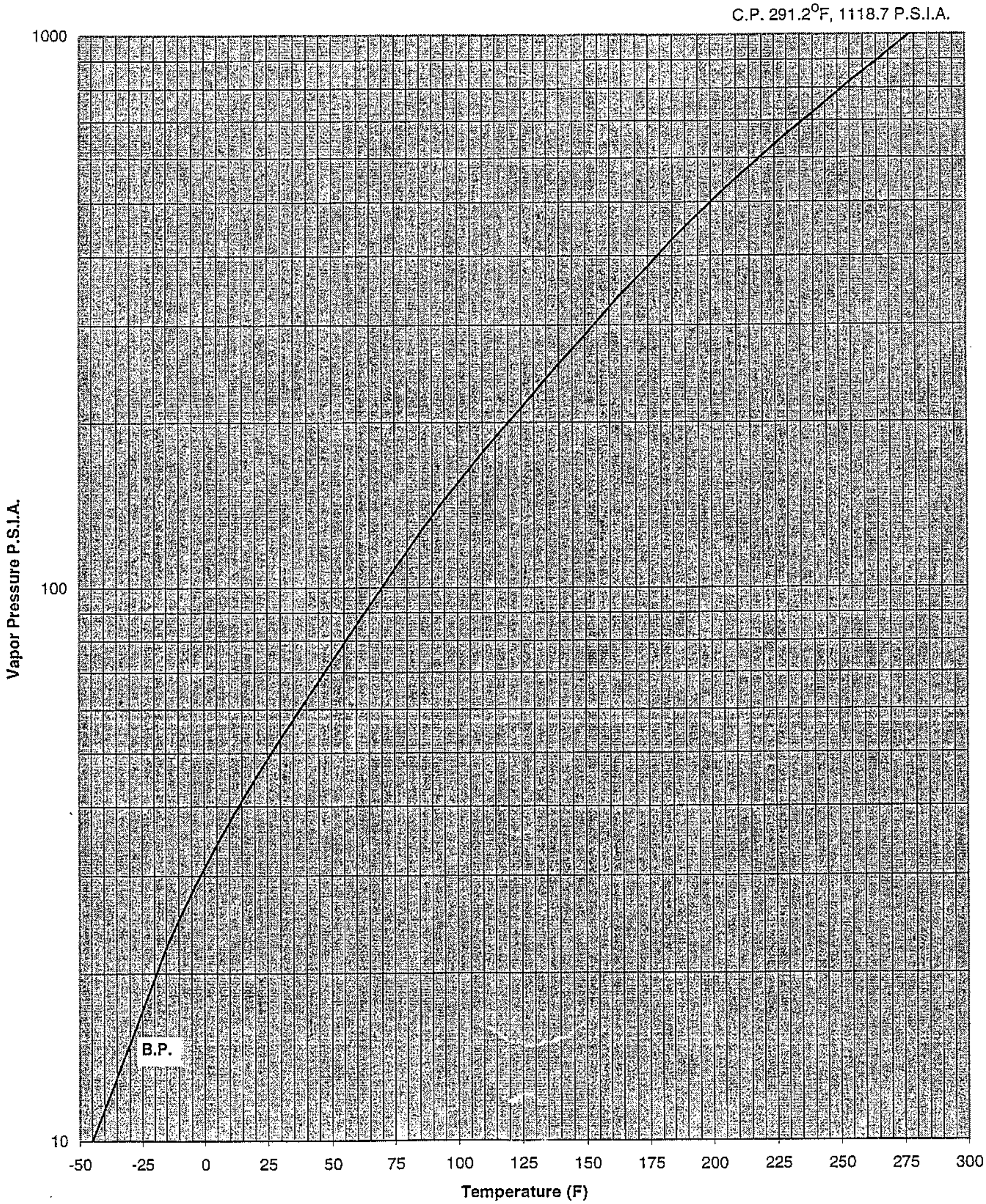
n-Butane



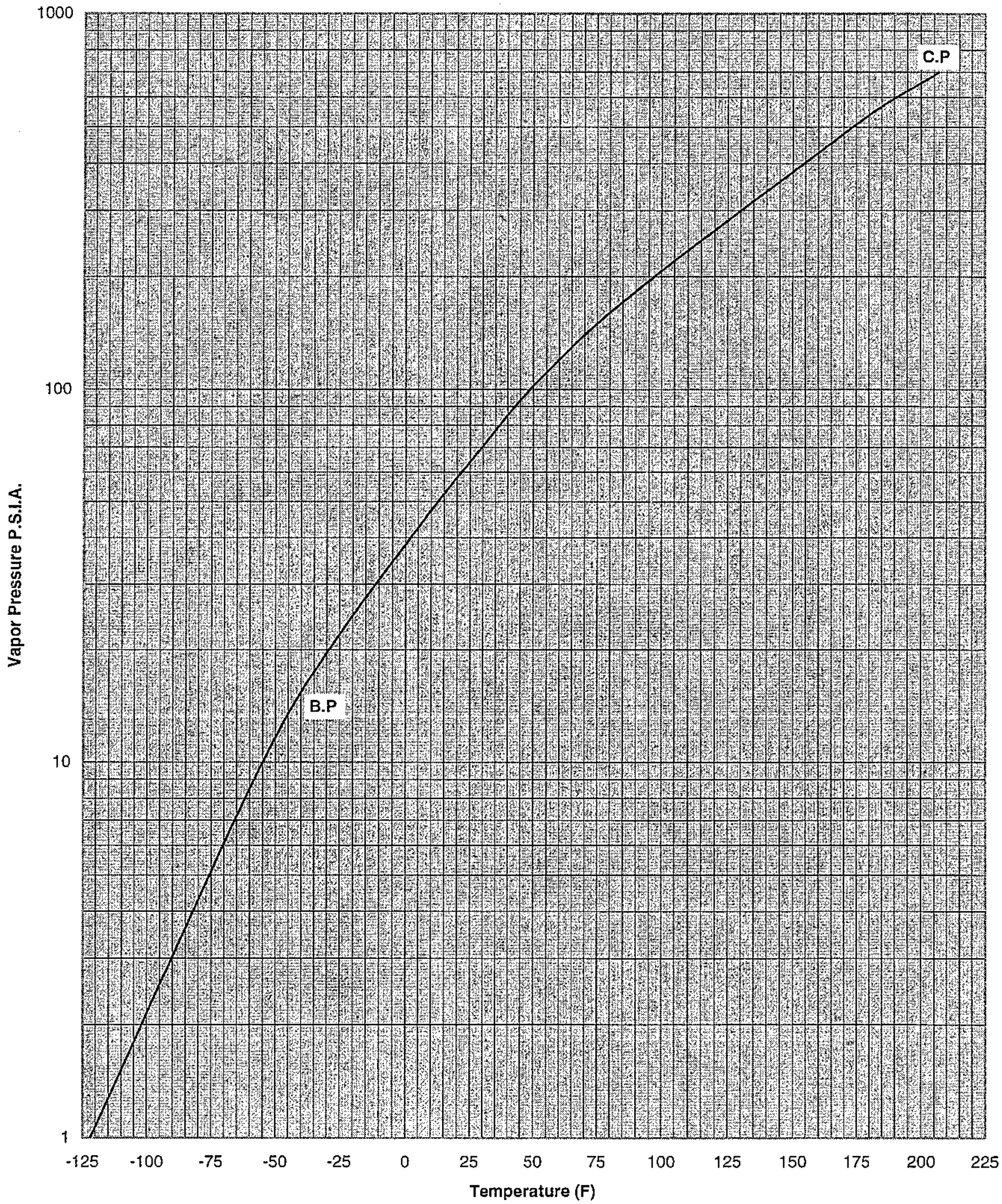
1000
100
10
Vapor Pressure P.S.I.A.
C.P.
B.P.
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
Temperature (F)


Carbon Dioxide
C.P. 87.8°F, 1071.6 P.S.I.A.
1000
100
10
1
Vapor Pressure P.S.I.A.
-150
-125
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
Temperature (F)

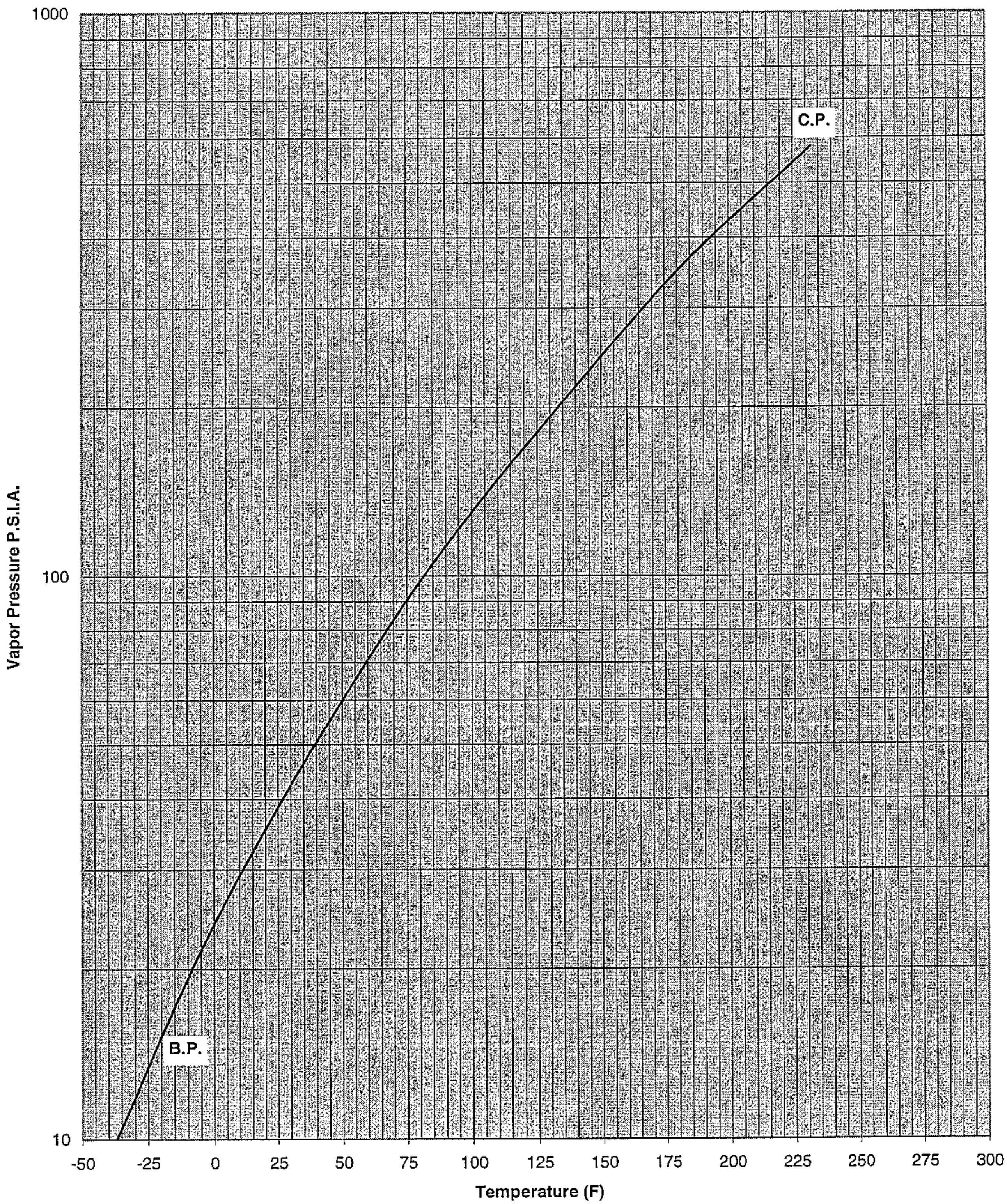
Chlorine


C.P. 291.2°F, 1118.7 P.S.I.A.
1000
100
10
Vapor Pressure P.S.I.A.
B.P.
-50
-25
0
25
50
75
100
125
150
175
200
225
250
275
300
Temperature (F)

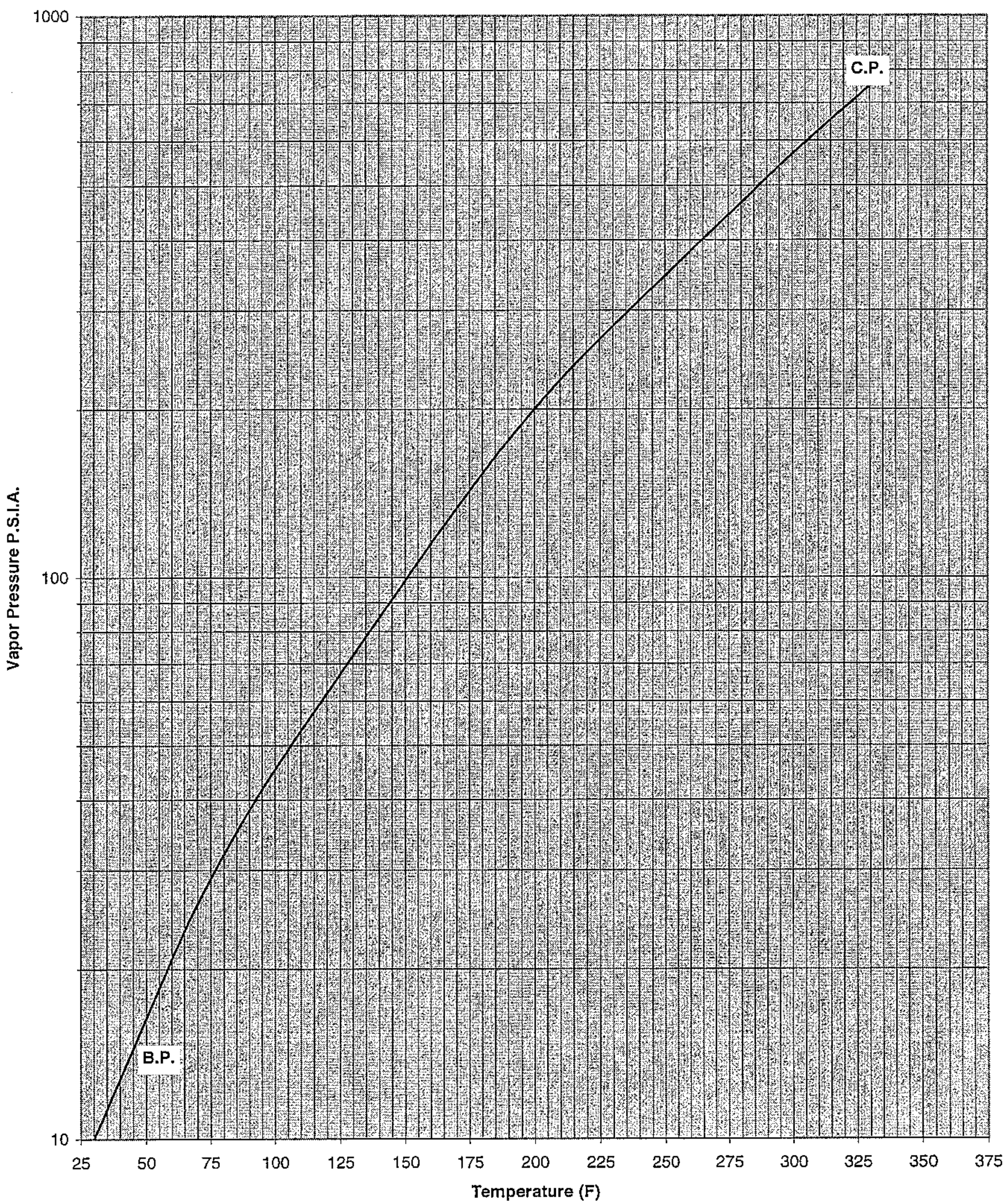
Chlorodifluoromethane



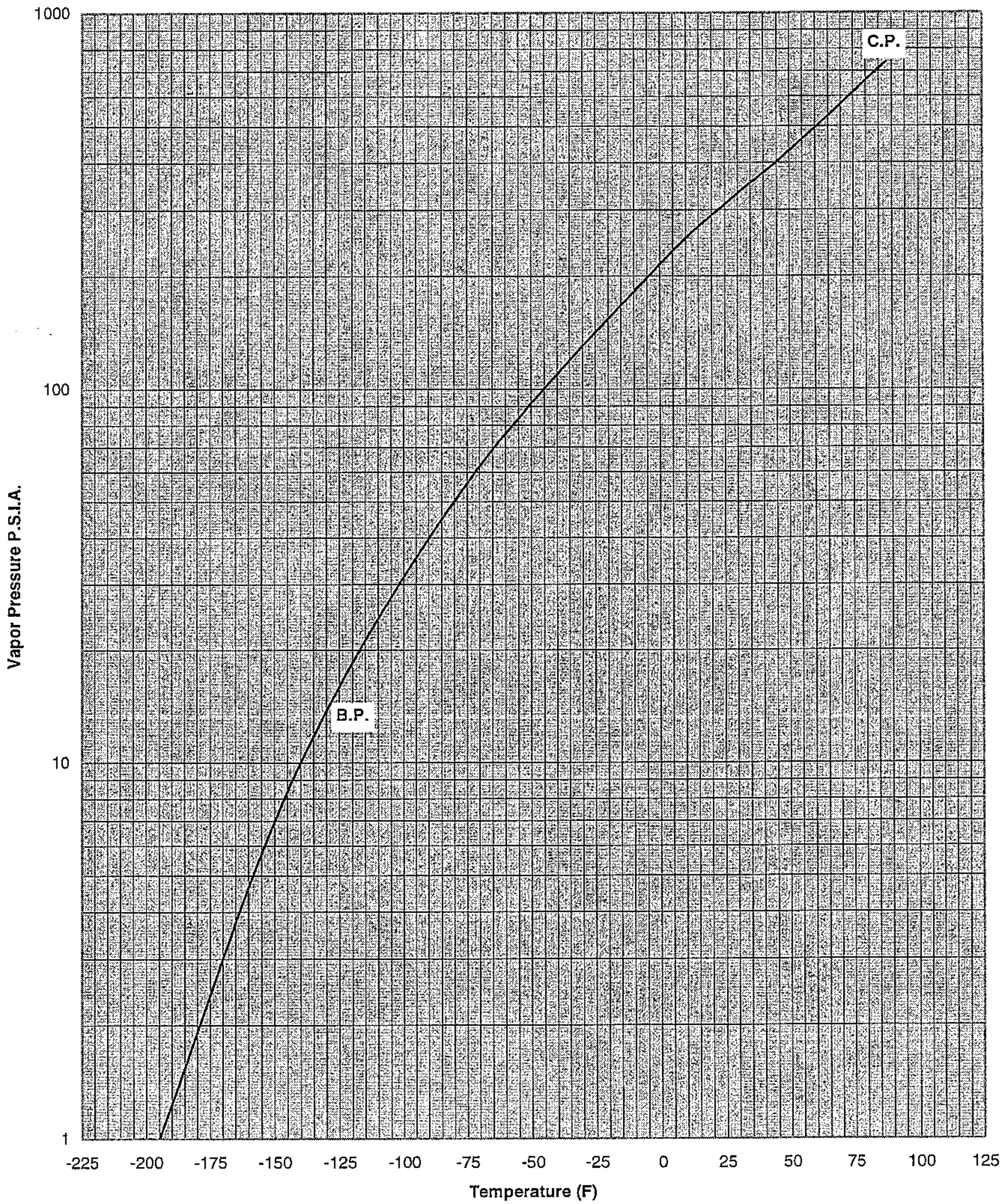
Dichlorodifluoromethane



Dimethylamine

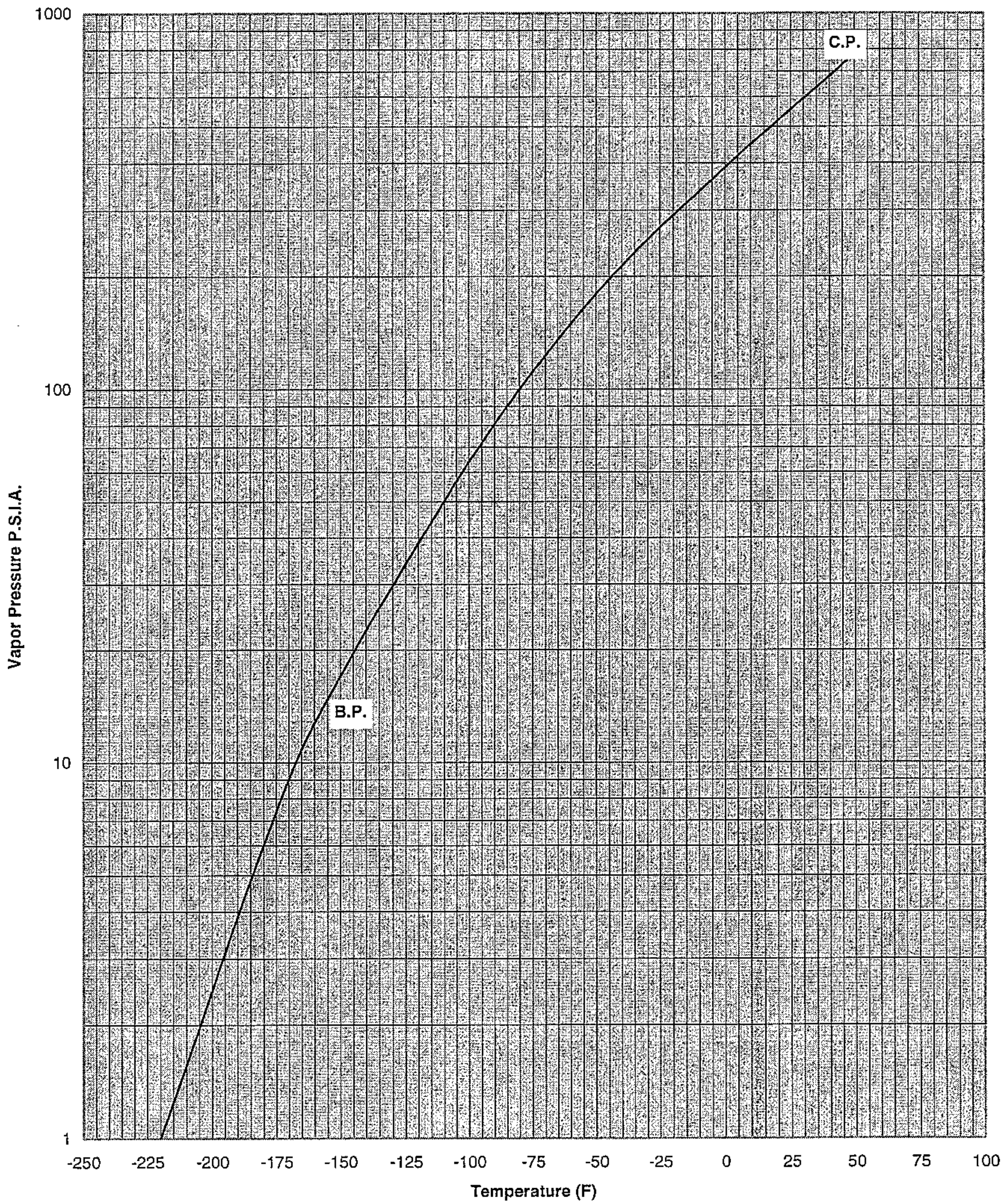


Ethane



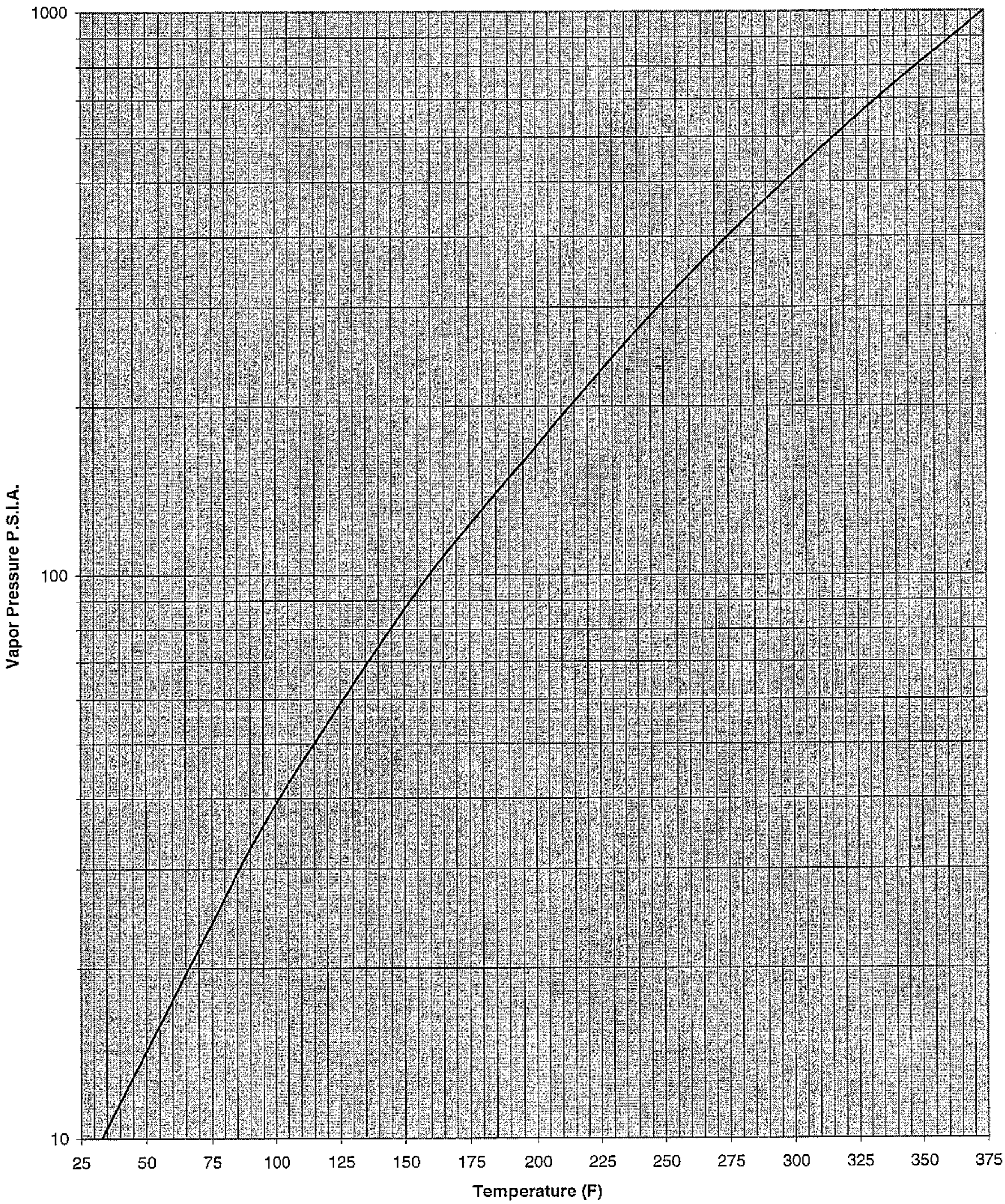
1000
100
10
1
C.P.
B.P.
Vapor Pressure P.S.I.A.
-225
-200
-175
-150
-125
-100
-75
-50
-25
0
25
50
75
100
125
Temperature (F)

Ethylene

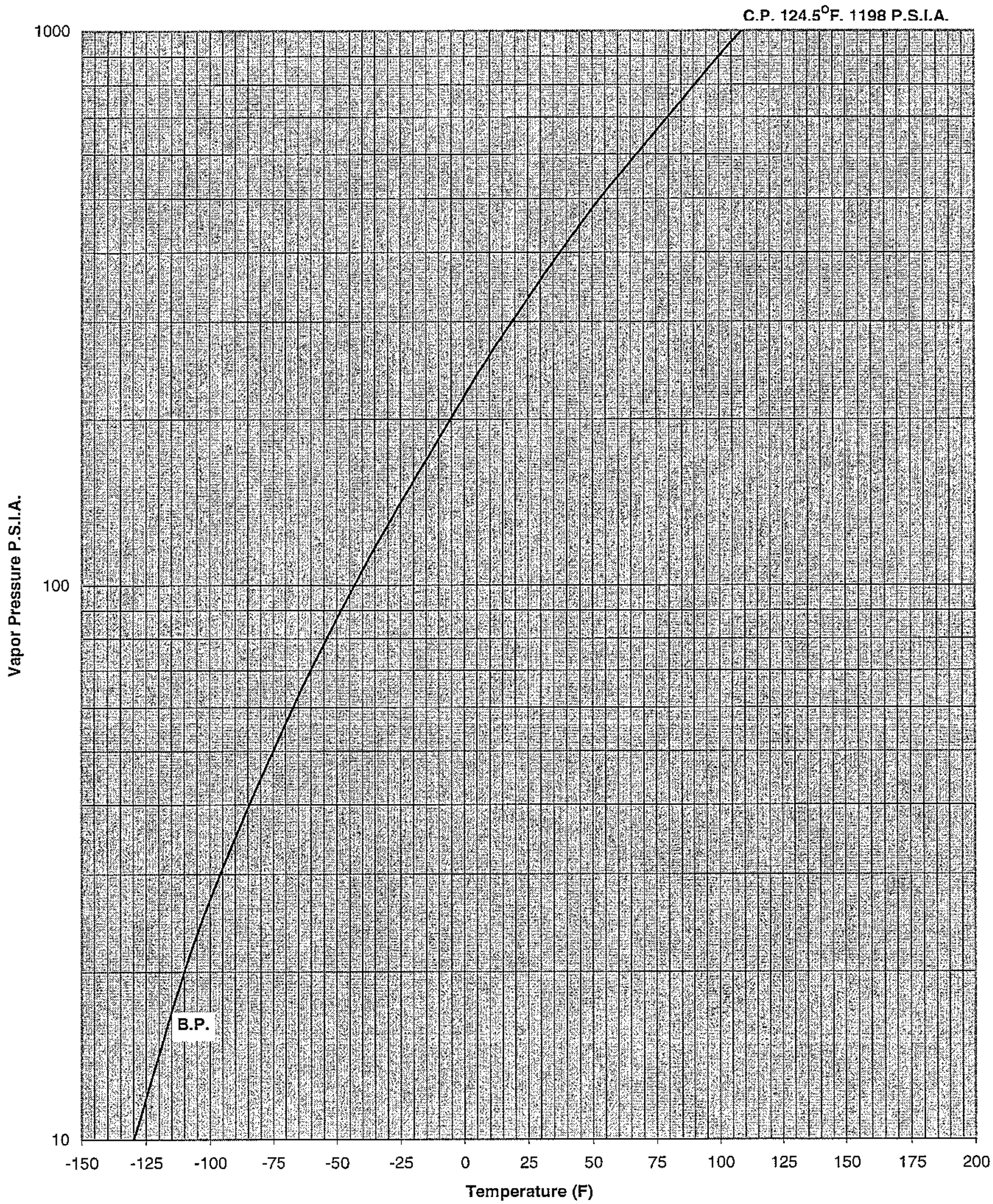


C.P.
B.P.
1000
100
10
1
Vapor Pressure P.S.I.A.
-250
-225
-200
-175
-150
-125
-100
-75
-50
-25
0
25
50
75
100
Temperature (F)

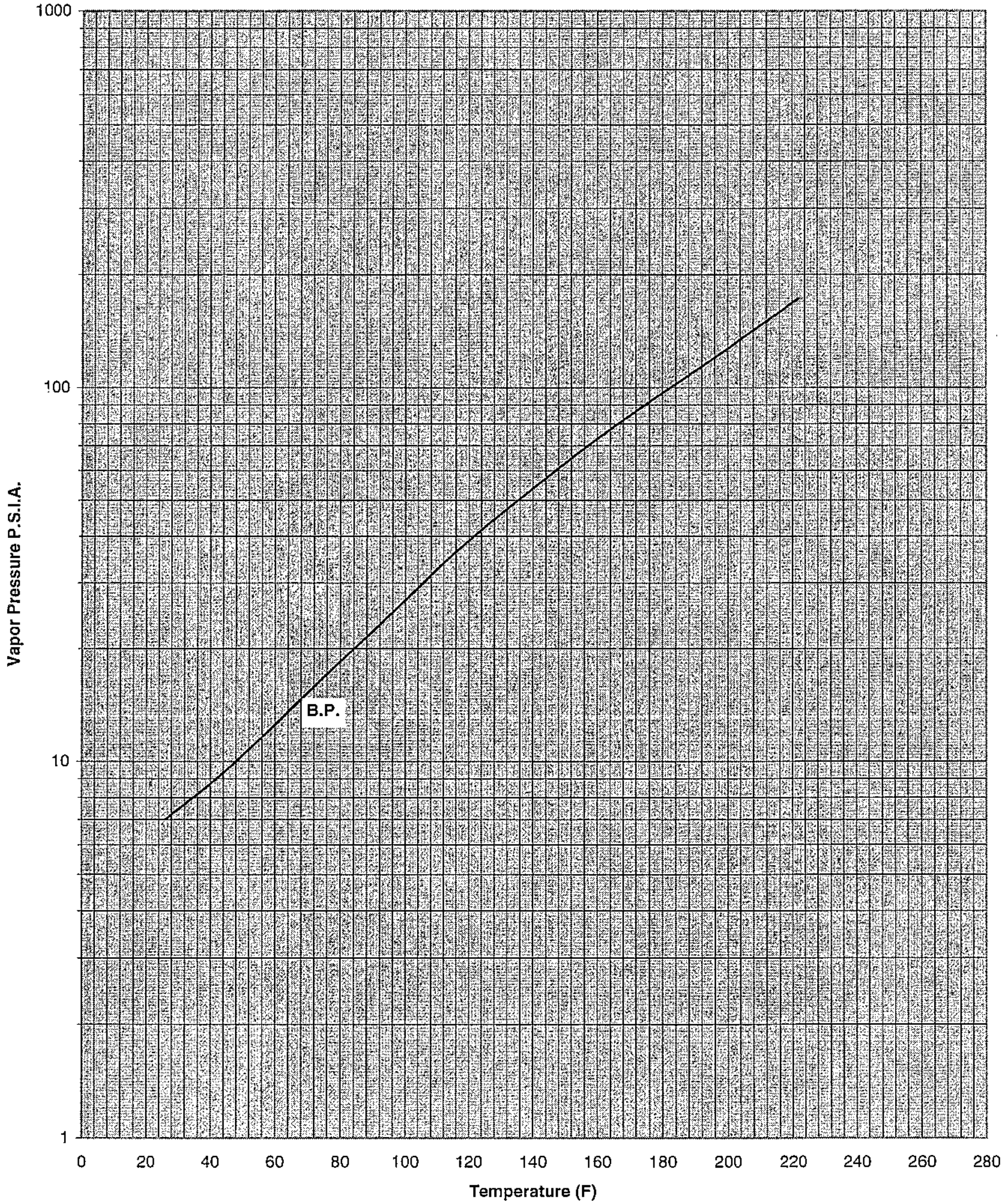
Ethylene Oxide

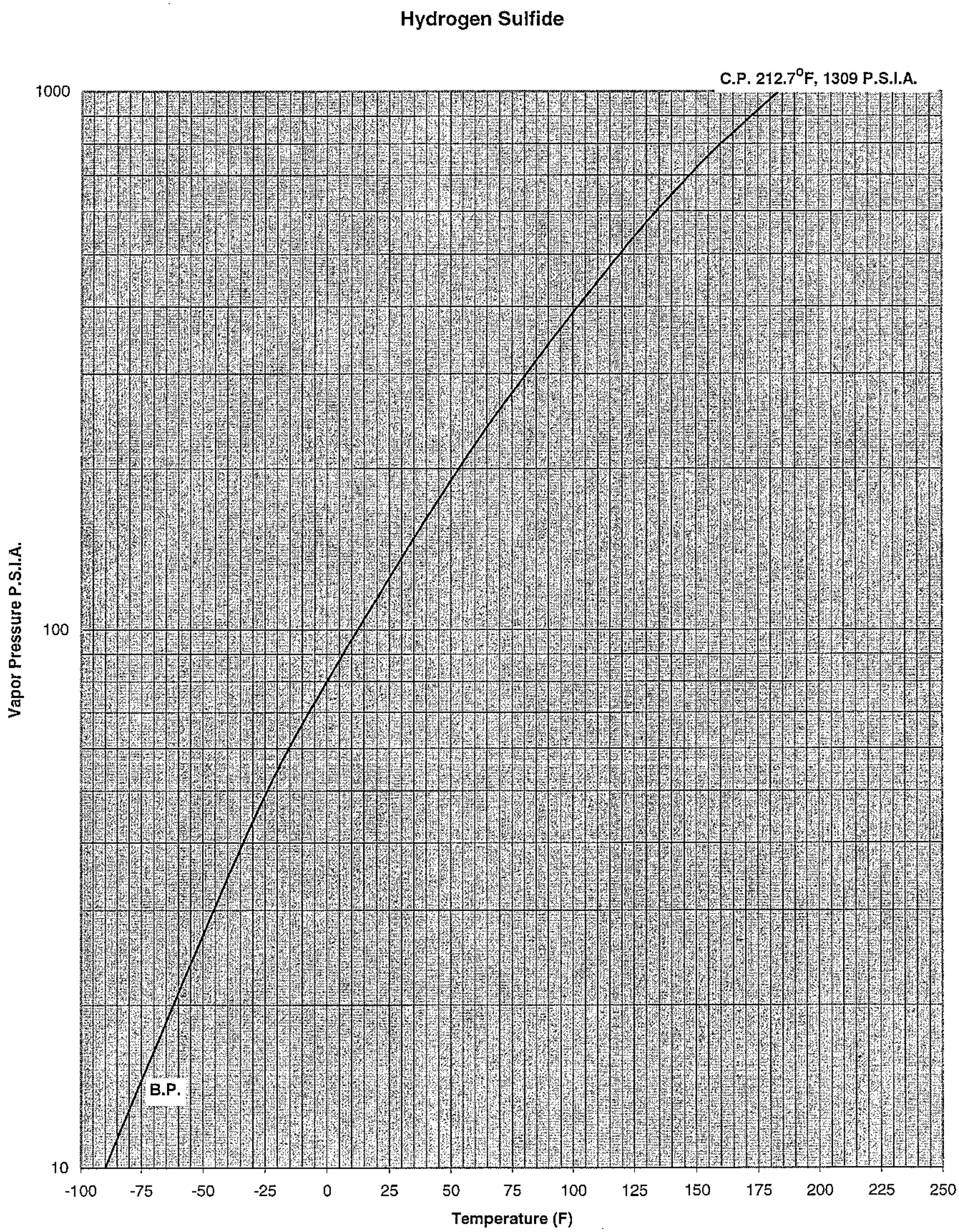


Hydrogen Chloride

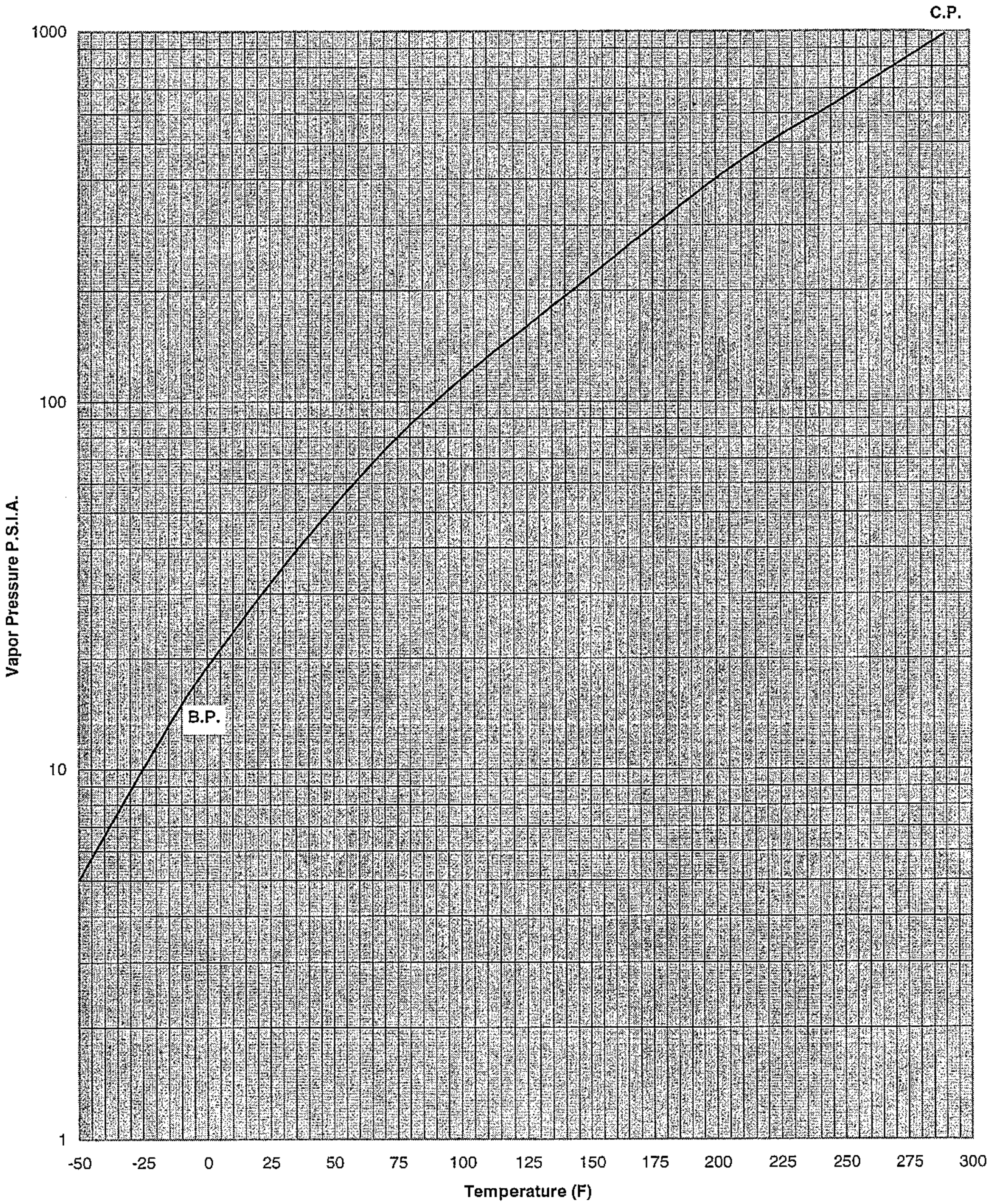


Hydrogen Fluoride

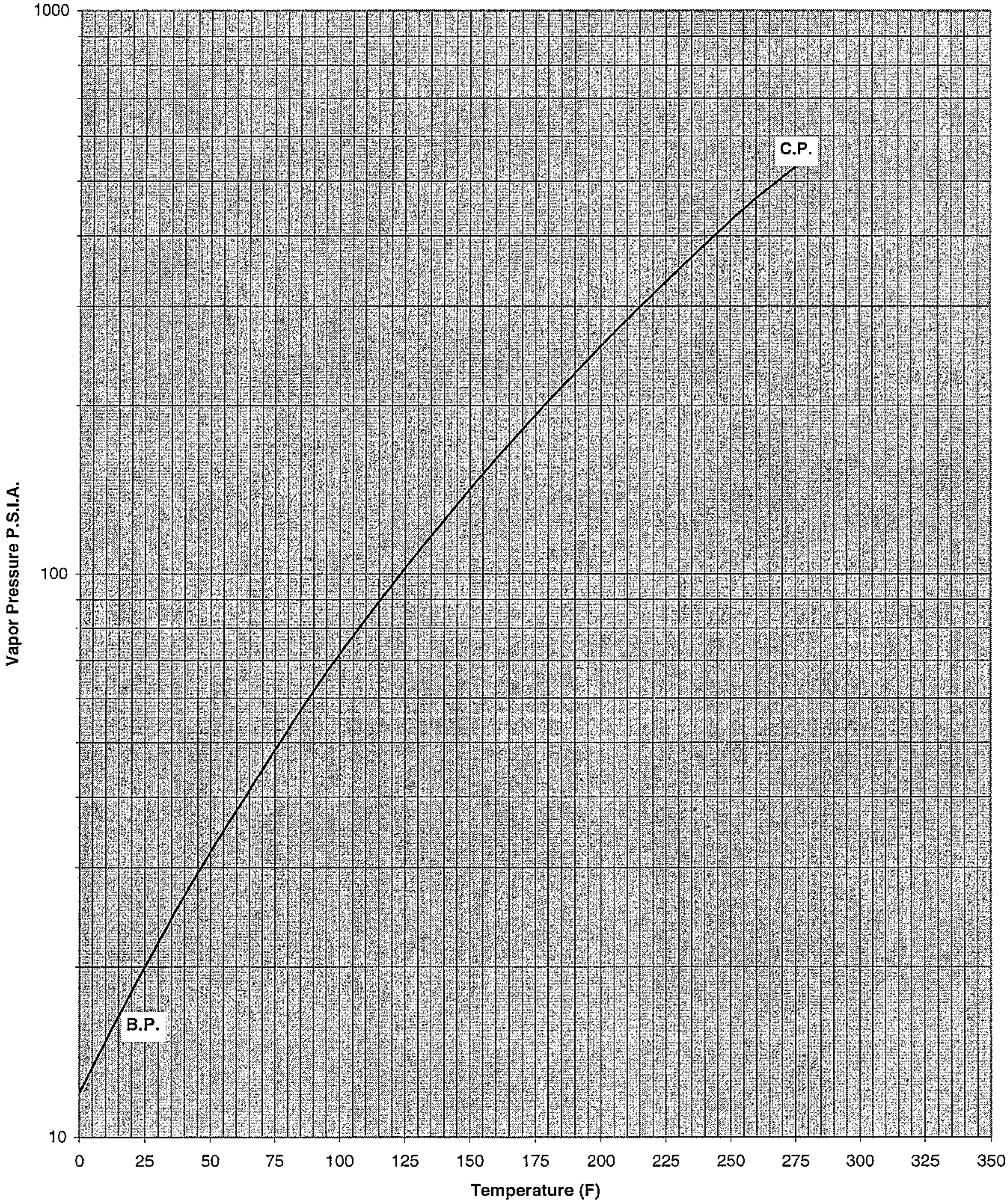



Hydrogen Sulfide
C.P. 212.7°F, 1309 P.S.I.A.
1000
100
10
Vapor Pressure P.S.I.A.
B.P.
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
225
250
Temperature (F)

Methyl Chloride

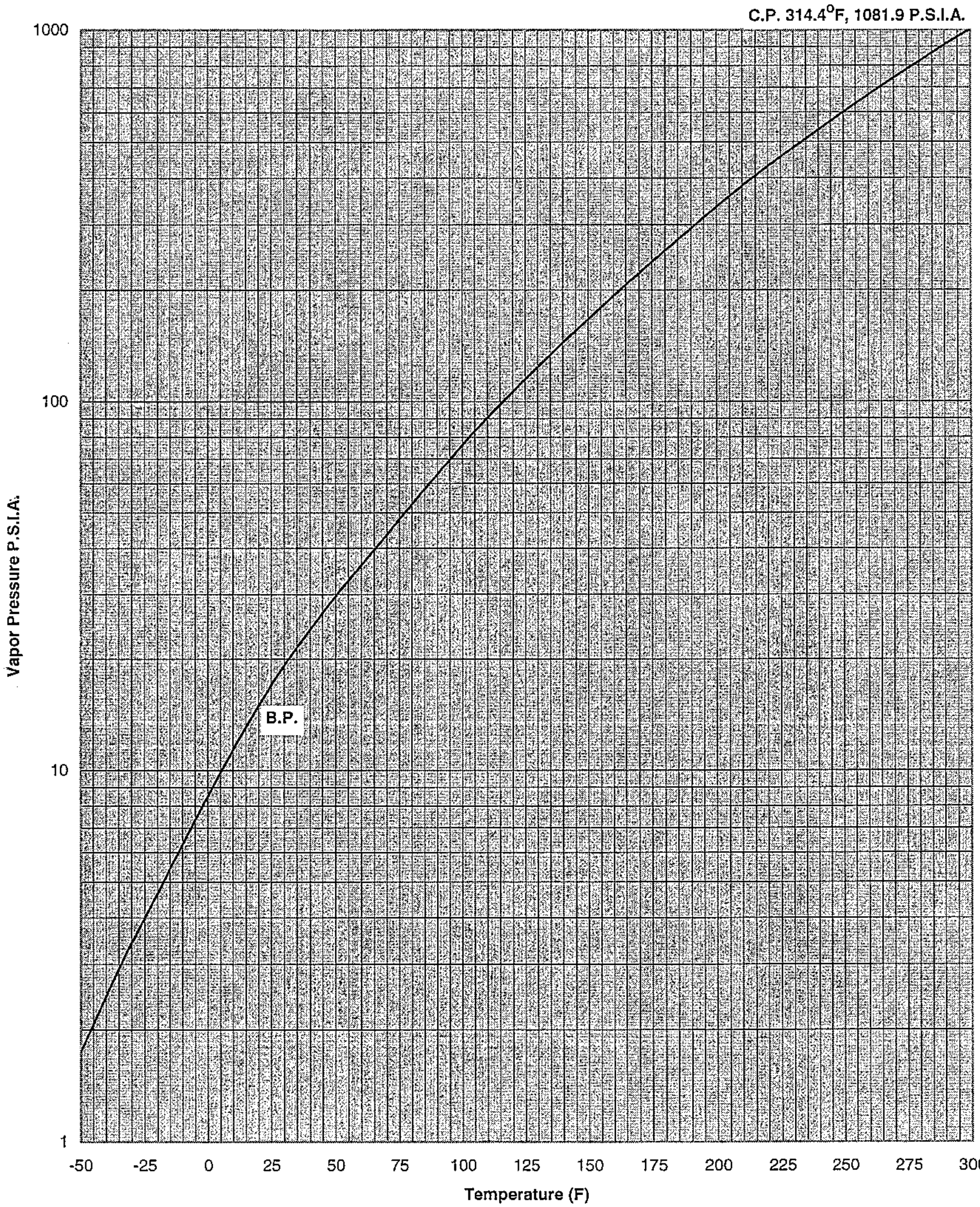


Isobutane

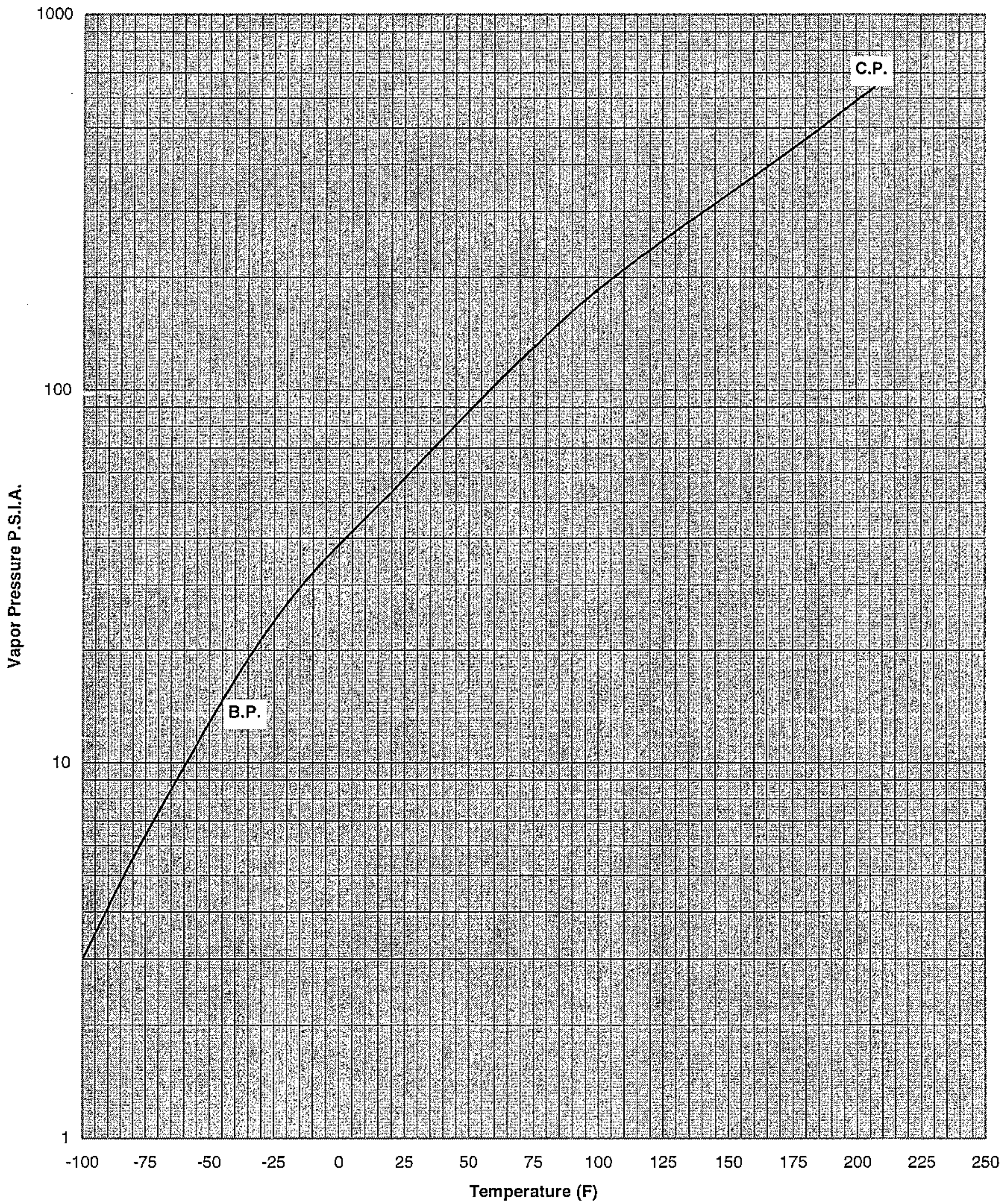


1000
100
10
Vapor Pressure P.S.I.A.
C.P.
B.P.
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
Temperature (F)

Monomethylamine

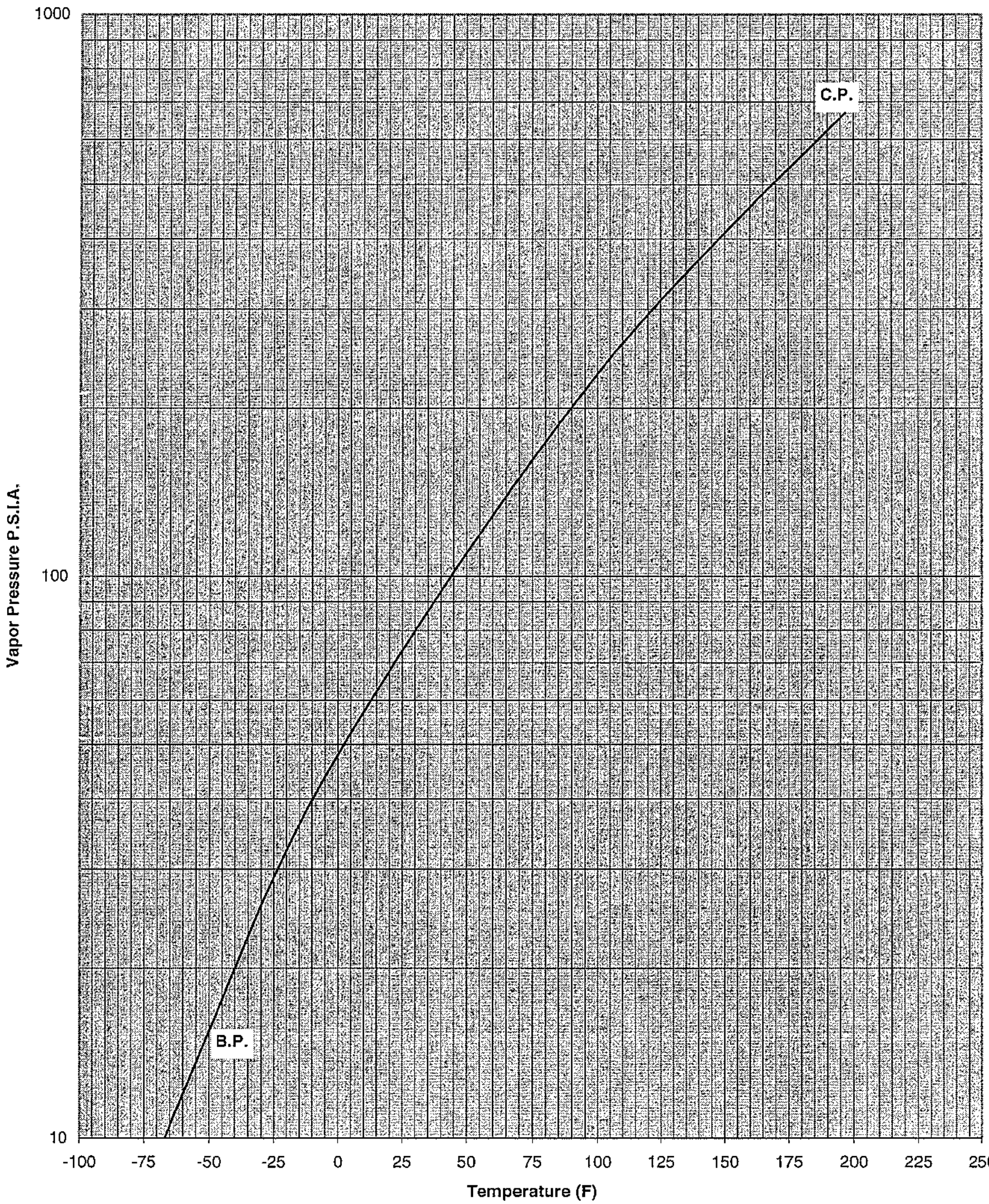


Propane



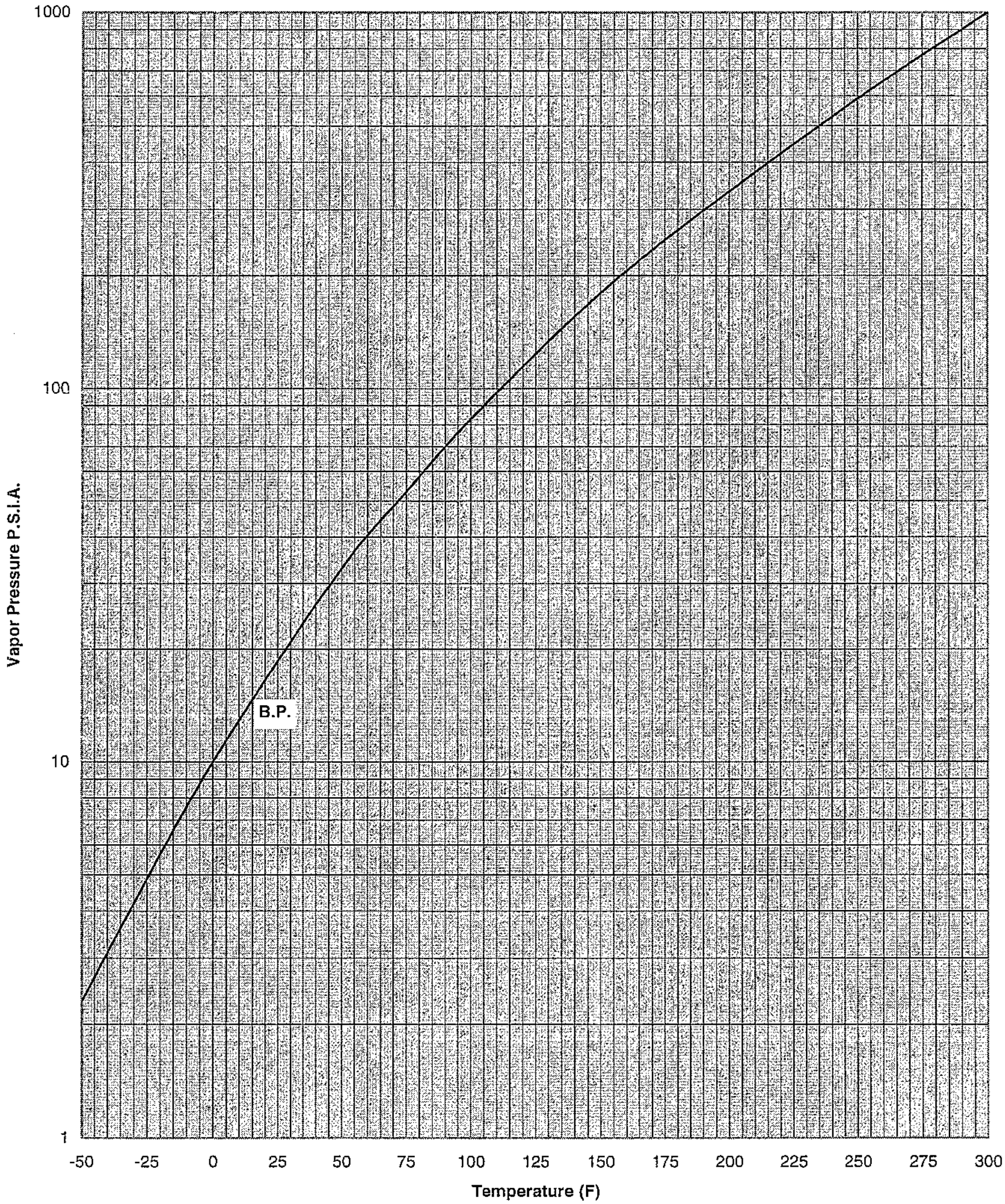
1000
100
10
1
Vapor Pressure P.S.I.A.
C.P.
B.P.
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
225
250
Temperature (F)

Propylene

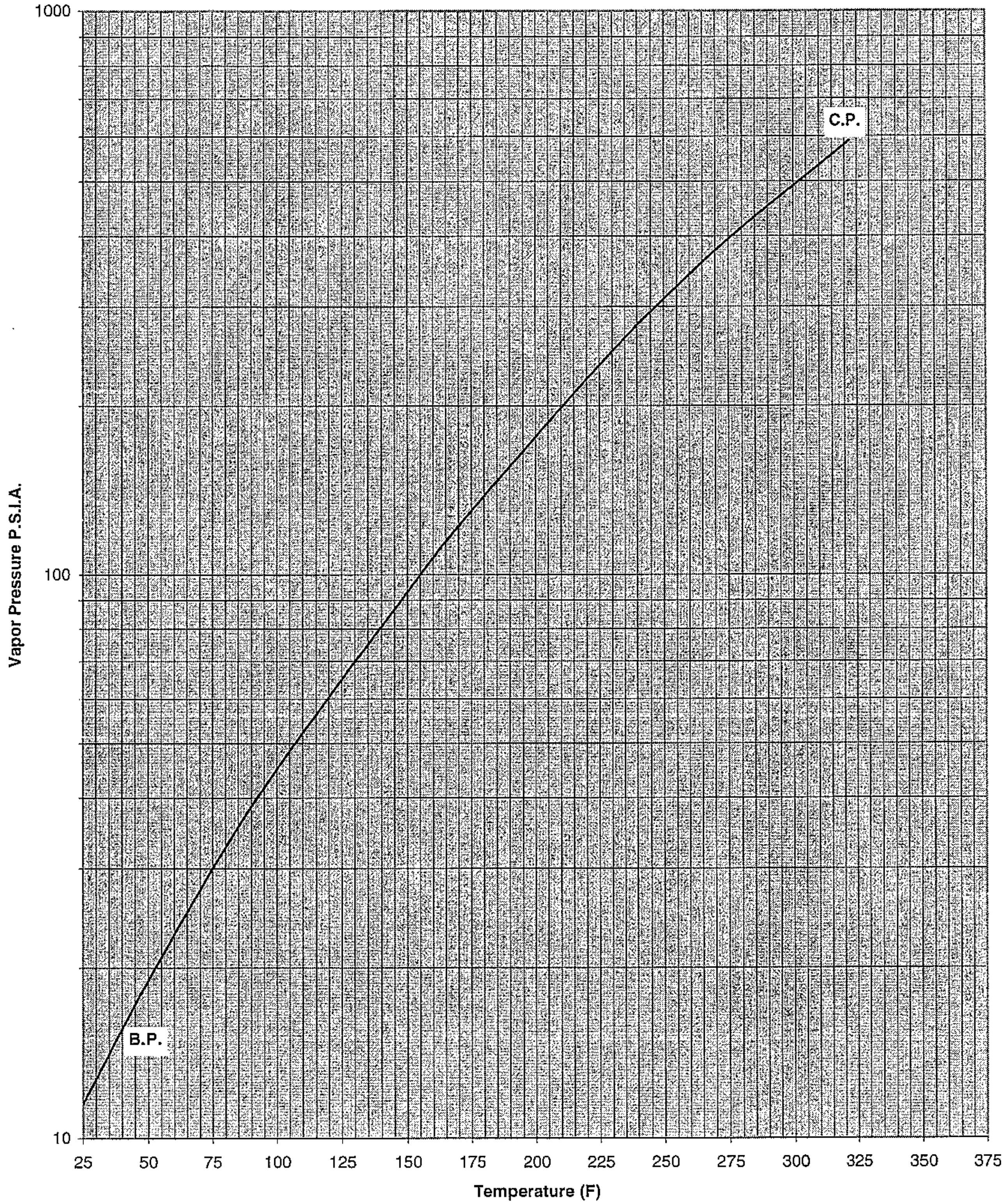


1000
100
10
Vapor Pressure P.S.I.A.
C.P.
B.P.
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
225
250
Temperature (F)

Sulfur Dioxide



Trimethylamine



Vinyl Chloride