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Phase I Literature Search and Evaluation — Final Report

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Final Report

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1.0 INTRODUCTION

Under Federal Railroad Administration (FRA) Contract No. DTFR 53-93-C-00001, Task Order 115, the Association of American Railroads Transportation Technology Center (AAR/TTC) is conducting a research project titled. "Damage Assessment of Tank Cars Involved in Accidents." Phase I of the project will evaluate the validity of guidelines currently used to assess the severity of damage to pressure tank cars caused by derailments.

In February 1993, the AAR/TTC produced a handbook on emergency response titled, *Field Product Removal Methods for Tank Cars.* The handbook 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 carrying hazardous materials that have been damaged in accidents. The publication and subsequent use of this handbook has pointed to the need for a companion handbook that identifies proven and reliable damage assessment procedures.

Since 1985, the AAR/TTC and other organizations have utilized a set of guidelines 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 when tank cars carrying hazardous materials shipped under pressure can be safely rerailed, unloaded in place, or whether nature should be left to take its course.

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

Phase I of the project focuses on evaluating the technical foundation for the guidelines. A search of the technical literature was performed and subsequently evaluated to identify which of the guidelines can be validated and which require additional modeling and validation in the Phase II effort. In this report and accompanying attachments, the results of the literature search and evaluation are presented and recommendations for the Phase II research are made.

2.0 OBJECTIVES

In an attempt to gather pertinent information that would assist in the assessment and validation of the current pressure tank car damage assessment guidelines, the Phase I work was designed to accomplish the following:

- Compile current guidelines for pressure tank car damage assessment;
- Survey individuals from various entities including major railroads, chemical shippers, government agencies, etc., to acquire additional information that might aid in the evaluation of the current damage assessment guidelines;
- Search the technical literature for previously published research, rules, regulations, guidelines and recommended practices which are, or may be applicable to pressure tank cars;
- Review the relevant material identified in the literature search and evaluate to determine if the literature can validate the guidelines;
- Write a report that includes a technical discussion of the applicable portions of the literature that validate the current guidelines and identify areas where additional modeling and validation will be required;

- Circulate the report for review and comment to selected individuals previously surveyed; and

- Prepare and submit to FRA a Final Phase I Report which documents the work performed under Phase I, identifies the conclusions drawn, and makes recommendations for modeling and work necessary to validate the guidelines.

3.0 PROCEDURES

The following subparagraphs will identify the procedures used to gather the information presented in this section. These procedures included the collection of current guidelines, administration and evaluation of an industry and government survey, and the identification of methods used to perform the literature search.

3.1 GUIDELINES

While pressure tank cars transporting compressed gases can sustain extensive damage in derailments without releasing their contents, delayed failures are possible and have occurred. During this delay, response personnel are likely to begin derailment clearing operations, and consequently, risk death or injury should the tank fail.

In the late 1970's, damage assessment guidelines were developed to help emergency response personnel make critical decisions whether tank cars damaged in derailments could be safely up righted and transported (either on their own trucks or on flat cars) for unloading or whether them must be unloaded in place. While these guidelines have been used for some years, there is no clear record of what methodology was used to establish the guidelines, and their primary author is no longer available to provide that information.

The following information identifies the specific tools (guidelines) which were extracted from the AAR/TTC Hazardous Materials Training Center *Tank Car Safety Manual* as found in Appendix 1. The Glossary found in Section 6.0 contains definitions of key terms found in this Section.

- 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.

- 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.

- Scores or gouges crossing a weld and removing only the weld reinforcement are not critical.

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

- Longitudinal scores or gouges crossing a weld and affecting the heat affected zones are critical and the contents of the tank car should be transferred immediately.

- Tanks having scores or gouges should be unloaded in place when the internal pressure exceeds half of the allowable internal pressure listed in the tables which follow. Tables 1 and 2 show the allowable pressures for 340W and 400W tanks respectively.

Table 1: Limiting Score Depths for 340W Tanks	
Depth of Score	Maximum Safe Internal Pressure, PSIG
1/16"	191 (89°F for commercial propane)
1/8"	170 (85°F for commercial propane)
3/16"	149 (76°F for commercial propane)
1/4"	127 (65°F for commercial propane

Note: In no case should a tank containing a score in excess of 1/16 inch for 340W tanks be shipped by rail, although the tank could be uprighted and even moved short distances for transfer.

Table 2: Limiting Score Depths for 400W Tanks	
Depth of Score	Maximum Safe Internal Pressure, PSIG
1/16"	228 (108°F for commercial propane)
1/8"	205 (99°F for commercial propane)
3/16"	188 (93°F for commercial propane)
1/4"	162 (82°F for commercial propane)

Note: In no case should a tank containing a score in excess of 1/8 inch for 400W tanks be shipped by rail, although it could be uprighted and even moved short distances for transfer.

While the values given in Tables 1 and 2 are conservative, they do not include the welded joint efficiency for tanks built prior to 1968. This amounts to an extra 10 percent safety factor.

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

- Sharp dents in the shell of the 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.

- 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; or
    - 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 shell 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.

- 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.

3.2 SURVEY

A survey was designed, constructed, and administered by the AAR/TTC in May 1995 in an attempt to acquire additional information that might aid in the evaluation of the current damage assessment guidelines. The survey was sent to various representatives of the FRA, National Transportation Safety Board, Canadian Transportation Safety Board, National Research Council of Canada, Transport Canada, AAR, Railway Progress Institute/Association of American Railroads (RPI/AAR) Tank Car Safety Research Project, major railroads, chemical shippers, tank car manufacturers, and others who are or were previously associated with the railroad industry that may have knowledge pertinent to this project. Fifty surveys were sent to representatives of the above referenced entities. Of the 50 sent, 30 survey responses were received, representing a 60 percent return of the total surveyed. The survey administered and the responses received are summarized below. At the request of several respondents, attribution is not given on direct quotes.

1. **Are you aware of any previously published research, rules, guidelines, or recommended practices which are, or may be applicable to the evaluation of the current guidelines for assessing the severity of damage to pressure tank cars?**

   The responses received were incorporated into the bibliography of references provided to the subcontractor for review during the literature search. Below is a summary of the literature identified by survey respondents.

- "Phase 18 Study: Integrity of Damaged Tank Cars," Association of American Railroads, Chicago, Illinois.

- AAR Standards and Recommended Practices, Sec. C - Part III, Specifications for Tank Cars, Specification M-1002.

- L. S. Beller, J. D. Mudlin, W. G. Reuter, and M. A. Tupper, "Survey of Nondestructive Methods for Evaluating Derailed Tank Cars," US Army Ballistic Research Laboratory Contract Report BRL-CR-539 (November 1984).

- J. L. Hechmer and G. L. Hollinger, "The ASME Code and 3D Stress Evaluation," *Journal of Pressure Vessel Technology*, 113, 481-487 (November 1991).

- National Transportation Safety Board, "Derailment of Burlington Northern Freight Train No. 01-142-30 and Release of Hazardous Materials in the Town of Superior," Hazardous Materials Accident Report NTSB/HZM-94/01, Notation 5842B, Washington, DC (March 1994).

- National Transportation Safety Board, "Derailment of Louisville and Nashville Railroad Company's Train No. 584 and Subsequent Rupture of Tank Car Containing Liquefied Petroleum Gas, Waverly, Tennesse," Railroad Accident Report No. NTSB-RAR-79-1, Notation 2313B, Washington, DC (February 22, 1978).

- National Transportation Safety Board, "Special Investigation Report: Tank Car Structural Integrity after Derailments," Bureau of Technology, Report No. NTSB-SIR-80-1, Washington, DC (1980).

- E. A. Phillips and W. A. Pellini, "Phase 03 Report on Behavior of Pressure Tank Car Steels in Accidents," Association of American Railroads, Report No. RA-03-6-48 (June 20, 1983).

- E. A. Phillips and H. Role, "Effectiveness of Shelf Couplers, Head Shields and Thermal Shields on DOT 112 (114) and 105 Tank Cars," Association of American Railroads, Report No. RA-02-5-51 (AAR R-610), Chicago, Illinois (June 13, 1985).

- K. Rahka, "The Anatomy of a Break Before Leak Case," ASME PVP-Vol. 281, *High Pressure Technology*, ASME, 49-54 (1994).

- W. G. Reuter, J. D. Mudlin, R. L. Harris, F. M. Haggag, W. L. Server, and J. S. Epstein, "Evaluation of Damaged Tank Car Structural Integrity," Department of Transportation, Federal Railroad Administration, Office of Research and Development Report DOT/FRA/ORD-88/02 (January 1988).

- Z. Rosenberg, J. Mironi, A. Cohen, and P. Levy, "On the Catastrophic Failure of High-Pressure Vessels by Projectile Impact." *Int. J. Impact Engng.*, 15(6), 827-831 (1994).

- D. K. Shaver, and R. L. Berkowitz, "Guideline Manual, Post Accident Procedures for Chemicals and Propellants." Air Force Rocket Propellant Laboratory Report AFRPL TR-82-077 (January 1983).

- D. K. Shaver, R. L. Berkowitz, and P. V. Washburne, "Accident Management Orientation Guide." Air Force Rocket Propellant Laboratory Report AFRPL TR-82-0075 (October 1983).

- Tank Car Fatigue Crack Growth Test, DOT/FRA/ORD - 93/10.

2. **Do you have any knowledge of unexpected behavior of damaged pressure tank cars that would aid AAR/TTC in evaluating the current tank car damage assessment guidelines?**

- Report RA-03-6-48, *Phase 03 Report on Behavior of Pressure Tank Car Steels in Accidents,* 6/20/83. The reports cited delayed ruptures in two separate incidents at Cumming, Iowa and Waverly, Tennessee.
- Vinyl Chloride car exploded in Livingston, Louisiana.
- Vinyl Chloride car failed following accident in Flomaton, Alabama, May 1995.
- Several other respondents indicated yes to the questions, however, no specific incidents were noted.

3. **Are you aware of any three-dimensional, finite element computer modeling work that has been done to simulate the behavior of damaged tank cars or pressure vessels (particularly under load)?**

- Transport Canada has developed a complete tank car Finite Element Analysis (FEA) model. Other models have or are being developed as part of a stub sill study being performed in conjuction with the Tank Car Research Committee.

- Battelle may have done an FEA of a tank car.
- Specific packages or companies with capabilities included: NIKE2D, NASGRO, NASCRAC, CRACKS 94, FM, PFRAC, Failure Analysis Associates, and Transoft, Inc.

4. **Are you familiar with the methodology Roy Holden used to develop the current tank car damage assessment guidelines?**

- One respondent indicated that the guidelines may have been based upon coupon samples that were taken from damaged tank cars and from tank cars that had failed.
- Several respondents indicated that the guidelines were developed primarily through the experience Mr. Holden gained attending derailments.
- Another respondent indicated that, through discussions with Mr. Holden, it was indicated that the guidelines were developed from engineering calculations (conservative) with an added "safety" factor.

5. **Did you assist Mr. Holden in the development of the current guidelines?**

- Several indicated that they had assisted Mr. Holden. Many of those indicated that they were involved in discussions with Mr. Holden regarding the guidelines.

6. **Did Mr. Holden consult with you during the development of the current guidelines?**

- Response the same as in Question 5.

7. **Do you know of anyone that worked with Mr. Holden in the development of the guidelines?**

- Gene Kunz
- W. J. Ruprecht
- George Binns
- Mike Miller
- E. A. Phillips
- Pat Student
- Ted Orr

8. **Do you have any reason to suspect that the current tank car damage assessment guidelines published by the AAR/TTC may not be reliable?**

- One respondent indicated that the guidelines were out of date. " No mention is made of normalized steels mandated in the mid-1980s, and it contains some errors and omissions."
- "Without published calculations, data and field testing to confirm the data, the guidelines should be suspect. All guidelines published must have back up information which has been published in specific research documents."
- One person noted that the last sentence on Page 6, Section 4, Paragraph 5, should be changed to, "if a score or gouge damages the weld and/or heat affected zone (HAZ), the damage is potentially critical. Reference Waverly Tennessee accident in which a crack initiated at the weld (not HAZ) where a gouge crossed it."

9. **Do you have any reason to believe that the current guidelines may be too conservative?**

Only two respondents indicated that they felt that the guideline may be too conservative. Their responses are as follows:

- "The descriptions of some of the damage types are not specific enough and to some extent are in error."
- "In today's environment, damaged tank cars are seldom moved when loaded, especially if hazardous materials are involved."

10. In your opinion, do the current tank car damage assessment guidelines published by the AAR/TTC meet the needs of emergency response personnel?

Most respondents indicated that, in their opinion, the current damage assessment guidelines do meet the needs of emergency response personnel. The following comments were supplied by those who did not agree.

- "Secure the advice of someone with tank car experience... is vague. The appropriate contacts are the designated shipper and carrier emergency response personnel."
- "The guidelines should be reviewed and definitions revised to meet the current regulations. Fractures and creases should also be discussed in greater detail."
- "They point a direction, but if this is all emergency response personnel have to go on, people are going to get hurt."

11. What other topics of concern to emergency response personnel would you like to see addressed by the guidelines?

- What lifting configurations can responders use to safely lift, roll, or drag a damaged pressure tank car considering different damage types and locations of damage.
- Responders are concerned over the inability to apply the damage assessment guidelines to jacketed tank cars short of physically removing the jacket. By removing the jacket using a cutting torch or other mechanical means, the responder may be introducing additional hazards that raise critical safety concerns.

- The guidelines should address what conditions responders should look for that may contribute to the delayed failure of a tank car.
- Responders would like to see a means of remotely inspecting a damaged tank car to assess the criticality of damage (i.e. Non-Destructive Evaluation techniques).
- "Responders need guidelines to perform damage assessment on general service tank cars."
- "Engineering calculations and data verification must be performed on current guidelines and then a statistical margin of safety must be added to the findings."
- A concern was raised over the affect of damage to pressure relief systems and applicability of guidelines under these conditions.
- Several comments identified a need within the guidelines for training requirements and available resources.
- "The guidelines do not appear to address the current problem of fatigue in the stub sill tank cars."
- "Fractures and creases are not discussed in great enough detail in the current guidelines."
- What effect does the increasing age of the tank car fleet have with respect to application of the guidelines. (i.e. double diameter tank cars built in early 1960s)

Several respondents also identified concerns that may not be appropriate to cover within this handbook, but more appropriately under the handbook titled, "Field Removal Methods for Tank Cars". The comments are included here merely as information.

- Responders need a tool or method to dislodge or move the excess flow check valve on pressure tank cars in order to allow responders to remove the liquid without moving a severely damaged tank car.

- "Liquid flaring of LPG from tank cars should be addressed and identify the limitations, capabilities, and advantages of the technique." This topic was covered in the *Field Removal Methods for Tank Cars* handbook. However, more study would be required to fully address this individuals concerns.

3.3 LITERATURE SEARCH METHODS

The objective of the literature search was to identify technical literature from previously published research, rules, guidelines, and recommended practices which are, or may be applicable to pressure tank cars or pressure vessels. Several methods were employed to perform this search. These included searches of catalog files for applicable documents from AAR libraries in Chicago, Pueblo and Washington, national and international computer searches of various libraries, technical information services, and professional organizations, as well as responses from surveys sent to various government and industry representatives. The search was performed by both AAR and subcontract personnel hired to assist with the search and review the information.

3.3.1 INSTITUTIONS AND/OR SOURCES INVESTIGATED

Using advances in computer technology to perform literature searches allowed the AAR to search for applicable documents in numerous locations. Many libraries were searched, including AAR libraries in Chicago, Pueblo, and Washington, University of Colorado, Colorado School of Mines, Colorado State University, and other nationally known libraries. Computer searches were also made of the Technical Research Information Services, Engineering Index databases, National Technical Information Service (NTIS), Defense Technical Information Center (DTIC), ASME Journal of Pressure Vessel Technology and conference proceedings of the ASME Pressure Vessel and Piping Division. Survey respondents were also a useful source of identifying technical literature and other contacts.

3.3.2 BIBLIOGRAPHY OF LITERATURE REVIEWED

A listing of the references that were reviewed during the Phase I portion of this project is contained in the report in Attachment 2. References 1 through 33 were documents supplied to the subcontractor by the AAR. References 34 through 37 were obtained from NTIS and DTIC. References 38 through 76 were obtained through the Technical Research Information Services and Engineering Index databases. A review of the abstracts for these 39 references showed that the documents did not contain any substantially new information compared with the information in References 1 through 37. References 77, 79 through 85, and 89 were obtained through the ASME Journal of Pressure Vessel Technology. Reference 78 was from a recent conference proceedings of the Pressure Vessel and Piping Division of ASME. References 86 through 88, 90, and 92 through 109 were obtained from a bibliography established by the subcontractor over the years.

4.0 RESULTS

AAR/TTC retained a subcontractor with expertise in metallurgy, finite element analysis, and fracture mechanics to assist in the literature search and review of relevant material. Upon completion of the review, a report was prepared to document the methods by which materials were collected, to discuss the applicable portions of the literature, to provide an assessment of the guidelines and the degree of validation, and finally to discuss their conclusions and recommendations for Phase II modeling and validation. A copy of the report titled, *Literature Search and Evaluation Pertaining to Damage Assessment of Tank Cars Involved in Accidents*, prepared by Stanford Research Institute (SRI), International is found in Attachment 2.

4.1 TECHNICAL DISCUSSION OF THE LITERATURE

The AAR's subcontractor identified 109 references as being potentially relevant to the guidelines. None of the literature reviewed specifically mentioned the establishment of the guidelines or indicated the basis on which they were established. Discussion with Mr. Holden's contemporaries indicate that the guidelines were based at least in part on the work of Mr. William S. Pellini, who following a career at the Naval Research Laboratory, acted as a consultant to the AAR for many years. These sources report that Mr. Holden interacted extensively with Mr. Pellini during the drafting of the guidelines, and that most of the available fracture analyses for tank cars are based on Pellini's work.

Pellini's "Slide Graph Fracture Analysis System" (SGFAS), and its use for the analysis of tank car failures and tank car safety seems to have particular relevance to the guidelines. The approach combines experimental data and service experience accumulated since the 1940s with Linear Fracture Mechanics (LEFM) to establish whether a freshly nucleated crack will arrest before unstable catastrophic failure occurs and whether a pre-existing crack will initiate and lead to unstable fracture. A more complete description of Pellini's SGFAS and a technical discussion of the other relevant literature reviewed is included in the SRI report in Attachment 2.

4.2 EXPERT REVIEW

The report prepared by SRI was sent to a number of individuals for review and comment. The individuals were selected because of their knowledge in the fields of tank car construction, metallurgy, fracture mechanics and finite element analysis. The individuals identified below participated in the review of the report and with few exceptions they agreed that the report was sound. In general, the reviewers indicated that the report provided a good assessment of the literature and that the recommended approach for validation of the guidelines appeared to be reasonable. The reviewers specific comments can be found in Appendix A.

- J. Robert Sims, Exxon Research and Engineering, Chairman ASME Post Construction Committee;
- Dr. William J. Koves, UOP, Chairman ASME Flaw Analysis Subcommittee;

- Dr. Stephen Wong, Procor Limited;
- Paul Kinnecom, Association of American Railroads;
- Diane Rocheleau, Transportation Safety Board of Canada;
- Edgar Ladouceur, Transport Canada.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon the review of over 100 references, the subcontractor has identified the analytical and experimental work necessary to evaluate the criticality of the damage (cracks, scores, gouges, dents, and wheel burns). They have found that the guidelines reflect a good, overall physical understanding of potentially dangerous damage to tank cars. Quantitative specifications are generally expressed in terms of convenient parameters that can be related to the degree of structural and material weakening caused by the damage. The additional conclusions drawn by SRI regarding the relevance and validity of the guidelines are presented below.

- The guidelines are often only qualitative and somewhat vague in their requirements.

- There is no record of analytical or experimental work to directly support and validate the guidelines. The subcontractor was able to reconstruct some of the reasoning that must have led to the guidelines. It appears that the guidelines rely on twenty-year or older analysis methods and do not reflect recent advances in computational and fracture mechanics.

- The effect on damage of loads applied to move or lift the derailed tank car is not explicitly accounted for in the guidelines even though these loads could be important in causing damaged areas to rupture.

- The phenomenon of delayed fracture is not appropriately documented and understood. The guidelines do not adequately address this important safety issue.

- The margins of safety associated with the current guidelines are not known.

- The guidelines do not consider advanced non-destructive evaluation (NDE) methods available to identify tank car damage and to monitor the damage during tank car handling at the accident scene.

To alleviate these shortcomings and improve the reliability and usefulness of the guidelines, SRI and AAR recommend that the following research be initiated:

- Identify typical rerailing load scenarios and calculate by finite element analysis methods the stress and strain fields they induce in pressurized tank cars. Use these results as loading conditions to assess the criticality of various types of damage in tanks cars.

- Assess the residual resistance of tank cars with large dents to buckling and plastic collapse when subjected to rerailing loads.

- Refine and validate the severity criteria for scores, gouges, and wheel burns using recent advances in analytical and experimental fracture mechanics.

- Assess the possibility for stable crack growth in fully plastic tank car steels and the implications for delayed fracture.

- Evaluate the applicability of current NDE equipment and recommend use of suitable NDE techniques in the guidelines.

- Monitor and participate in the activities of the committee on "Post-Construction Standards" of the Pressure Vessel and Piping Division of the American Society of Mechanical Engineers.

SRI recommends that the structural and fracture mechanics analysis aspects of the proposed research be accomplished by combining nonlinear finite element simulations with advanced elasto-plastic fracture and local fracture theories to quantify the severity of various types of tank car damage. This analytical effort should be performed in conjunction with an experimental effort using small laboratory specimens that will provide material properties data as well as validation for the analyses.

The results of this research should be used to reformulate the guidelines in more precise and quantitative terms so that their use will contribute to increased safety at derailment sites.

6.0 GLOSSARY

Below are definitions of key terms used in this document:

tank: "Tank" in this document refers to the actual tank car tank.

jacket: The jacket is the first thin steel outer shell that holds the insulation or thermal protection in place and protects the tank from the elements. The jacket is not designed to hold the leaking contents of the car.

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 rounded point.)

heat affected zone: The heat affected zone is an 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 on the welding process.

internal pressure: Internal pressure is the force against the internal surfaces of the tank caused by the vapor pressure of the contents.

crack: A crack is a narrow split or break in the tank metal which may penetrate through the tank metal.

score: A score is a relocation of tank or weld metal so that the metal is pushed aside along the line of contact with another object. This causes a reduction in tank metal thickness.

gouge: A gouge is removal of the tank or weld metal along the line of contact with another object. This causes a reduction in tank metal thickness.

wheel burn: A wheel burn is similar to a gouge but is caused by prolonged wheel contact with the tank.

dent: A dent is a deformation that changes the tank contour from that of original manufacture as a result of impact with a relatively blunt object (coupler or end of an adjacent car).

rail burn: A rail burn is a long dent, usually parallel to the length of the tank which crosses a weld and causes cold work. It may be caused by the tank passing over a section of rail.

radius of curvature: Radius of curvature is 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 more gentle bend.

transition temperature: Transition temperature is the point where the properties of steel change from ductile to brittle.

APPENDIX A - EXPERT REVIEW

Comments were received from several individuals after their review of the Draft Final Report titled, *Literature Search and Evaluation Pertaining to Damage Assessment of Tank Cars Involved in Accidents,* prepared by SRI. In the list below, the reviewers are identified along with the company and/or organization they represent and their comments. Several of the comments were not received prior to the SRI report being finalized, and were not incorporated. Those comments will be taken into consideration when Phase II modeling and validation efforts are planned and during the drafting of the handbook.

- J. Robert Sims, Exxon Research and Engineering, P.O. Box 101 Florham Park, NJ 07932; ASME Pressure Vessel and Piping Division, Post Construction Committee Chairman.

    (1) "The document is an excellent summary of the problem, and gives good guidance for the future work which is needed."

    (2) "The discussion of dents and delayed fracture appears to be well reasoned. Slow, stable crack growth due to time dependent behavior of materials is a very real possibility and should be studied if additional work is undertaken in this area."

    (3) "The proposed work should be of interest for other applications such as pipelines and other pressure vessels."

- Dr. William J. Koves, UOP, Inc., 25 East Algonquin Road, Des Plaines, IL 60017-5017; ASME Pressure Vessel and Piping Division, Chairman of the Flaw Analysis Subcommittee to the Post Construction Committee.

    (1) "The procedures for evaluating dents is a simple, field expedient method and the radii of curvature appear somewhat arbitrary."

    (2) "Limiting the radius of curvature is a good practical method, since that limits strain (and cold work) as well as stress concentration. However the influence of global damage, out of roundness, etc. on the stress at the local critical regions is not evaluated."

    (3) "Loads other than internal pressure do not seem to be addressed. Support attachment stresses as well as those due to lifting the car should be evaluated. High local compressive stresses could cause buckling in low pressure applications."

    (4) "Scores, gouges, and wheel burns could be evaluated as local thin areas, using some of the information already published."

    (5) "The use of NDE should be considered in critical applications since cracks in a cold work region may behave in a brittle manner."

    (6) "The effect of damage on material properties must also be considered. The effect of cold work or heat due to friction should be evaluated."

    (7) "The ASME Subcommittee on Flaw Evaluation will be addressing some similar issues and would like to cooperate with the AAR in any way."

- Dr. Stephen Wong, Chief Engineer. Rail Car Division. Procor Limited, 2001 Speers Rd., Oakville, Ontario L6J 5E1.

  (1) "We feel the report achieved its objective of gathering information relating to damaged tank cars and pressure vessels, and their residual structural integrity, thus providing a good assessment of the validity of the current AAR guidelines."

  (2) The report revealed omissions, inconsistencies, and/or errors in the guidelines that should be resolved. The findings appear to be sound.

  (3) The approach SRI recommends to validate the criteria and to improve the reliability and usefulness of the guidelines appears to be reasonable.

  (4) Any revisions to the guidelines should maintain a significant factor of safety to allow its use under field conditions.

  (5) "The existing guidelines are direct, simple, easy to understand and use. Any revisions should also be easy to understand and use."

- Paul Kinnecom," Assistant Director of Tank Cars, Customer Operations, Operations and Maintenance Department. Association of American Railroads, Washington Headquarters, 50 F Street, N.W., Washington DC 20001.

  (1) Page 15 of the report make reference to a TC-135A steel specification. "TC-135A was a draft steel specification that was proposed, but never implemented for tank car construction. It is not representative of tank car steels, and conclusions based upon a study of TC-135A should be made with care."

  (2) "On Page 13, reference is made to an "A-340" tank car and it is implied that such a car may transport carbon dioxide, hydrogen, chloride, or hydrogen sulfide with associated tank stresses (due to commodity pressure) of up to 60% of the tank material yield stress. The referenced commodities are required by DOT to be transported in -500, -600, and -800 lb. tanks, respectively. The logic of this paragraph needs to be revisited."

- Diane Rocheleau, Superintendent, Materials Engineering, Engineering Branch, Transportation Safety Board of Canada, 1901 Research Road, Gloucester, Ontario K1A 1K8.

  (1) "Page 23: rail burn vs. rail dent. I see a burn as resulting in metallurgical changes in the metal, for example the creation of an untempered martensitic layer. A dent would not have such a microstructural change. If a rail impacts the tank car, yes a rail dent, but if the tank car slides along the rail and the material is blued or if a significant gouge appears and localized heating of the microstructure took place, I would call this a rail burn."

(2) "Page 28, I fully agree that NDE methods should be considered, since stresses can be measured using methods such as infrared thermography, acoustic emission, etc."

- Edgar Ladouceur, Chief of Response Operations, Transport Canada, Canada Building, 344 Slater Street, Ottawa, Ontario K1A ON5.

  (1) The report does a good job of providing background information regarding the origin of the guidelines as well as identifying the shortcomings of the guidelines.

  (2) "The recommendations put forth in the report regarding future research appear reasonable and appropriate."

  (3) "The only caution flag that I would raise is that it will be important to ensure that the final product be something useful at the field level. A small pocket guide would be helpful for responders in the field. The margins of safety associated with using the "rule of thumb" information contained in the pocket guide would also need to be well identified."

ATTACHMENT 1

SECTION G

TANK CAR DAMAGE ASSESSMENT

PRESSURE TANK CAR DAMAGE ASSESSMENT

OVERVIEW

Background

Pressure tank cars transporting compressed gases have sustained extensive damage in derailments without releasing their contents. However, tank damage without an immediate release of the contents has led to delayed releases (up to 40 hours after the damage was sustained, e.g. Cumming, IA (April 1969) and Waverly, TN (February 1978)). During this delay, response personnel are likely to get involved in derailment handling operations, and consequently, may sustain death or injury if the tank should fail.

Response personnel must analyze the problem with pressure tank cars in order to plan their response. A key task in the analysis process is that of determining the extent of damage suffered by the tank.

Scope and Purpose

This document outlines the steps to be taken to determine the extent (severity) of damage to pressure tank cars, i.e., damage without the release of the contents. It will present:

- The factors affecting the severity of tank damage;
- The type of tank construction information required before inspecting the tank;
- An explanation of the significant types of tank damage;
- The type of tank damage information required from the inspection; and
- Some guidelines for interpreting the severity (extent) of the tank damage.

Appendix A (page 10) explains how to use the Tank Car Dent Gauge.

Safety Precautions

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

1. Control access to the emergency scene to minimize exposure to unauthorized personnel.
2. Determine if hazardous materials are present.
3. If hazardous materials are present, survey the incident to identify the contents and car types involved, and determine if any hazardous material shipments are leaking.

Note: A leaking hazardous material may increase the threat to people, property or the environment or it may cause an already damaged car to fail, releasing its contents.

4. Obtain information on the hazards and behavior characteristics of each hazardous material involved.
5. Keep fire, lights, internal combustion engines, smoking materials, and other sources of ignition away from the area.
6. Wear appropriate personal protective equipment for the hazards associated with the emergency.
7. Secure the advice/assistance of someone with tank car experience, i.e. shipper personnel, carrier personnel (railroad hazardous material or mechanical specialists), tank car manufacturer or repair personnel, and AAR Bureau of Explosives personnel.

Definitions

Tank: The word tank in this document refers to the actual tank car tank.

Jacket: The jacket holds the insulation or thermal protection in place and protects them from the elements. The jacket is not designed to hold the leaking contents of the tank car.

SECTION 1: FACTORS AFFECTING THE SEVERITY OF TANK DAMAGE

Even when pressure tank cars are damaged, they still have high strength. However, a slight growth in a crack and/or an increase in internal pressure can trigger a failure of the tank.

The factors affecting the severity of tank damage include:

- Ductility of tank metal; and
- Internal pressure causing stress on the tank metal.

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 cracks, the crack tends to be small, whereas the crack in a brittle steel tank tends to run linearly and cause the tank to fail.

Four conditions affect the ductility of tank metal, these include:

- Specification of the steel
- Temperature of the steel
- Cold work
- Heat affected zone

Specification of the Steel

From 1937 to 1966, pressure tank cars were made of steels identified as AAR M-115, ASTM A-285 grade C, ASTM A-212 grade B, and ASTM A-515 grade 70. All of these steels had an unpredictable transition temperature which varies from 20° to 80° F. (Transition temperature is the point where the properties of steel change from a ductile to a brittle nature. A metal's transition temperature increases sharply as a result of cold work with metal becoming more brittle at the point of cold work.) These steels tend to be more brittle at temperatures below their transition temperature.

Starting in 1967, pressure tank cars have been made of AAR-TC-M-128 Grade B (fine grain, high tensile strength steels) having a transition temperature of 20° F or less. These steels tend to be more ductile at lower temperatures.

Temperature of the Steel

The temperature of the steel affects its ductility. The higher the temperature of the steel at the time of damage, the more ductile (less brittle) the steel will be and the less risk there is for failure.

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

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 rounded point. Cold work reduces the ductility of the material.

The transition temperature of the steel is increased sharply as a result of cold work, i.e., the steel becomes more brittle where the cold work takes place.

Heat Affected Zone

The heat affected zone is an 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 heat affected zone is most vulnerable to damage as cracks are likely to start there.

Internal Pressure

Internal pressure is the force against the internal surfaces of the tank, caused by the vapor pressure of the contents, creating stress on the tank.

An increase in internal pressure in a damaged pressure tank car is a concern. A change in internal pressure caused by an ambient temperature increase may be enough to cause a micro crack to grow.

Stress tends to make cracks grow. A crack or notch in a tank will remain stable until a critical stress is reached. The critical stress is the point where the crack will start to grow, become unstable, and propagate. The higher the internal pressure, the more risk there is of the tank failing.

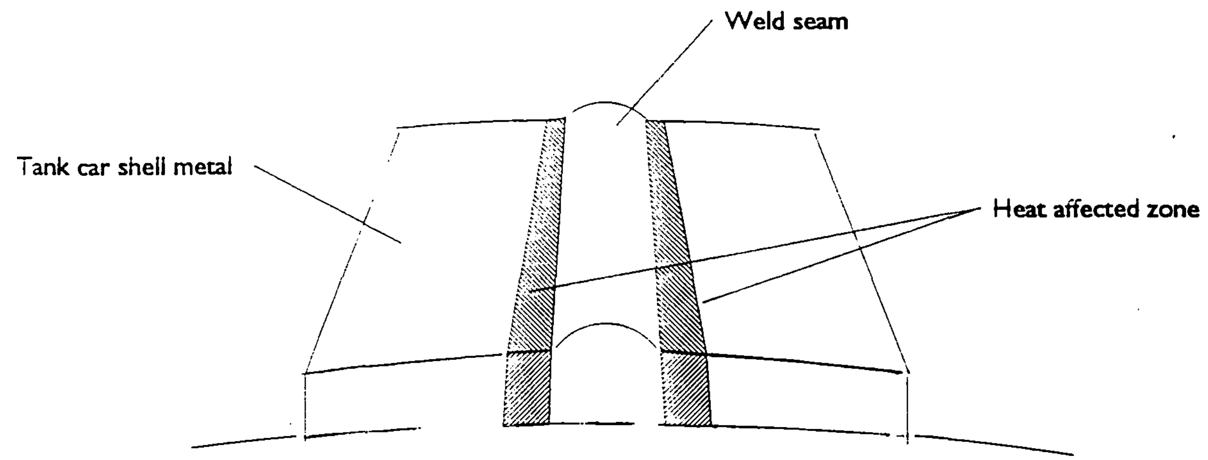


Figure 1. Heat affected zone

SECTION 2: DETERMINING TANK CAR CONSTRUCTION FEATURES

Before inspecting a damaged tank car, it is important to understand the features of that car, both in terms of tank construction and fittings. This section will discuss how to determine the construction features of a tank car. This information will assist the inspector in documenting the extent of damage to the tank.

Sources of Tank Car Construction Information

The following sources can be used to obtain information on a specific tank car's construction features:

- **Type of tank car** - interpretation of the specific characteristics visible as you look at the car may provide some basic information on construction features;
- **Specification Marking** - interpretation of the tank car's specification marking may provide some basic information on construction features;
- **Tank Car Manuals** - reviewing tank car manuals (i.e., GATX Tank Car Manual and UTLX Tank Car Manual) may provide detailed information on construction features; and
- **"Certificate of Construction"** - obtained from the manufacturer's, owner's, or AAR Bureau of Explosives' files.

Construction Information Required

An adequate inspection is based on an understanding of certain construction features of the tank car, including:

- **Reporting marks (initials) and number** - tank cars are identified by the reporting marks (initials) and number (found in 9" letters and numbers) to the left as you face the sides and on the ends of the car.
- **Specification marking** - specification marking stencilled (at least 2" letters and numbers) on the right end of each side of a tank car as you face it (not found on the ends of the car).
- **Tank car type** - determined from specification marking.
- **Tank test pressure** - determined from specification marking.
- **Tank capacity** - tank car capacity information is found by weight of water capacity on the sides and by gallons on ends of tank cars.
- **Amount in tank** - (with unit of measure) determined from shipping documents.
- **Construction material, type, grade, thickness** - material identification is part of the head stamping. It may be visible on uninsulated or non-thermally protected tank cars, but it is not visible when the car is jacketed or covered with sprayed-on thermal protection.
- **Year of construction** - date of construction is found as part of head stamping and is stencilled on the sides of the car.
- **Insulation**
- **Thermal protection** - jacketed or sprayed-on.
- **Underframe** - continuous or stub sill.

SECTION 3: TYPES OF TANK DAMAGE

When inspecting a damaged tank car, the inspector must be able to recognize various types of damage. This section introduces the typical types of damage including:

- Cracks
- Scores
- Gouges
- Wheel burns
- Dents
- Rail burns

Crack

A crack is a narrow split or break in the tank metal which may penetrate through the tank metal.

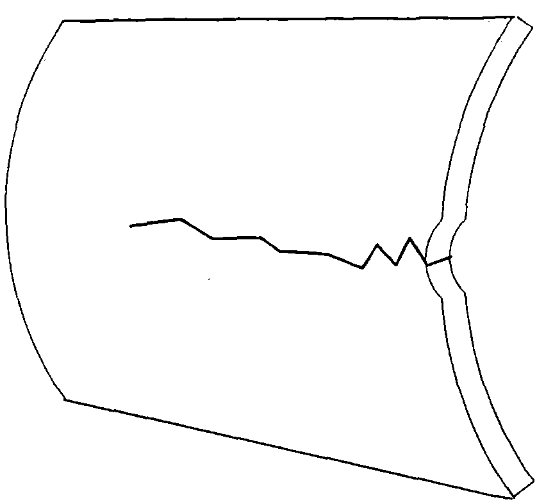


Figure 2. Crack

Score

A score is a relocation of tank or weld metal so that the metal is pushed aside along the line of contact with another object. This causes a reduction in tank metal thickness.

Knife through butter analogy

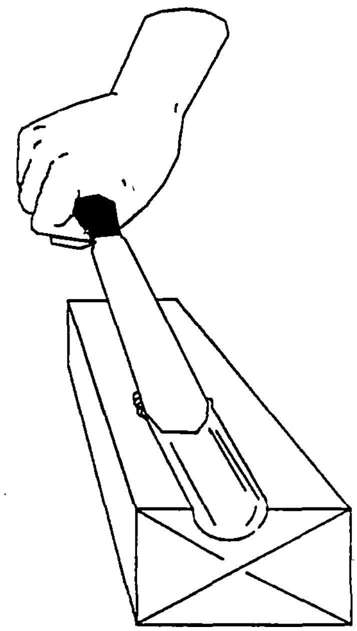


Figure 3. Score

Gouge

A gouge is a removal of the tank or weld metal along the line of contact with another object. This causes a reduction in tank metal thickness.

Chisel on wood analogy

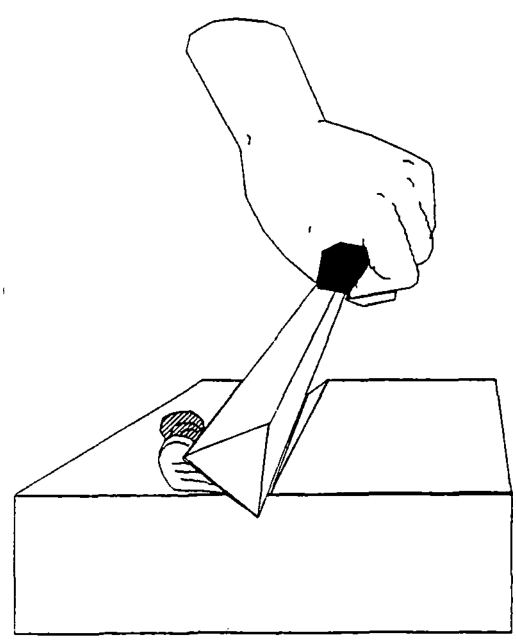


Figure 4. Gouge

Wheel burn

A wheel burn is similar to a gouge but is caused by prolonged wheel contact with the tank.

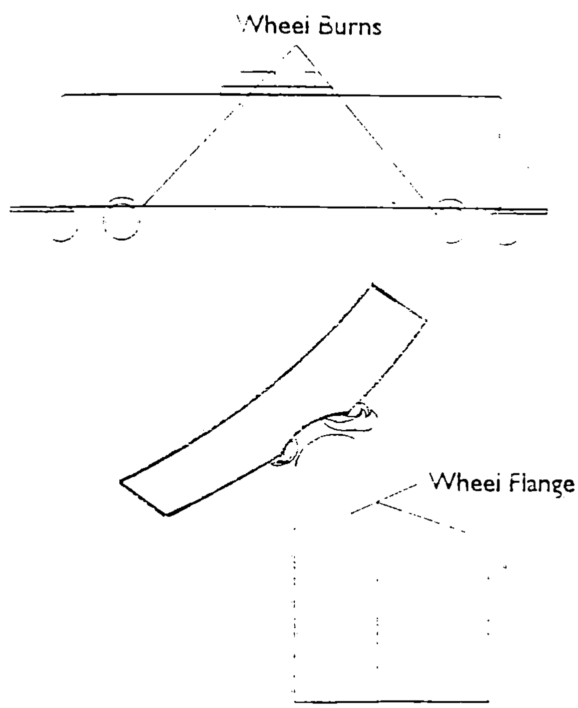


Figure 5. Wheel burn

Dent

A dent is a deformation that changes the tank contour from that of original manufacture as a result of impact with a relatively blunt object (coupler or end of an adjacent car).

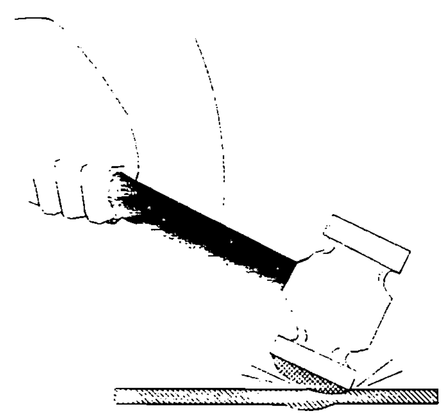


Figure 6. Dent

Rail Burn

A rail burn is a long dent, usually parallel to the length of the tank, i.e., parallel to the longitudinal axis of the tank, which crosses a weld, and causes cold work. It may be caused by the tank passing over a section of rail.

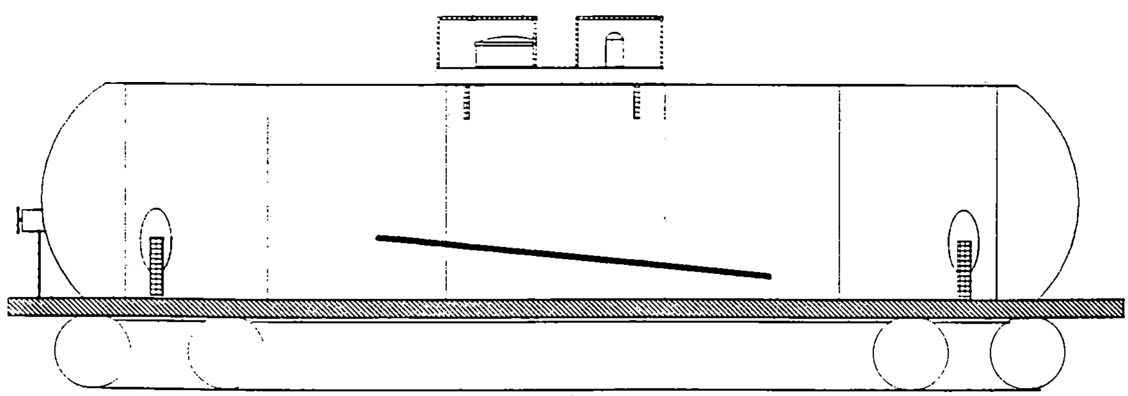


Figure 7. Rail Burn

SECTION 4: INSPECTING DAMAGED TANK CARS

An inspection of damaged tank cars requires an examination of all accessible surfaces for the type (i.e., cracks, scores, gouges, wheel burns, dents, and rail burns), location, direction, and extent of damage.

Since it is usually not possible to see the entire surface of the tank, reinspect the tank during and after adjacent cars or surrounding materials are removed.

Guidelines

The following steps should be taken when inspecting damaged tank cars:

1. Examine all accessible surfaces for cracks, scores, gouges, wheel burns, dents, and rail burns. Pay close attention to this type of damage in the longitudinal direction.

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

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

4. Where a score, gouge, or wheel burn crosses a weld, measure the depth of weld metal removed. If a score or gouge crosses a weld, the damage is more critical if it removes the weld's base metal, not just the weld reinforcement (crown metal).

5. 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.

6. Measure the radius of curvature for each dent or rail burn at the point of sharpest bend using the Tank Car Dent Gauge (see Appendix A for instructions).

Definition: Radius of curvature is 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 more gentle bend. There is no problem with a gentle radius of curvature unless it is in conjunction with other damage.

Notes:

1. If the radius of curvature is less than the minimum radius specified, the damage is critical.

2. Reduction in tank volume due to massive denting is not a major consideration unless it is suspected that atmospheric temperature may approach the "shell full temperature" of 115° F summer loading or 95°F winter loading. The loss of volume due to massive denting will lower the shell full temperature three or four degrees F. Massive denting could reduce tank shell capacity by as much as 5%.

7. Identify the dents which have scores or gouges associated with them and those which cross a weld.

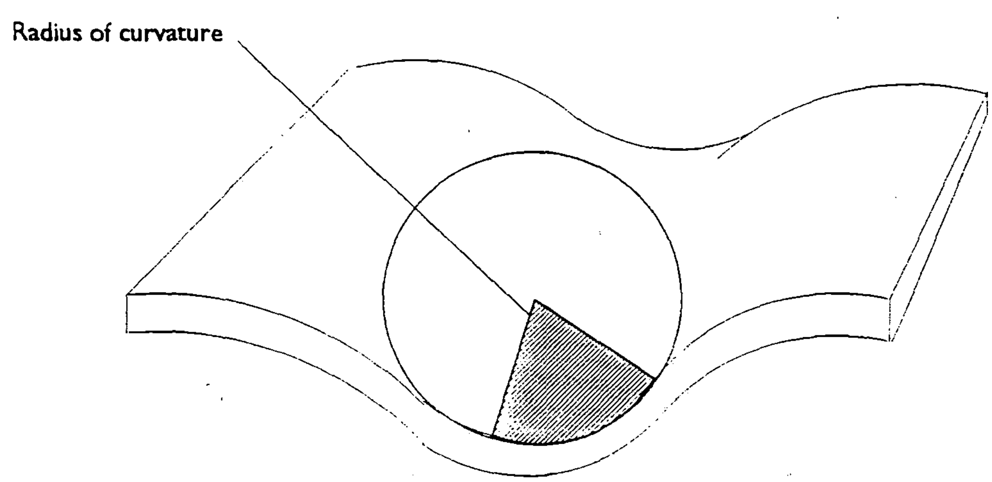


Figure 8. Radius of curvature

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

8. Examine each point of minimum curvature on a dent or rail burn for cracks and record any cracks found no matter how small.

   Relatively large cracks are visible to the naked eye. For smaller cracks, the use of crack penetrant may be helpful in locating cracks. Often material will weep through even a small crack, therefore, look for signs of frosting or clear liquid on pressure tank cars.

9. Determine the temperature of the tank metal.

Note: Attaching a thermometer to the shell of the tank will accomplish this. The thermometer must be attached to the tank, not the jacket.

10. Determine the internal pressure of the tank car.

    Determination of the internal pressure is essential in deciding if a tank should be picked up or be unloaded where it is. The pressure may be obtained by either:

    a. Reading a pressure gauge attached to the sample line, or gauging device or other fittings (when reducers are available); or

    b. by taking the temperature of the contents and referring to the vapor pressure/temperature graphs for the contents.

Notes:

1. Graphs are available from the Compressed Gas Handbook, the shipper, or the manufacturer of the commodity.

2. Most pressures are shown as absolute pressure, therefore 14.7 must be **subtracted** to obtain gauge pressure.

In the event that neither temperature nor pressure can be measured, a fair estimate of temperature can be made from the ambient temperature. Keep in mind that the temperature of the tank's contents may lag ambient temperatures by 6 hours. Since the tank contents may stratify by temperature change, pressure must be measured directly since pressure determined from temperature may be inaccurate.

Keep in mind, internal pressures in residue tank cars containing residual vapors may be equal to that in loaded tank cars.

SECTION 5: INTERPRETING TANK DAMAGE TO PRESSURE TANK CARS

Having collected information on the types, location, direction, and extent of tank car damage, the information must be analyzed to determine its significance in terms of potential behavior of the tank. This section discusses the significance attached to various types and combinations of tank damage, including:

- Cracks
- Scores and gouges
- Wheel Burns
- Dents (including rail burns)

Accurate assessment of tank damage on jacketed tanks is difficult without removal of the jacket and insulation/thermal protection, thus increasing the time to complete the inspection and increasing the risk to response personnel.

If the jacket cannot be removed from the damaged area, the uncertainties associated with tank damage assessment will increase the risk to response personnel.

Note: Tank cars in classes 105, 112J, 114J, and 120 are jacketed cars. Tank cars in classes 112A, 112S, 112T, 114A, 114S, and 114T are not jacketed cars. Pressure tank cars classed as 109A may or may not be insulated and, if insulated, the insulation is held in place by a jacket.

Damage to the jacket of an insulated or thermally protected pressure tank car is not serious unless such damage penetrates through to the tank itself.

Cracks

Since there is no way to detect a crack that has become critical, you have no way to predict an incipient failure. Decisions must be made quickly and the handling of severely damaged tank cars completed as quickly as possible.

- 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 attachments to 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.

Scores and Gouges

Scores and gouges in conjunction with dents are discussed under the dents section.

- Scores or gouges crossing a weld and removing only the weld reinforcement are not critical.

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

- Longitudinal scores or gouges crossing a weld and affecting the heat affected zones are critical and the contents of the tank car should be transferred immediately.

- Tanks having scores or gouges should be unloaded in place when the internal pressure exceeds half 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.

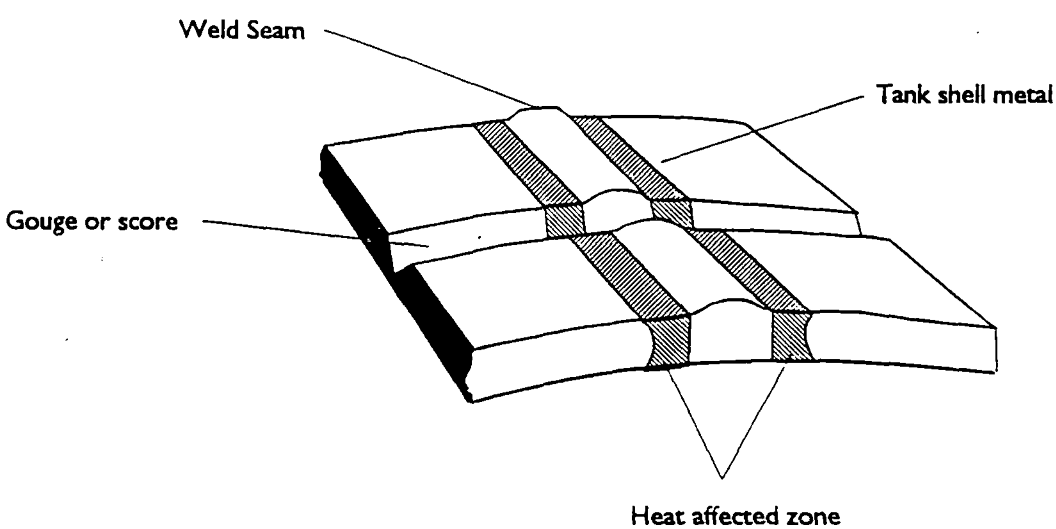


Figure 9. Longitudinal score crossing weld seam

Table 1: Limiting Score Depths for 340W Tanks

Depth of Score	Maximum Safe Internal Pressure, PSIG
1/16"	191 (89°F for commercial propane)
1/8"	170 (85°F for commercial propane)
3/16"	149 (76°F for commercial propane)
1/4"	127 (65°F for commercial propane)

Note: In no case should a tank containing a score in excess of 1/16" for 340W tanks be shipped by rail, although the tank could be uprighted and even moved short distances for transfer.

Table 2: Limiting Score Depths for 400W Tanks

Depth of Score	Maximum Safe Internal Pressure, PSIG
1/16"	228 (108°F for commercial propane)
1/8"	205 (99°F for commercial propane)
3/16"	188 (93°F for commercial propane)
1/4"	162 (82°F for commercial propane)

Note: In no case should a tank containing a score in excess of 1/8" for 400W tanks be shipped by rail, although it could be uprighted and even moved short distances for transfer.

While the values given in Table 1 and 2 are conservative, they do not include the welded joint efficiency for tanks built prior to 1968. This amounts to an extra 10% safety factor.

Wheel Burns

Wheel burn damage does 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 closest loading facility, provided it is moved with care; not in ordinary train service.

- Sharp Dents in the shell of the 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%.

  1. 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; or
     - Include a score or gouge.

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

  2. For dents in the shell 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.

- 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" for tanks built prior to 1967 or less than 2" 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.

Additional Comments

The decision on the movement of a loaded tank car from the derailment scene which has been damaged to a lesser extent than the limits described above is generally made by the carrier involved along with FRA consultations and permits as needed. Damaged tank cars may be moved on temporary trucks to a point where the contents can be transferred. The tank may be moved on a flat car as long as the weight of the tank car does not overload the flat car, however, the tank must be adequately blocked and braced, the fittings intact, and the car properly placarded.

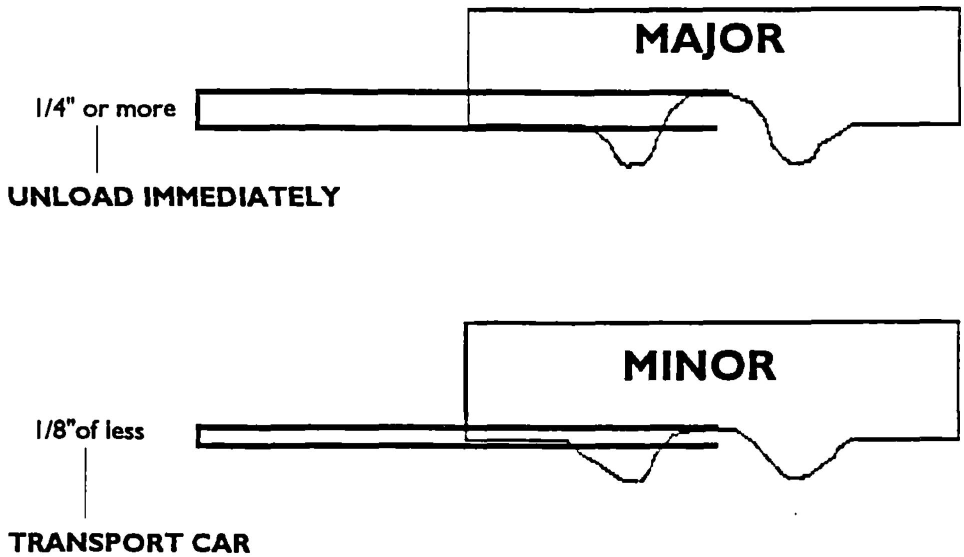


Figure 10. Wheel burns on loaded car

APPENDIX A: Using the Tank Car Dent Gauge

Introduction

The Tank Car Dent Gauge is a "go-no-go" device used to compare the radius of curvature of a dent in a tank car to accepted standards in order to determine the severity of damage.

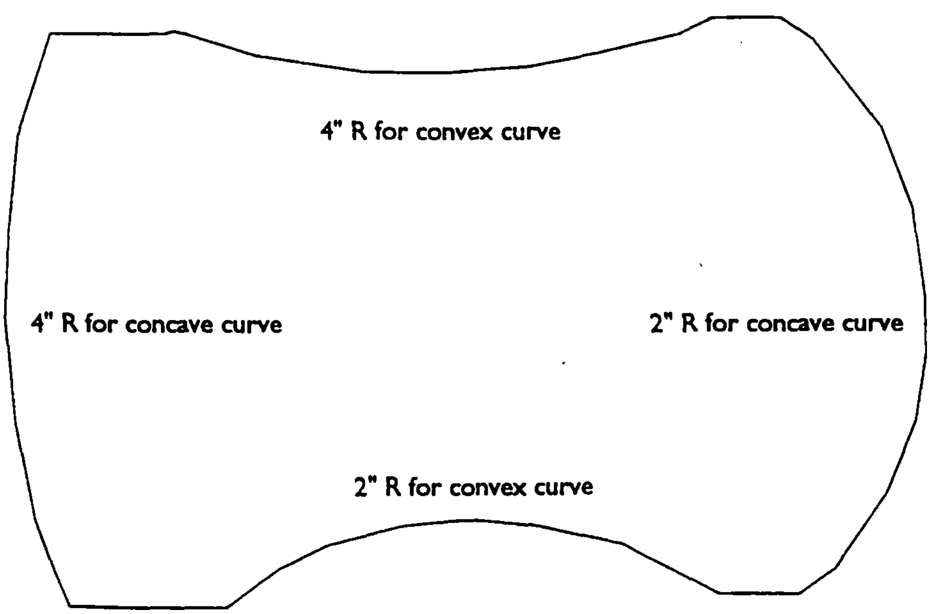
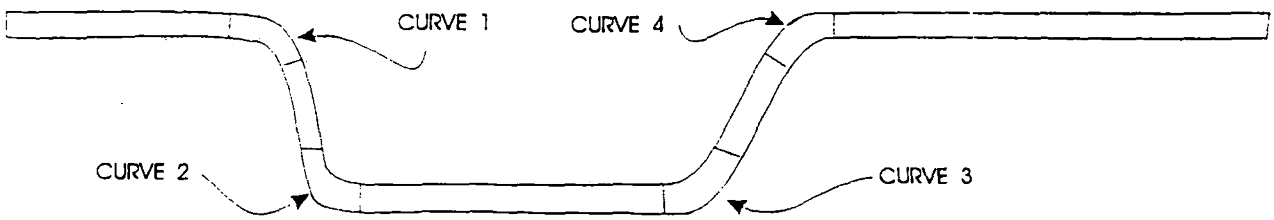


Figure 11. Diagram of Dent Gauge (not exactly to scale)

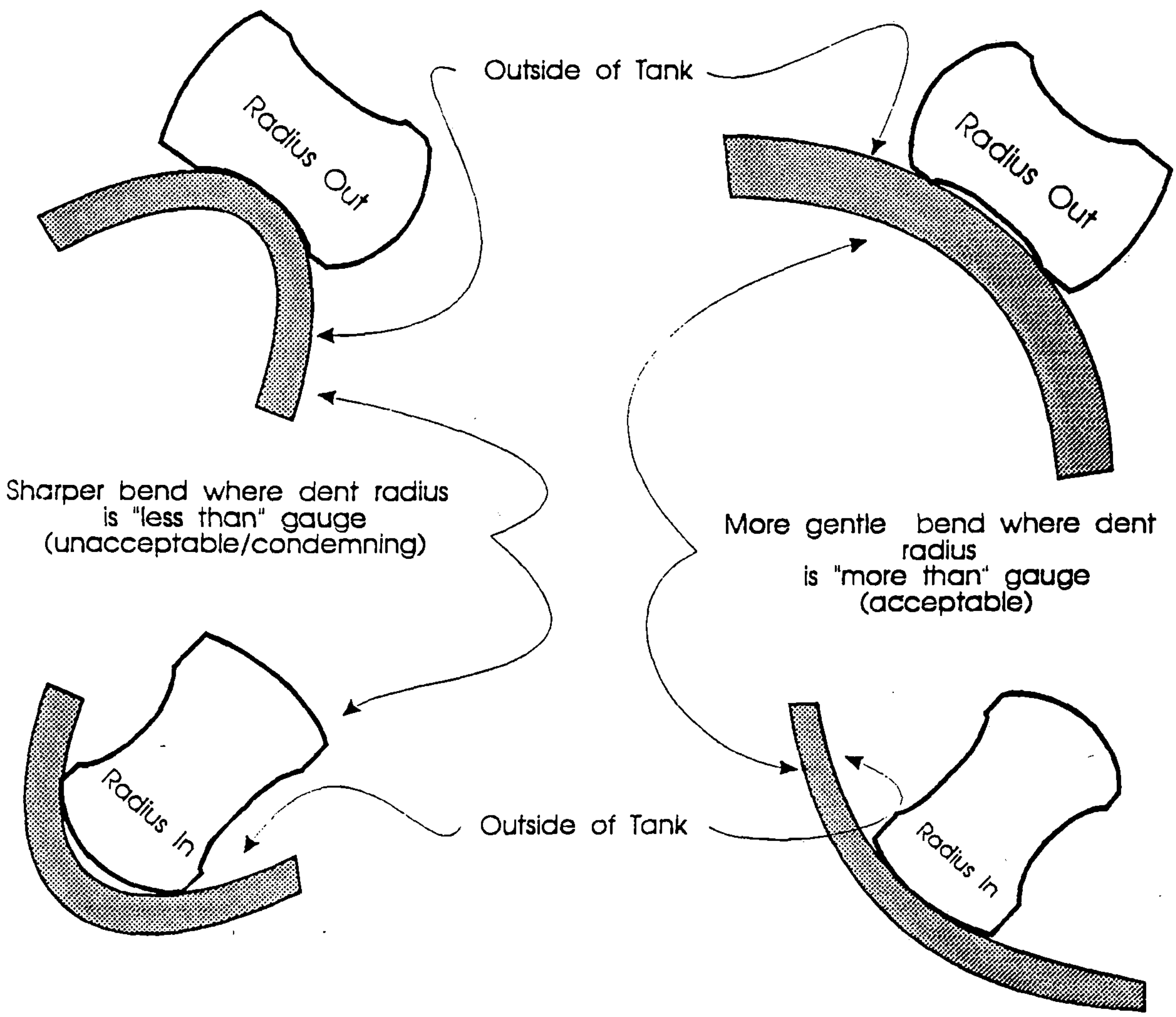
Introduction for using the Tank Car Dent Gage

The instructions on this page will explain the use of the Tank Car Dent Gauge in determining whether or not the radius of curvature is within acceptable limits.

Place the Tank Car Dent Gauge against the sharpest bend in the dent for measurement. The following examples indicate how to read the results of the comparison of the radius of curvature of the dent to that of the dent gauge.



Section of Dent (shown reduced size). This dent contains four curves numbered 1, 2, 3, and 4. Curves 1 and 4 are bent "out" relative to the tank. Curves 2 and 3 are bent "in" relative to the tank.



TANK CAR DAMAGE ASSESSMENT WORKSHEET	**Car Initials & Number:**

Tank Car Characteristics

Type of Car: ☐ Non-pressure ☐ Pressure ☐ Cryogenic ☐ Other____________________

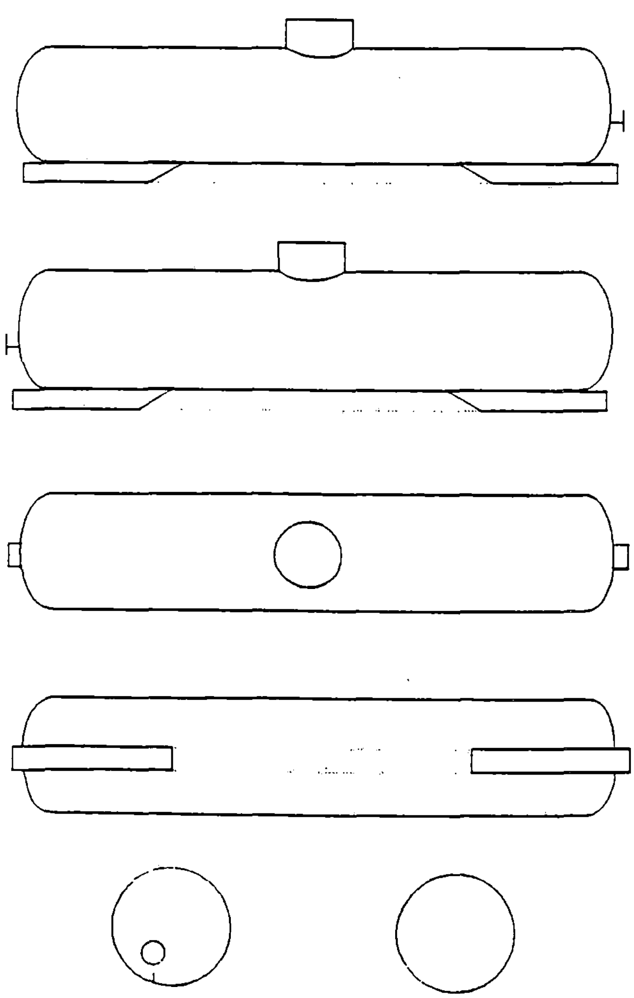
Specification No. :	Shell Capacity:
Year Constructed:	Tank Test Pressure:
Underframe: ☐ Continuous ☐ Stub Sill	
Thermal Protection: ☐ Jacketed ☐ Sprayed-on	
Construction Material: Type/Grade: ______ Thickness: ___________	

Features	Y	N
Jacketed		
Insulated		
Thermal Protection		
Linings		
Claddings		
Heater Coils		

Stress: ☐ Thermal ☐ Mechanical ☐ Chemical ☐ None

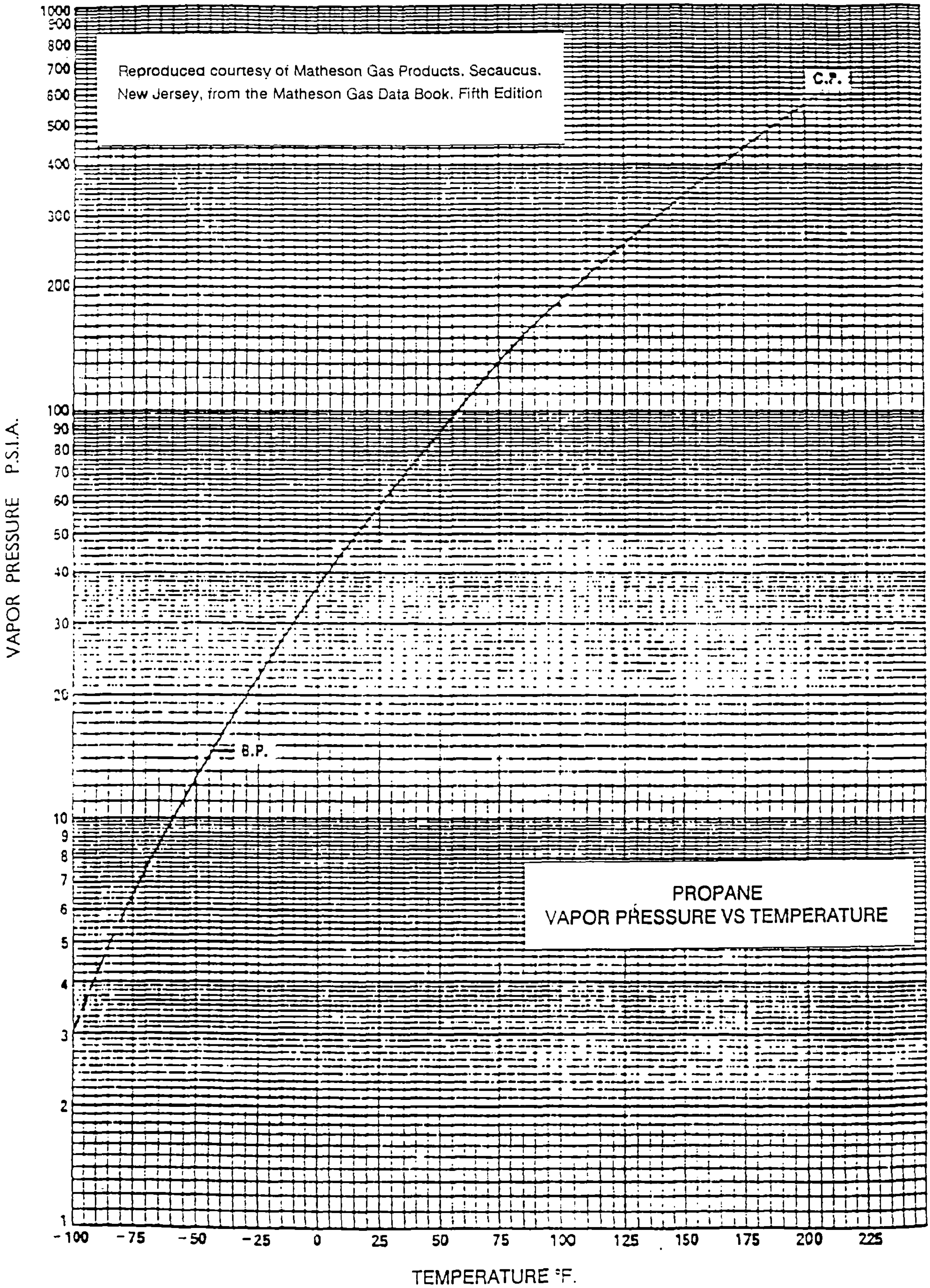
Jacket, Tank and Head Damage

Indicate location and severity of damage(punctures, crack scores, gouges, wheel burns, dents, rail burns, underframe, and leaks) on the appropriate diagram(s).



Fitting Damage

Fitting	Damage	Description
☐ Liquid Valve	☐ YES ☐ LEAKING	
☐ Vapor Valve	☐ YES ☐ LEAKING	
☐ Air Valve	☐ YES ☐ LEAKING	
☐ Bottom Outlet Type:_________	☐ YES ☐ LEAKING	
☐ Safety Relief Device Type:_________	☐ YES ☐ LEAKING	
☐ Vacuum Relief	☐ YES ☐ LEAKING	
☐ Gauging Device Type:_________	☐ YES ☐ LEAKING	
☐ Manway Cover	☐ YES ☐ LEAKING	
☐ Fill Hole	☐ YES ☐ LEAKING	
☐ Sample Line	☐ YES ☐ LEAKING	
☐ Thermometer Well	☐ YES ☐ LEAKING	
☐ Washout	☐ YES ☐ LEAKING	
☐ Sump	☐ YES ☐ LEAKING	
☐ Other Type:_________	☐ YES ☐ LEAKING	



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B.P.
PROPANE
VAPOR PRESSURE VS TEMPERATURE
VAPOR PRESSURE P.S.I.A.
TEMPERATURE °F.
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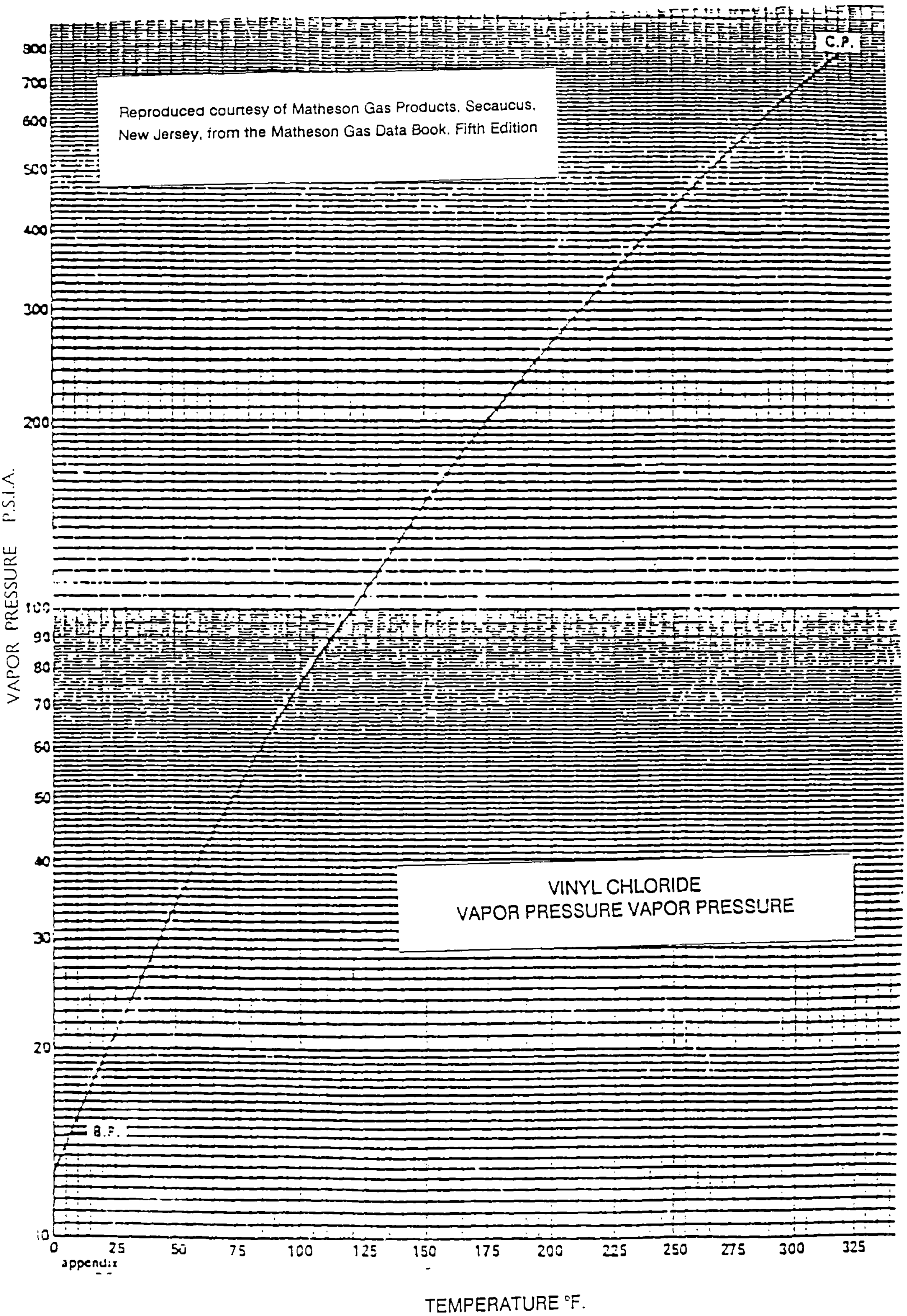
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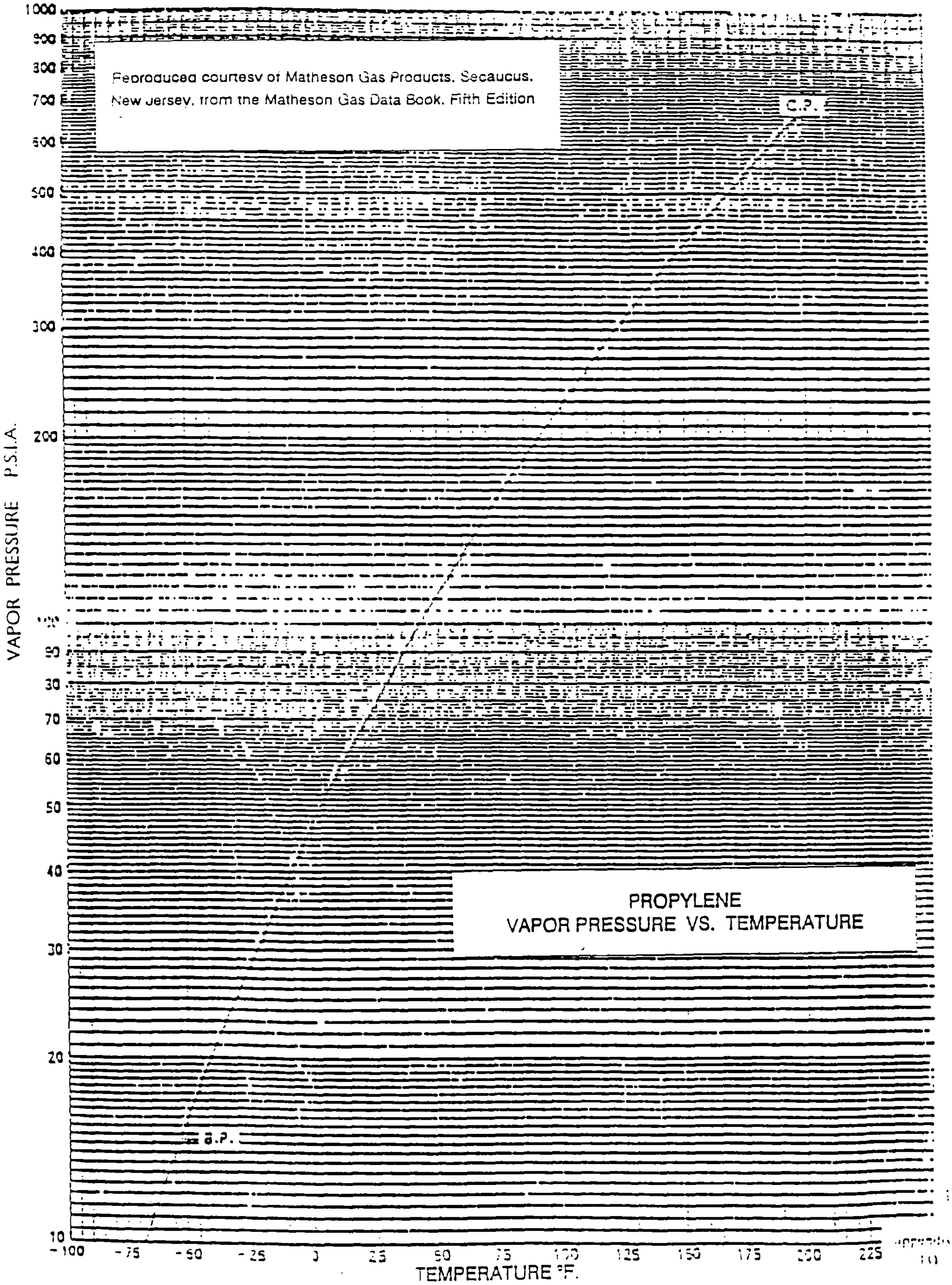
VINYL CHLORIDE
VAPOR PRESSURE VAPOR PRESSURE
C.P.
B.P.
VAPOR PRESSURE P.S.I.A.
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
25
50
75
100
125
150
175
200
225
250
275
300
325
appendix
TEMPERATURE °F.



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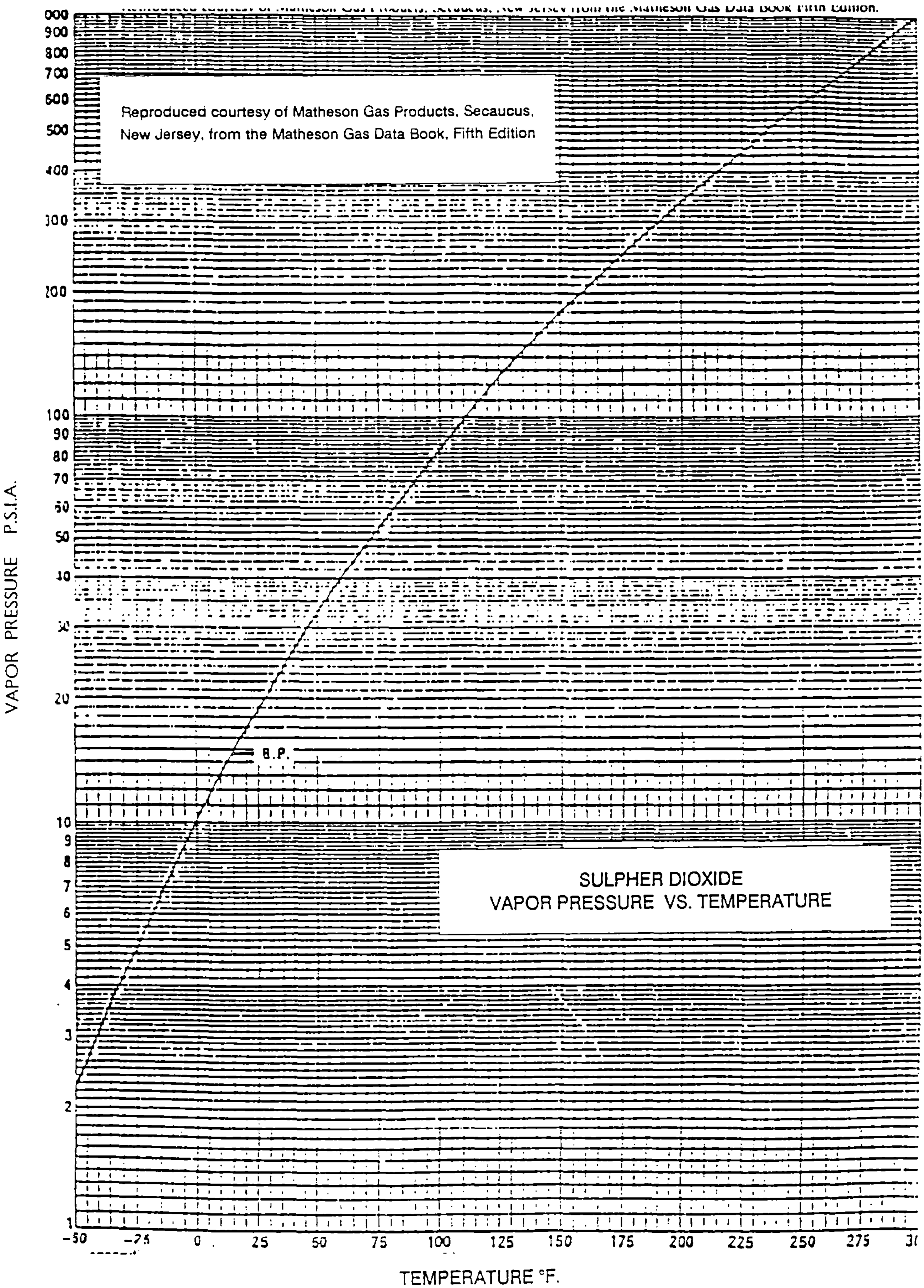
PROPYLENE
VAPOR PRESSURE VS. TEMPERATURE
C.P.
B.P.
VAPOR PRESSURE P.S.I.A.
TEMPERATURE °F.
1000
900
800
700
600
500
400
300
200
90
80
70
60
50
40
30
20
10
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
225



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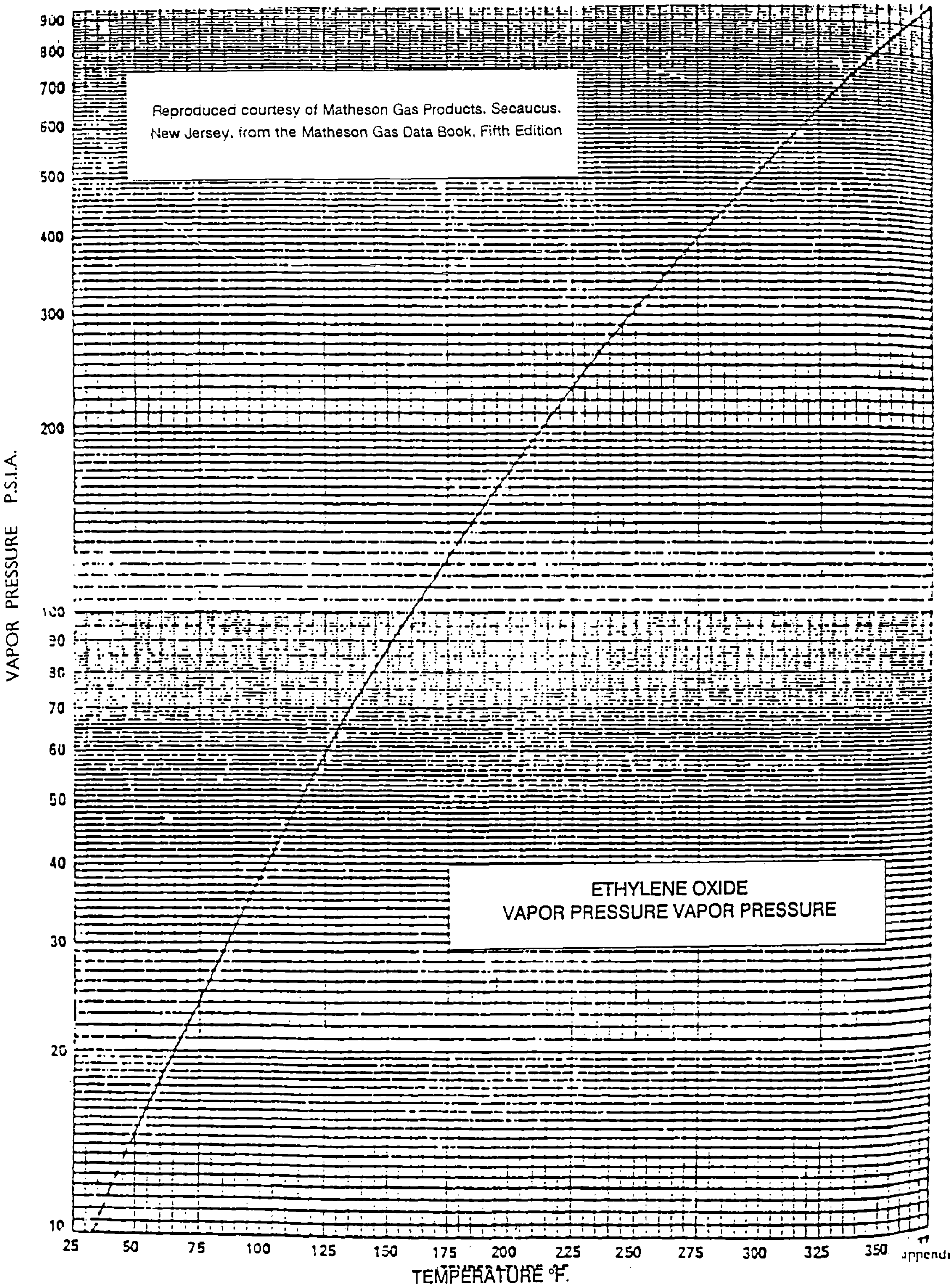
SULPHER DIOXIDE
VAPOR PRESSURE VS. TEMPERATURE
VAPOR PRESSURE P.S.I.A.
TEMPERATURE °F.
B.P.
900
800
700
600
500
400
300
200
100
90
80
70
60
50
20
10
9
8
7
6
5
4
3
2
1
-50
0
25
50
75
100
125
150
175
200
225
250
275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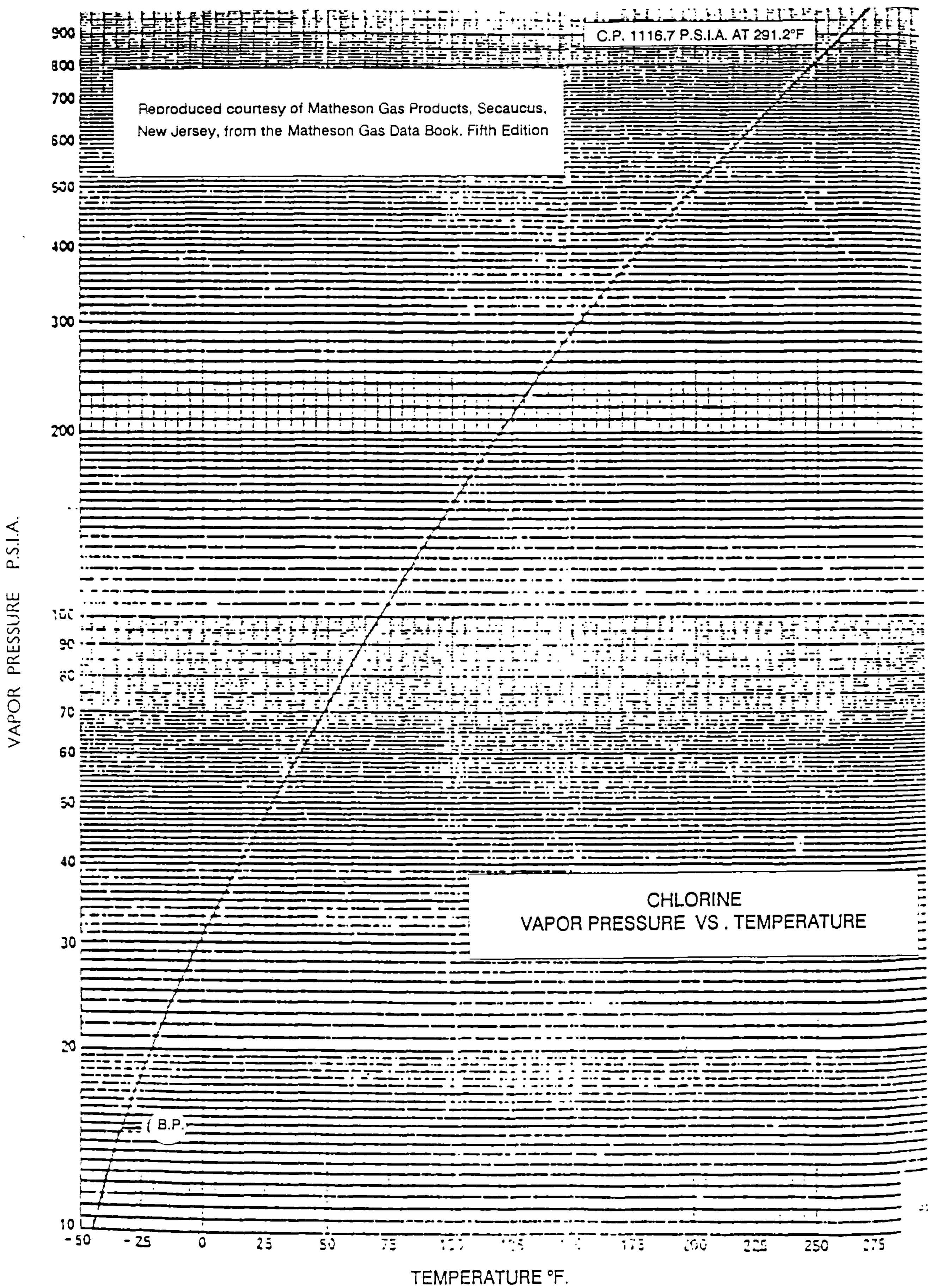
ETHYLENE OXIDE
VAPOR PRESSURE VAPOR PRESSURE
VAPOR PRESSURE P.S.I.A.
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
25
50
75
100
125
150
175
200
225
250
275
300
325
350
TEMPERATURE °F.


C.P. 1116.7 P.S.I.A. AT 291.2°F
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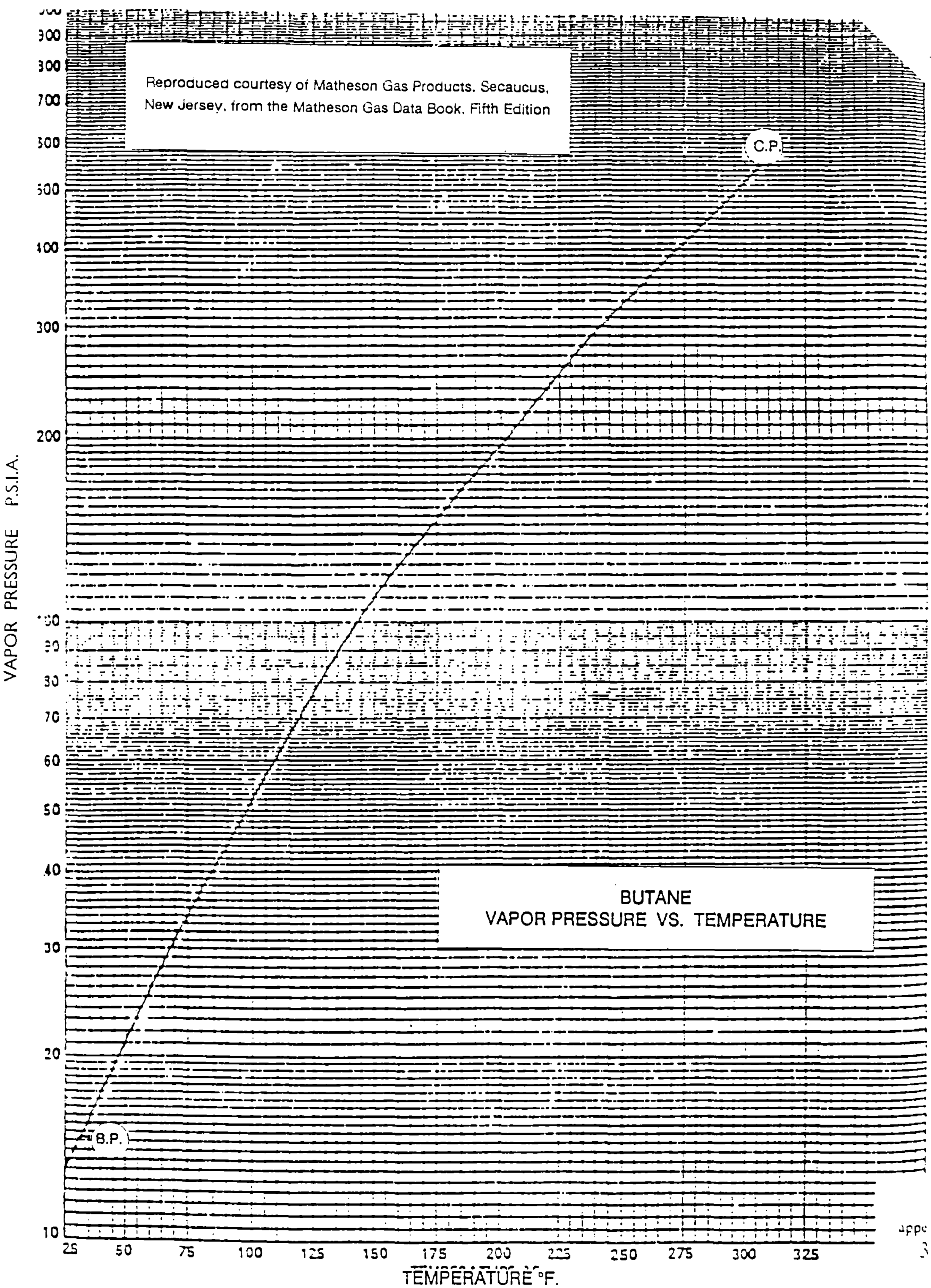
CHLORINE
VAPOR PRESSURE VS. TEMPERATURE
B.P.
VAPOR PRESSURE P.S.I.A.
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
-50
-25
0
25
50
250
TEMPERATURE °F.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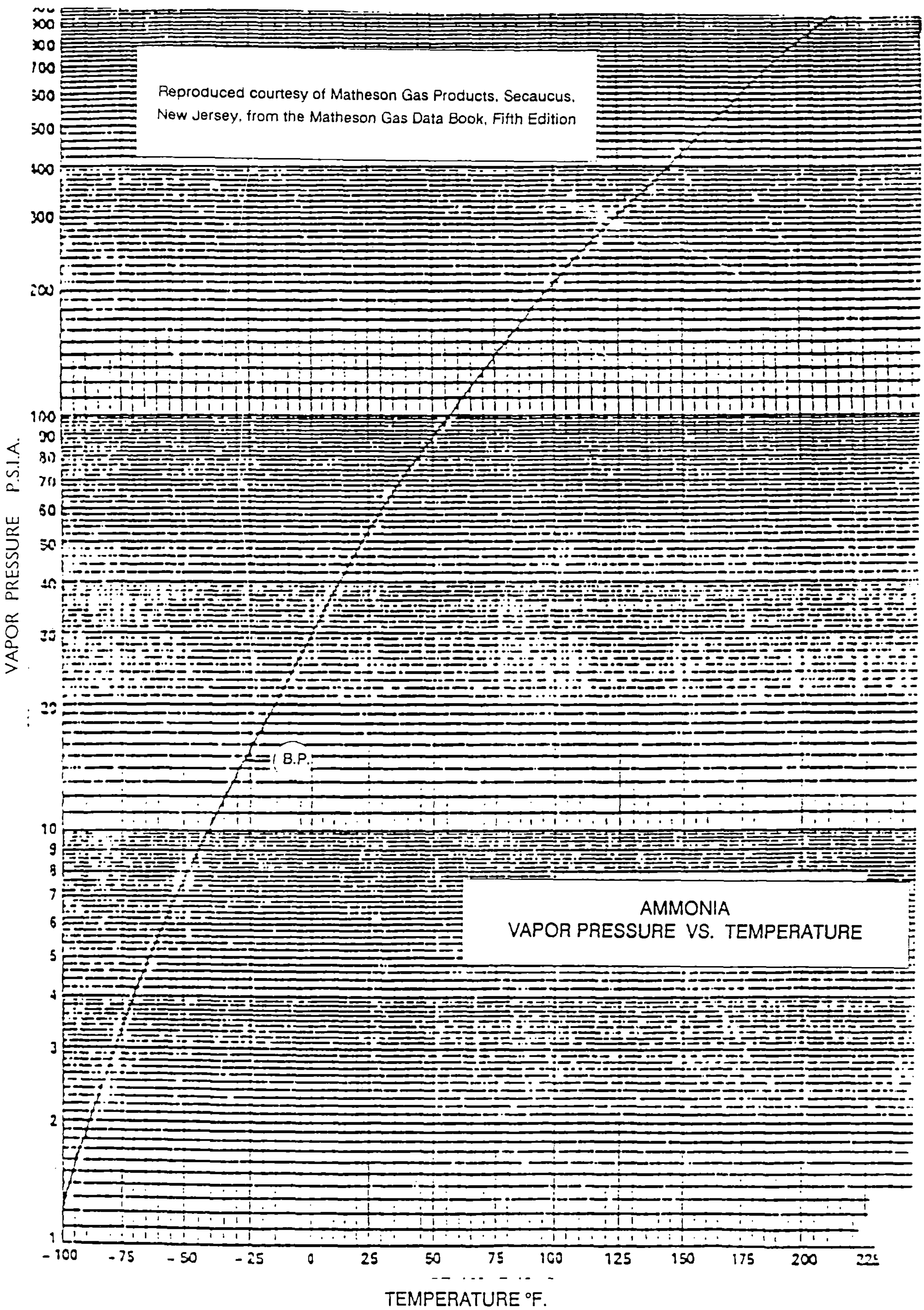
C.P.
BUTANE
VAPOR PRESSURE VS. TEMPERATURE
B.P.
VAPOR PRESSURE P.S.I.A.
700
500
400
300
200
70
60
50
40
30
20
10
25
50
75
100
125
150
175
200
225
250
275
300
325
TEMPERATURE °F.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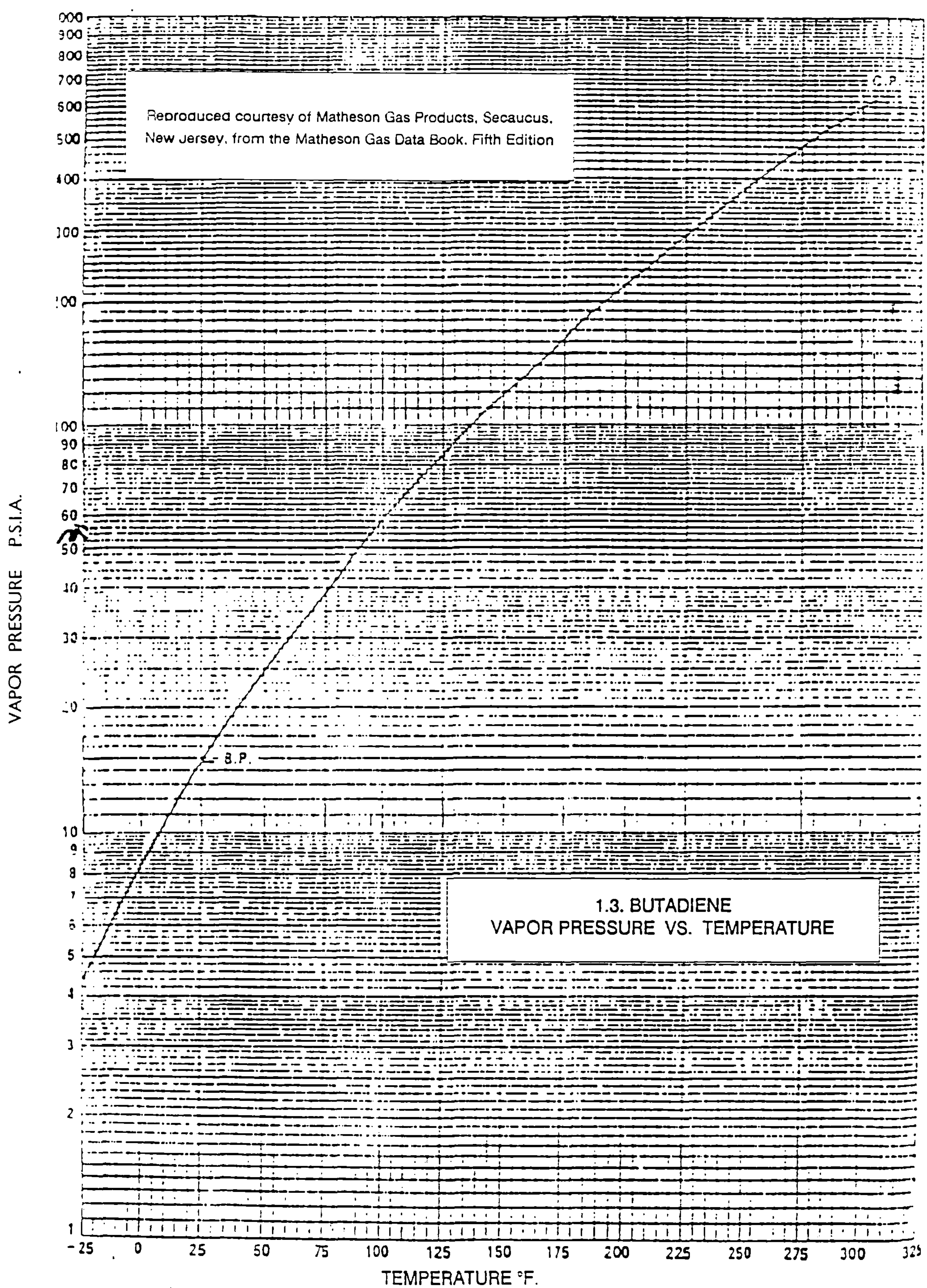
AMMONIA
VAPOR PRESSURE VS. TEMPERATURE
VAPOR PRESSURE P.S.I.A.
TEMPERATURE °F.
B.P.
100
90
80
70
60
50
40
30
10
9
8
7
6
5
4
3
2
1
-100
-75
-50
-25
0
25
50
75
100
125
150
175
200
300
200



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1.3. BUTADIENE
VAPOR PRESSURE VS. TEMPERATURE
VAPOR PRESSURE P.S.I.A.
TEMPERATURE °F.
C.P.
B.P.
900
800
700
600
500
400
100
90
80
70
60
50
10
9
8
7
6
5
4
3
2
1
-25
0
25
50
75
100
125
150
175
200
225
250
275
300