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REVIEW OF PROPOSED SPECIFICATIONS RELATING TO THE SHIPMENT OF ETHYLENE IN TANK CARS AT CRYOGENIC TEMPERATURES

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FINAL REPORT

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16. Abstract

This report reviews proposed specifications and shipper regulations for 113 series tank cars for transporting liquid ethylene at cryogenic temperatures. The study was limited in scope and was to be directed primarily at the holding time requirements necessary for safe shipment of the commodity.

The insulation requirements based on a 30-day holding time capability with a design margin of 15 days are considered responsive to needs and are reasonable and practical within the current state of the art. A further definition of conditions for heat transfer calculations and measurement are suggested to assure consistent design and performance.

Apparent deficiencies are noted in the proposed in-transit pressure rise specification; a candidate modification is described.

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FOREWORD

The work described in this technical report was performed under Contract No. DOT-FR-20069 by the Systems Research Department of Calspan Corporation for the U. S. Department of Transportation, Federal Railroad Administration. The basic contract deals with the general design of tank cars for transporting hazardous materials.

This special report deals only with the results of a limited scope ad hoc task reviewing FRA furnished information regarding proposed regulations for cryogenic tank cars transporting ethylene.

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I. INTRODUCTION

1.1 Background

Liquefied ethylene is currently shipped in Class 113 tank cars under Department of Transportation (DOT) Special Permit provisions (49 CFR 170.15) of the Hazardous Materials Regulations.[1] Class 113 cars feature an inner container for carrying the cryogenic commodity, supported within an outer shell. The annular space is filled with a porous insulation and evacuated.

Specifications for cryogenic car tanks may be found in AAR.60 and 61 (tentative) of the Association of American Railroads Specifications for Tank Cars[2] applicable for cryogenic fluids in the minus 100^{o}F to minus 423^{o}F temperature range and 49 CFR 179.400[1] for liquefied hydrogen only.

In 1973, the Compressed Gas Association (CGA) petitioned for changes in 49 CFR 179, Specifications for Tank Cars, to eliminate the need for DOT Special Permits on such cars. There have been a number of subsequent iterations involving proposed changes in car design (49 CFR 179 and AAR.60) and shipper regulations (49 CFR 173) for ethylene between DOT and the AAR Committee on Tank Cars (of which CGA is a member). The proposed changes furnished Calspan for review are reproduced as Appendix A.

1.2 Objective

The objective of this study was to:

- Review FRA furnished material on existing practices and experience in shipping liquid ethylene.
- Review FRA furnished material relating to existing design practices for 113 series cars in ethylene service.

- Formulate and investigate the effectiveness of proposed modifications to shipping regulations and tank car design specifications relating to the shipment of ethylene at cryogenic temperatures.

1.3 Scope

A limited scope effort of approximately 80 man-hours of professional labor were to be expended toward the above objectives. Primary effort was to be directed toward the holding time requirements necessary for safe shipment of the commodity.

II. GENERAL CONSIDERATIONS

2.1 Basic Safety Philosophy

It is fundamental and noncontroversial that the design of a tank car meet all normal operational conditions for a useful period of time. Additionally, provision should be made to account for design or material uncertainties, degradation during a useful life span, and to safely respond to any reasonable combination of extreme conditions which might exist during normal usage.

Consideration of extreme conditions must include an analysis of potential "threats" and their probability of occurrence. Concomitant with this analysis, the mode and consequences of failure should be studied to arrive at a design providing the desired level of protection.

The ultimate design goal from the safety standpoint is to provide a system which will survive, or fail in a safe manner regardless of the severity of the environment. This goal is seldom practical from an economic standpoint, even if it should be practical from a technical viewpoint. It can be difficult, therefore, to arrive at a consensus in selecting a level of protection. Inevitably some value judgements must be made, even though they cannot be quantified precisely, in arriving at reasonable safety criteria.

Although the safe shipment of any hazardous commodity requires involvement of the transport vehicle designer, shipper, carrier and receiver, shipment of hazardous cryogenic commodities presents special problems requiring a particularly cohesive plan involving all these elements.

A fundamental difference in cryogenic shipping of hazardous material from that of other hazardous tank car commodities, is that only a limited period of time exists for which transport may take place before a potentially unsafe condition is automatically created. A loaded cryogenic car, left to its own devices, is "a car with a guaranteed leak". This is so because the vapor pressure of the commodity exceeds the relief valve start to discharge setting at temperatures below expected outdoor ambient temperatures; indeed it may be higher than the design burst strength of the car. The driving potential (temperature difference) for heat transfer, and subsequent pressure rise, is always available from the atmosphere. Therefore, at some point in time the car will vent unless unloaded first. Venting of a hazardous commodity is not always dangerous, but it is potentially so -- and therefore should be avoided where possible.

2.2 Ethylene Properties

Ethylene: CH_2CH_2

Description: Colorless gas; sweet odor and taste.

Life Hazard: Medical anesthetic, moderate concentration in air causes unconsciousness.

Fire and Explosion Hazards: Flammable gas. Forms flammable mixtures with air over a wide range. Flammable limits, 3.1% to 32%. Ignition temperature, 842°F. Vapor density is approximately the same as air. Spontaneously explosive in sunlight with chlorine. Can react vigorously with oxidizing materials.[3]

It should be noted that the vapor density is nearly equivalent to air only if both are at the same temperature. Ethylene vapors venting from a cryogenic car are substantially heavier than surrounding air at moderate temperatures of e.g. 70°F, and will remain so throughout a significant equilibrating period. This fact, coupled with the wide flammable range makes such venting a potent hazard.

Figure 1 illustrates the vapor pressure-temperature relationship for ethylene, along with the car and relief system pressure specifications.

2.3 Existing Practice on Design and Shipping of Liquefied Ethylene

Cars designated for liquefied ethylene loading under AAR.62-2[2] are DOT Classes 113C120W and 113D120W cars. DOT Class 113A60W cars have been operated in ethylene service. There are significant differences in car structural design between builders, for example, in sill design and in inner container supports. The latter may involve proprietary designs for limiting heat transfer. Commonly, car capacities are of the order of 30,000 gallons (~127,000 pounds of ethylene). Given current regulations (49 CFR 179.13) on maximum rail loading weights of 263,000 pounds for new cars handling hazardous commodities, continuous underframe cars can be weight limited for construction with conventional materials. Stub sill designs may make the 34,500 gallon volume limitation. Perlite is the common insulation used. All builders depend on evacuation of the between-shell annulus, limiting heat transfer, to secure holding times permitting shipments to arrive at consignees without enroute loss of product. Existing special permits are not consistent in specifying acceptable pressure rises or holding times, the latter varying from not specified to 60 days, and there are no requirements for performance with loss of vacuum. AAR.60.4 insulation requirements are based on a thirty-day holding time. It is evident, however, that some car builders have designed conservatively well beyond the 30 day requirement.

Relief systems consist of a safety relief valve for primary relief and a secondary vent system (rupture disc) operating at a higher set point than the primary system. (See Table 1 for specifications.) An alternate standard was proposed by CGA to permit two relief valves.

Shipping data received from FRA covered shipments lasting from 5 to 31 days. Because the majority of the data came from one builder/shipper the average of approximately 11 days should be interpreted with great care in application to future needs for a general specification.

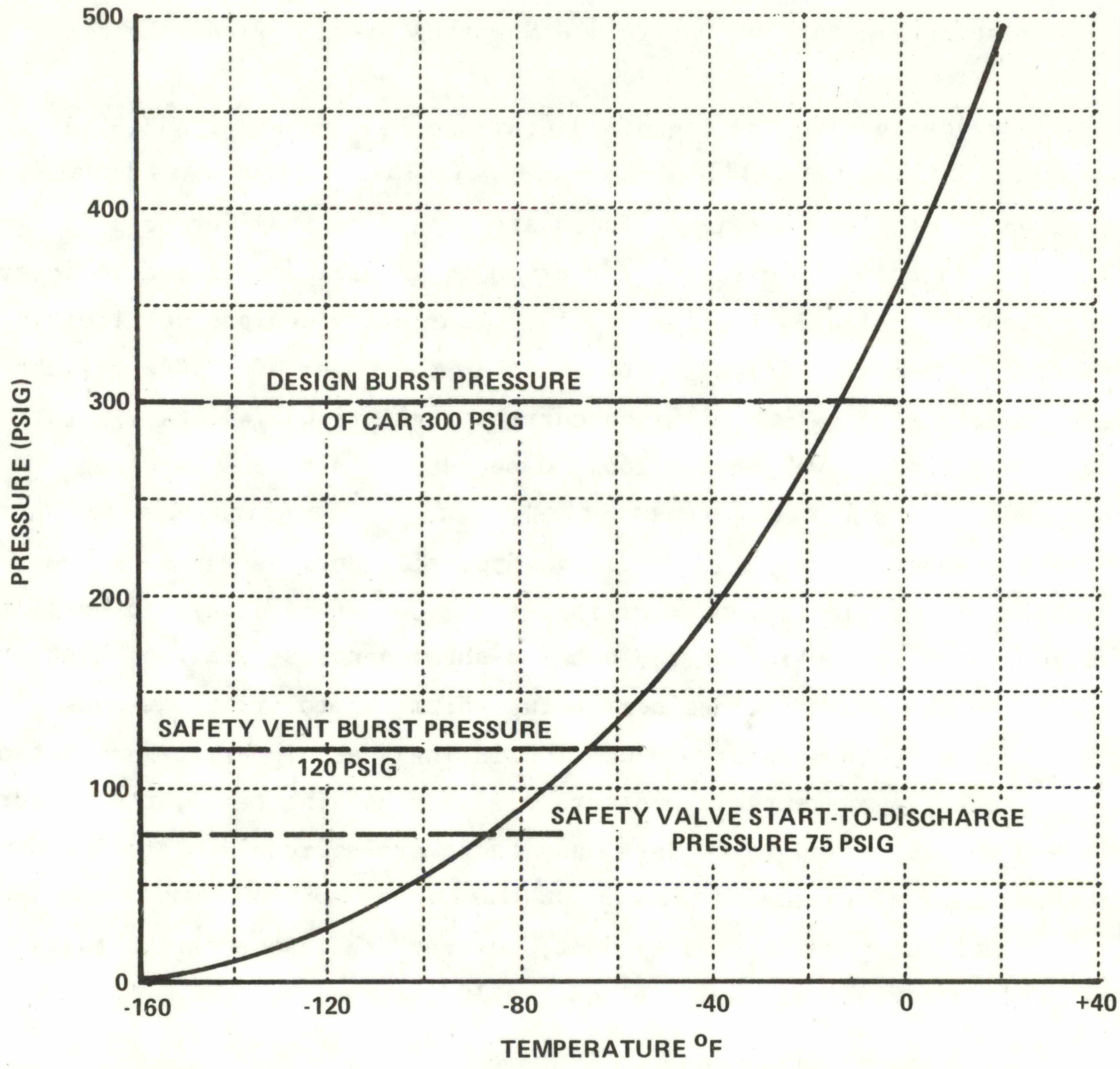

Figure 1 VAPOR PRESSURE VS TEMPERATURE RELATIONSHIP FOR ETHYLENE COMPARED WITH CLASS 113x120W CAR SPECIFICATIONS

Table 1 CLASS 113x120W TABULATED SPECIFICATIONS

AAR.61 INDIVIDUAL SPECIFICATION REQUIREMENTS APPLICABLE TO LOW TEMPERATURE TANK CAR TANKS.

AAR.61-1 INDIVIDUAL SPECIFICATION REQUIREMENTS. IN ADDITION TO AAR.60 THE INDIVIDUAL SPECIFICATION REQUIREMENTS FOR THE INNER CONTAINER AND ITS APPURTENANCES ARE AS FOLLOWS:

DOT SPECIFICATION	113C120W	113D120W
LADING TEMPERATURE (MINIMUM F)	-260	-155
MATERIAL (SEE AAR.60-7(a))	AAR.61-3	AAR.61-4
IMPACT TESTS (WELDS AND PLATE MATERIAL 1/)	NOT REQUIRED	REQUIRED
IMPACT TEST VALUES	NOT REQUIRED	AAR.61-4(a)(1)
MAXIMUM HEAT TRANSFER (BTU PER DAY PER LB OF WATER CAPACITY MAX.)(SEE AAR.60-4(a))	0.4121 2/	0.3641 3/
BURSTING PRESSURE PSI	300	300
MINIMUM PLATE THICKNESS INCHES SHELL (SEE AAR.60-6(a)) HEADS (SEE AAR.60-6(a),(b), AND (c))	 3/16 3/16	 3/16 3/16
TEST PRESSURE PSI (SEE AAR.60-22(a))	120	120
SAFETY VENT BURSTING PRESSURE (MAX. PSI)	120	120
VALVE START-TO-DISCHARGE PRESSURE PSI (±3 PSI)	75	75
VALVE VAPOR TIGHT PRESSURE (MINIMUM PSI)	60	60
VALVE FLOW RATING PRESSURE (MAXIMUM PSI)	85	85
PRESSURE CONTROL DEVICE START-TO-VENT (MAXIMUM PSI)	NOT REQUIRED	NOT REQUIRED
RELIEF DEVICE DISCHARGE RESTRICTIONS (SEE AAR.60-18)	AAR.61-2	AAR.61-2
TRANSFER LINE INSULATION (SEE AAR.60-16(a)(1)	NOT REQUIRED	NOT REQUIRED

1/ IMPACT TESTS FOR TEST PLATE WELDS AND PLATE MATERIAL USED FOR INNER CONTAINER AND APPURTENANCES SHALL BE IN ACCORDANCE WITH AAR SPECIFICATIONS FOR TANK CARS, APPENDIX W, W9.00.

2/ DETERMINED FOR LIQUID METHANE AT A MAXIMUM SHIPPING PRESSURE OF 10 PSIG AND A START-TO-DISCHARGE PRESSURE OF 75 PSIG.

3/ DETERMINED FOR LIQUID ETHYLENE AT A MAXIMUM SHIPPING PRESSURE OF 25 PSIG AND A START-TO-DISCHARGE PRESSURE OF 75 PSIG.

TAKEN FROM AAR SPECIFICATION FOR TANK CARS, 1 OCTOBER 1972

The shipping data suggest that substantial differences exist between cars and shippers in their ability to successfully ship ethylene without enroute failures. This is particularly true of 60W cars (i.e., cars with 60 psig test pressure) operating under special permit. The 60W cars are not considered further inasmuch as prime consideration was to be given to 120W cars in the study here reported.

2.4 Some General Criteria for Establishing Regulations for Cryogenic Ethylene Shipments

2.4.1 Designer Responsibility

2.4.1.1 Holding Time

The designer must design to prevent venting of product under all normal shipping conditions, and allowing for some degradation in the insulation of the car. The loss of vacuum is a predictable occurrence. Ideally, shipment should be able to be made without venting given complete loss of vacuum. This may be impractical, but there should be a specific design specification for both vacuum and non-vacuum conditions. The loss of vacuum heat transfer specification should as a mimimum be sufficient to prevent gross release of product.

2.4.1.2 Relief System Design

Relief system design must consider the effect of frost build-up on system performance. The relief system must be adequate to relieve safely the contents of a tipped or overturned car, with vacuum loss, and exposed to fire.

2.4.1.3 Structural Considerations

Considering the fact that loss of product can result in disaster, structural design must take into account high rate yard impacts and derailment from a puncture standpoint. Failure of draft gear cushioning must also be considered in basic car design.

2.4.2 Special Shipper Responsibility for Cryogenic Ethylene Cars

Given that it will be impossible to design cryogenic cars with infinite holding times, it follows that action must be taken by the shipper in advance of the known holding time capability of the car. Initial action would be to trace the car and secondary action, if delivery had not been effected would be to physically find the car and assure that conditions are within safe limits. The shipper should make available to carriers information for instructing them in correct procedures to follow if a car is found to be venting in transit.

2.4.3 Special Carrier Responsibility for Cryogenic Ethylene Shipments

Current regulations for expedited movement of hazardous materials (49 CFR 174.582) may need an addition restricting the allowable time for forwarding on branch line deliveries. Without relieving the shipper of responsibility for initiation of car tracing on delayed shipments, the carrier should be required to notify the shipper of delays in transit, for example if the car is bad-ordered. There is some evidence that stratification and other effects result in higher pressure rises per given heat input than would be expected for ethylene at saturated conditions. Hence, long-term standing of a loaded car is to be avoided.

The carrier should also notify the shipper of venting noted in transit and take precautions to properly isolate a venting car.

III. REVIEW OF PROPOSED REGULATIONS AND SPECIFICATIONS

3.1 Introduction

The strong interrelationship between the proposed shipper regulations and the proposed tank car specifications requires that they be considered together. Therefore, the individual specification items are not taken in serial order, and items of general agreement are not commented on.

3.2 Filling Density

Note 5 of the proposed shipper regulations requires that the car should not be liquid full at the start-to-discharge pressure of the car (75 psig). This is desirable to prevent a compressed liquid condition and possible premature venting. However, the proposed maximum filling density of 51.1 per cent is not consistent with Note 5. Given the specific volume relationships for ethylene stated in Reference 4, the car would be shell full at 51.1 per cent filling density at the start-to-discharge pressure.

As a practical matter, the specific volume of a commercial ethylene may deviate somewhat from the pure material -- but not necessarily in the desired direction. It would appear prudent to limit filling density to 50.8 per cent, a value which would provide approximately 0.5 per cent outage for pure ethylene at the start-to-discharge pressure.

3.3 Holding Time

3.3.1 Design and Initial Test

The proposed specification on design of the insulation system is based on establishing in practice holding times of 30 days with a design margin of 15 days, hence a 45 day design holding time*. Let us consider the adequacy and practicality of these holding times.

*The holding time is predicated on an atmospheric temperature of 90°F.

At the outset, it should be noted that neither the proposed design specification or stationary heat transfer test specify the vacuum requirement, an important omission which will be discussed further.

On a nationwide basis, the average freight car daily mileage has been about 55 miles per day[5]. No distribution giving extremes of low or high mileage are given. The maximum single trip in the continental U. S. likely to be taken is approximately 3,500 miles. On this basis, approximately 64 days would be required on the average to reach a destination 3,500 miles away.

The average freight car mileage is biased, however because out of service cars are included in the figure. As a result, the mileage is lower than might be expected for in-service cars. Trip time data furnished Calspan for ethylene cars did not include mileage data, making it difficult to establish meaningful daily mileage figures from that source. A reasonable estimate is that the 11 day average trip figure was probably accumulated on an average route mileage not exceeding 1,200 miles. This is based on typical origins in the Texas, Louisiana Gulf area with destinations in Great Lakes or Northeastern industrial areas, for example Houston to Chicago. This would indicate average daily mileages in the 100 mile per day category.

We believe the 100 mile per day figure to be more representative of actual and expected future practice than the consolidated U. S. fleet statistics. On this basis, then a 45 day design holding time would be adequate for shipment between any two continental U. S. shipping points with a cushion for longer than average transit times. A thirty day holding time would not cover all plausible transit times; in fact, it was equalled and exceeded in actual trip data furnished FRA. However, the combined probability of a transit time exceeding thirty days and the average atmospheric temperature equalling 90°F is small. Therefore, thirty days could be considered a reasonable lower bound or cut-off point for acceptable car performance.

It may be expected that most car builders would meet the required heat transfer limitations by using a high vacuum in the inner to outer shell annulus, although the proposed specification is mute on this point. Maintenance of high vacuum conditions in a large vessel in the railroad environment is a difficult task. Trip data for 111 shipments with 7 to 19 day transit times for one group of 113 series cars indicated vacuum failures occurred 6 times, a better than 5% rate. It would be highly desirable to meet a 30 day holding time requirement at atmospheric pressure. It is doubtful, however, that any existing equipment could meet such a requirement, and within the scope of this contract, we cannot make a determination of its immediate practicality for new construction.

We can suggest an interim measure within the known state-of-the-art that would further define the proposed holding time requirement to secure consistent design, and test conditions as follows:

- The proposed heat transfer rate requirements shall be met with pressure no less than 100 microns in the vacuum annulus.
- The minimum acceptable holding time with loss of vacuum shall not be less than 10 days.
- Tests will be conducted with car initially filled to maximum permissible filling density (this is to achieve consistent heating areas).

Holding time for a given shipping pressure and safety-relief setting is strongly affected by vacuum level. It is therefore necessary to specify the absolute pressure basis for design and test if satisfactory performance is to be realized in the field. A better than ten day no vacuum holding time is claimed by one builder now; hence, it must be considered a practical value. This limitation provides a minimum performance standard that would permit most shipments to reach their destinations without gross release of contents in the event of vacuum failure. It should be noted that the holding time values are not unrelated. A design meeting the requirement of 45 days holding time at 100 microns would be consistent with a thirty day capability at 250 microns and ten days with complete loss of vacuum within the parameters of current design.

3.3.2 Shipper Responsibility for In-Transit Cars

In Section 2.4.2, we discussed general criteria for follow-up action by shippers. Note 8 of the proposed regulations calling for notification of the AAR Bureau of Explosives whenever the car is not received by the consignee within 20 days after shipment would appear to fall short of desired action consistent with proposed holding time capability of the car. It is suggested that car location trace be initiated ten days after shipment (earliest time venting may be expected with vacuum failure) and transit progress monitored until the 20th day. In addition to notification of the B of E on the 20th day, shipper should take action at that time to physically locate and verify car condition.

3.3.3 In-Transit Pressure Rise Requirements

It is highly desirable to have a mechanism for detecting cars in-service whose insulative capabilities have fallen below acceptable limits. The proposed new paragraph to 49 CFR 173.31(b)(5) calling for average pressure rise per day checks on each shipment, and a follow-up static check of suspect cars, addresses precisely this point. In addition to the desirability of having such a regulation, we would agree that it is highly desirable to have as simple a specification as possible which will provide adequate protection. Because of the physical conditions and thermodynamic properties involved, the proposed simplified pressure rise specification appears inadequate for determining the acceptability of cryogenic cars.

The proposed specification uses a straight line 2.5 psig/day average pressure rise over the period of transit at the accept or reject criterion. The actual pressure versus time behavior of the car will be significantly non-linear. Initial pressure rise with time will be high due to heat inputs from a "warm" car, and due to the high temperature difference (driving force) between the atmosphere and the lading. With the passage of time, the temperature difference, hence heat transfer, reduces and so does the rate of pressure rise. There is a counter-force in that pressure increases exponentially with increase in internal energy, which will cause a reversal of the pressure rise trend. However, the safety-relief valve setting constitutes the upper limit to pressure rise inasmuch as above that pressure the valve will discharge thus maintaining tank pressure between the limits of 60 to 75 psig. It follows that the maximum average pressure rise possible on a shipment in a 113D120W car shipped at 20 psig is only (1) $\frac{(75\text{-}20 \text{ psig})}{30 \text{ days}}$ = 1.83 psig/day for a transit time of 30 days, the specified acceptable minimum holding time. Detection cut-off for the 2.5 psig criterion is

(2) $\frac{(75\text{-}20)\text{psig}}{2.5 \text{ psig/day}}$ = 22 days for 113D120W cars at maximum shipping pressure

(3) $\frac{(75\text{-}10)\text{psig}}{2.5 \text{ psig/day}}$ = 26 days for 113C120W cars at maximum shipping pressure

Thus, for any trip exceeding 22 days, all 113D cars would pass regardless of product loss or true condition. Hence, for long duration trips where most concern is required, the criterion fails. Conversely, a shipper whose transit times are very short may repeatedly fail the test with a "good" car. Thus, the 2.5 psig/day criterion is leveraged the wrong way. The application of a 1.8 psig/day criterion for 113D cars, and a 2.1 psig/day criterion for 113C cars would eliminate the acceptance of "bad" cars, i.e., cars that would vent before 30 days given the 90^{o}F ambient temperature condition. However, this would tend to accentuate the rejection of good cars involved with short trips. The effect is illustrated in Figure 2.

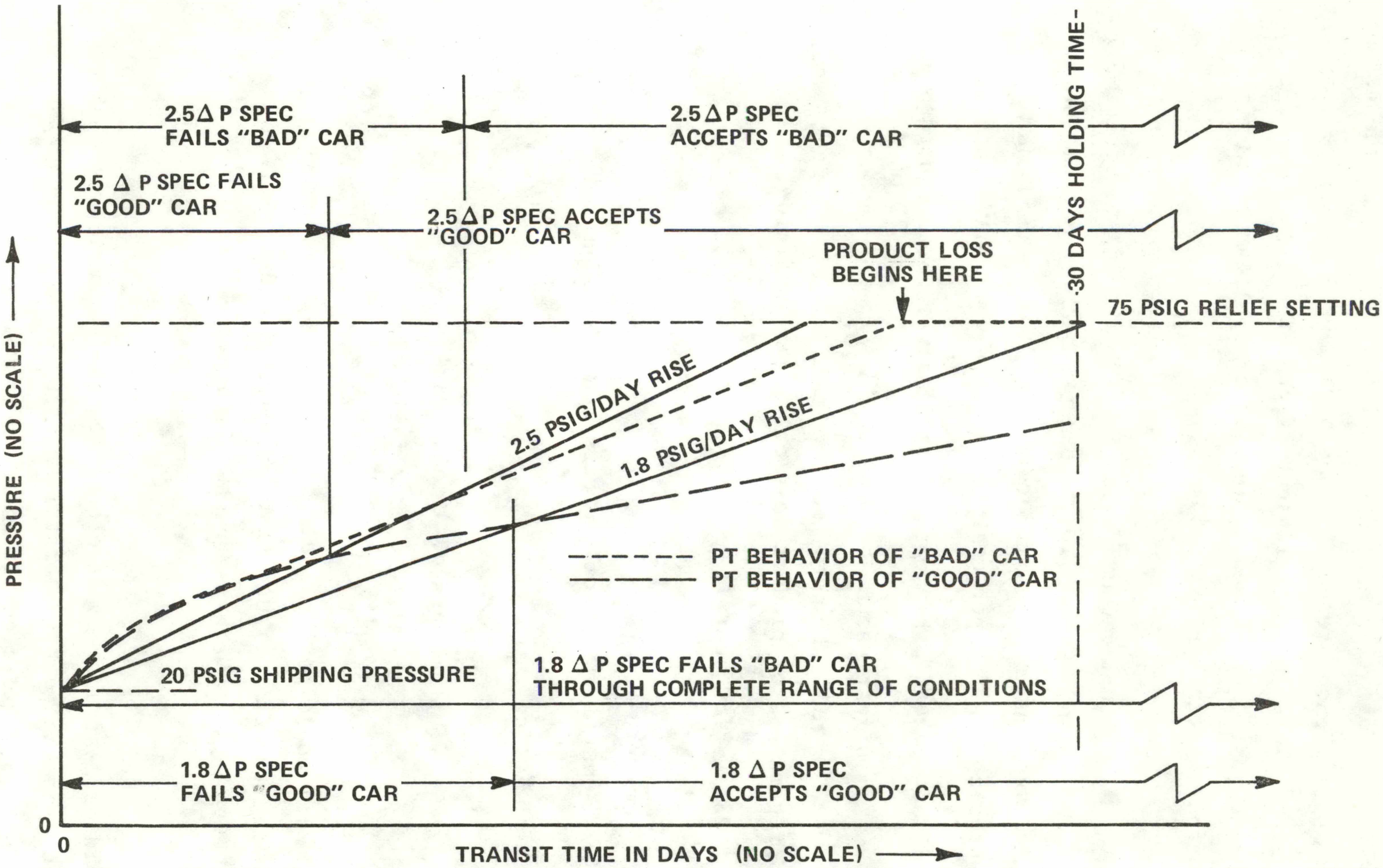

Figure 2 DISCRIMINATING POWER OF FIXED AVERAGE PRESSURE RISE PER DAY SPECIFICATION TO ESTABLISH ADEQUATE HOLDING TIME – 113 SERIES CARS

Another problem for a 2.5 psig/day specification is that the actual thermal conditions usually encountered in transit will be less severe than that of the basis of design. This built-in leniency factor tends to further reduce the sensitivity of the test. Consider the results of application to actual shipping data from four special permit holders:

Permit #4717 111 Total Shipments 7 to 19 days, avg. under 11 days

6 lost vacuum (hence, "bad" cars if transit time long)

1 of 6 above lost product ("bad" by definition)

2.5 psi/day criterion would have detected 3 cars that lost vacuum, including the one that lost product. Fifty per cent of bad cars would have passed.

Permit #5736 6 total shipments 8 to 31 days; three exceeded 22 days

0 lost vacuum or product

2.5 psi/day criterion accepted all; note, however that 50% of shipments would have been accepted regardless of product loss or vacuum condition.

Permit #6231 (60W cars)

45 shipments of 7 - 25 days

27 lost product

4 would have failed 2.5 psi/day; 85% of bad cars would have passed.

Permit #6392

25 shipments of 4 to 12 days

1 identified vacuum failure

None lost product.

The 1 certain "bad" car would have passed the 2.5 psi/day requirement; 12 cars would have failed the 2.5 psi/day test, of which 4 had identifiable problems that would reasonably be expected to allow product loss with a 30-day shipment.

It would be desirable to develop accept/reject criteria that would more closely follow the inherent temperature-pressure-time characteristics of ethylene. As an interim measure an alternate in-transit pressure rise specification is proposed in Figure 3.

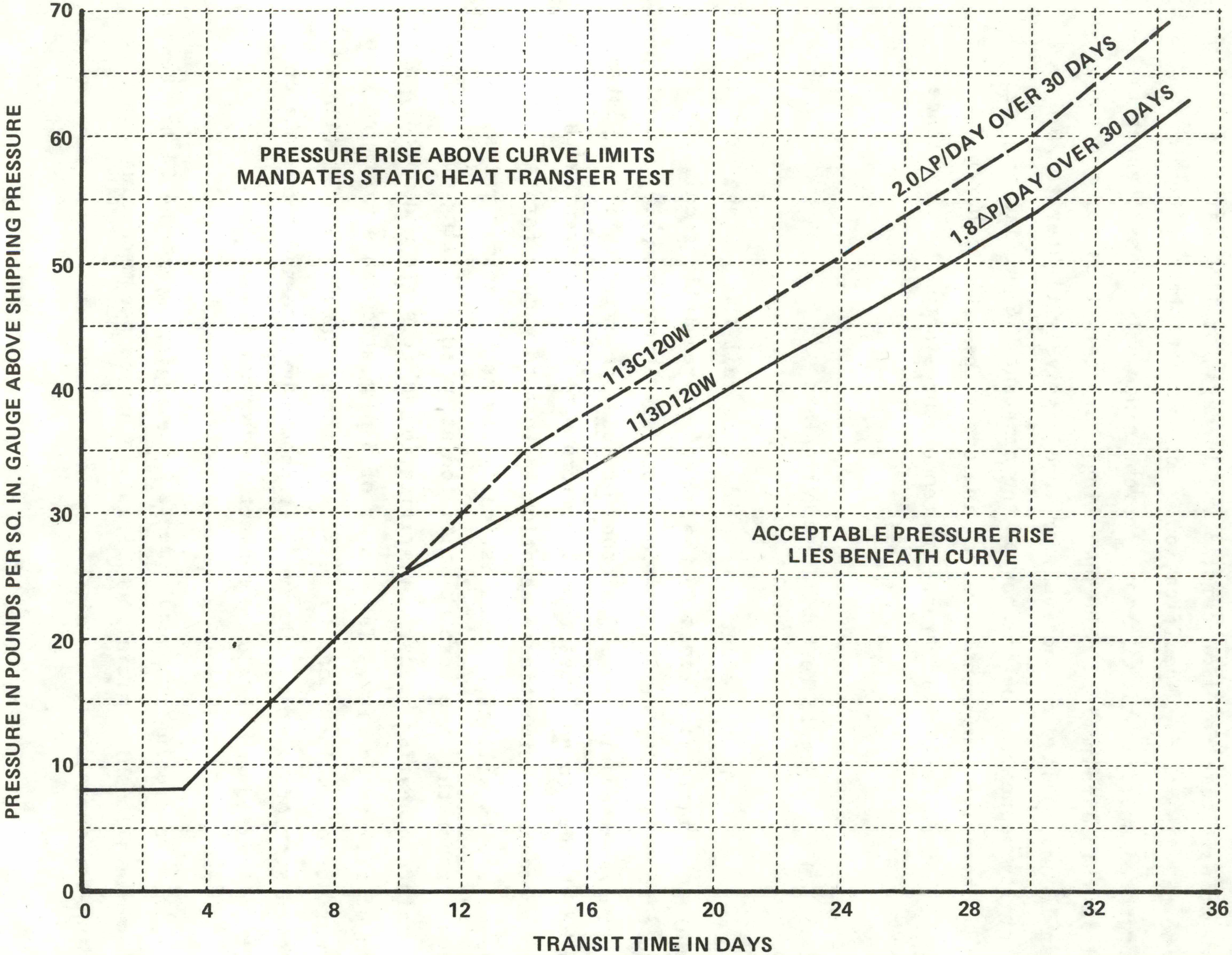

Figure 3 CONCEPTUAL IN-TRANSIT PRESSURE RISE SPECIFICATION

The conceptual specification operating characteristic between 3 and 10 days transit time for 113D cars, 3 and 14 days for 113C cars, is identical to the 2.5 psi/day specification. For transit times 3 days or less the proposed specification is more lenient since only gross changes are meaningful in this data region. The operating characteristics for the two curves past 10 and 14 days respectively are progressively tighter to 30 days to substantially reduce the deficiency of the constant 2.5 psi/day proposal in detecting defective equipment involved in long trips. The inherent deficiency of not correcting for range of temperatures actually experienced remains.

3.3.4 Static Test of In-Service Cars

In the event in-service cars fail the average pressure rise per day in-transit requirements, the proposed regulations call for a static pressure rise test, or evaporation test (see Appendix A). Current language permits evacuation to 100 microns or less; however, it is suggested that this be changed to not less than 100 microns to be consistent with design requirements. Permitting evacuation in test to vacuum far below in-service requirements will give unrealistically low heat transfer rates. It is recommended further that the test be initiated at maximum filling density to achieve consistent heating areas. Stratification effects are undoubtedly also a function of filling density. The choice of 5 psig acceptable pressure rise in a 24 hour period would appear to reasonably accommodate stratification effects for a stationary test. However, it should be stressed that data on the effect is limited and should be subject to further study.

In interpreting the requirements, the beginning of the 24 hr. test period would follow an allowable initial equilibrating period accommodating car cool down and top-off-operations.

IV. ADDITIONAL COMMENT ON AAR GENERAL SPECIFICATIONS FOR TANK CARS

It is presumed that additional portions of AAR60 and Appendix A of the AAR Specifications for Tank Cars not shown in the proposed tank car specifications appended to this report, will in fact be incorporated, perhaps by reference, in the proposed Federal Regulations.

Attention is drawn to AAR.60-4 (c), Insulation, the referenced paragraph requiring insulation to be self-extinguishing as defined in ASTM D1692. This requirement gives the erroneous impression that control of the fire-resistive properties of candidate insulation is established. The particular test referenced, however, is unsuitable for establishing the fire-resistive properties of materials such as foam plastics or elastomers such as urethanes, materials which might be considered for some applications.[6]

Another point of interest is the inner container support system strength requirements for meeting longitudinal accelerations from impact (AAR.60-12). The specification requires capability to withstand 7G accelerations with conventional draft gear. AAR Specification M-901 requires that conventional draft gear must withstand 1,000,000 lbs impact, or approximately 3.7 G's with a loaded ethylene car. Thus the 7G specification would appear to be adequate. However, longitudinal acceleration capability may be reduced to 3G where a chshioning device with an ability to limit body forces to 400,000 lbs maximum at 10 mph is used. AAR Specification M921 rates cushioning devices in miles per hour at which 500,000 lbs coupler force is reached. Given a typical end-of-car cushioning device, this would be about an 11 mph cushion to meet AAR.60-12. Tests require sill loading capabilities to 1,250,000 lbs -- or nearly 4.7G's for a loaded ethylene car.

It would appear inappropriate to require a less stringent requirement for inner container supports. Moreover, cushioning devices degrade and fail. Visual detection of failure is often difficult, particularly if the device uses spring return to neutral position. Therefore, it would seem unjustifiable to relax requirements for a cushion car to less than those of a conventional draft car, with the exception that yield in the supports would be permitted as long as there was no uncontrolled product loss.

References 7 and 8 point out several inadequacies in relief system requirements that are appropriate to 113 series cars. AAR.60-18 covers the specifications for these cars. Formula A8:06a is identical to equation 10, page 44 of Reference 7, with the exception that capacity required is halved on the apparent presumption that the thermal conduction through the fittings, etc. will be negligible compared to conventional insulated car construction. The severe inadequacies pointed out in Reference 7 for this formula remain valid. It has been pointed out in Reference 8 that safety-relief valves actually used in insulated car service usually have capacities far greater than the specification requires. However, leaving the specification "as is" invites trouble.

The use of a secondary safety vent is a highly desirable feature.[9] The specification for the safety (AAR,60-18(1)) fails to define the flow requirements in a meaningful manner. Also, quality control provisions for design factors such as fatigue resistance, or installation factors such as bolt torque, important for rupture discs, are not considered.

V. KEY CONCLUSIONS AND RECOMMENDATIONS

A holding time for cryogenic ethylene cars of 30 days appears to be a reasonable lower bound for acceptable in-service performance. A design margin with respect to acceptable heat-transfer to the lading in-service is a necessity. The proposed specification, which in effect provides a design holding time of 45 days, is reasonable and practical within the current state of the art.

There is a need for fixing vacuum requirements in the design and test performance specifications.

The need for in-service check and test requirements for monitoring the insulative qualities of cars is addressed in the specifications as proposed. The proposed in-transit pressure rise specification posed to meet this need, however, has substantial deficiencies.

The existing AAR.60-18 safety relief provisions for ethylene cars share some of the serious deficiencies which have been previously noted for other cars transporting liquified gases.

In the near-term it is recommended that:

- Safety relief flow requirements for liquid and gaseous ethylene be established for cars exposed to derailment and fire conditions.
- A study of the pressure-time-temperature behavior of cryogenic fluids shipped by rail, including ethylene, be conducted to establish a basis for meaningful pressure rise in-transit specifications and car test requirements.

In the longer term, and divorced from the current specifications under consideration, a design and economic trade-off study be conducted for hazardous cryogenic liquid cars which could provide holding times of at least 30 days without an evacuated insulation.

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9. Letter, F. Vassallo, Calspan Corporation, to Donald Levine, Federal Railroad Administration, 9 January 1974.

APPENDIX A

PROPOSED SHIPPER REGULATIONS ETHYLENE TANK CARS

(1) DOT-113C 60W tank cars should not be included in regulations.

(2) Amend 173.317 Table as follows:

	Filling Density Percent: Note 5		Max. Shipping Pressure: Note 1	Max. Abs. Pressure in Annular Space: Note 2	Required Tank Car: Notes 3 4, 5, 6, 7
	Max.	Min.	(psig)	(Microns Hg)	
Ethylene, Liquefied	51.1	45.9	10	250	DOT 113C 120
			20	250	DOT 113D 120

Note 1: The maximum shipping pressure is that pressure which must not be exceeded when car is offered for transportation.

Note 2: The maximum abs. pressure in annular space is that pressure which must not be exceeded when car is offered for transportation.

Note 3: The loading temperature must not be colder than the minimum temperature stenciled on the jacket.

Note 4: Special commodity stencil is required.

Note 5: The liquid portion of the cold compressed gas must not completely fill the tank at a temperature that will result in a pressure equal to the start-to-discharge pressure of the safety relief valve. For definition of filling density see 173.314. (c) Note 1.

Note 6: Prior to return of empty cars, liquid must be drained from cars and pressure must be reduced to less than 10 psig.

Note 7: For special commodity requirements, see 179. XXX-X (Note: These should be same as AAR.62-2).

Note 8: The shipper shall notify the Bureau of Explosives whenever the car is not received by the consignee within 20 days after shipment.

(3) Add new paragraph as follows:
173.31 (b) (5) Special requirements for DOT-113C 120W and DOT-113D 120W tank cars in ethylene, liquefied service.

(a) The average pressure rise per day must be determined for each shipment. If the average pressure rise exceeds 2.5 psi per day, a static pressure rise test or an evaporation rate test shall be made to determine if the car can be continued in service. The static pressure rise test shall consist of reducing the absolute pressure in the annular space to 100 microns or less on the loaded car, holding the car for 24 hours, and determining the product pressure rise. If the increase in product pressure does not exceed 5 psig and the increase in absolute pressure in the annular space does not exceed 25 microns, the car can be returned to service. The evaporation rate test, as outlined in part 179, may be used in lieu of the static pressure rise test. The acceptable evaporation rate shall not exceed 120% of the specification to which the car was built. If the increase in product pressure, the absolute pressure in the annular space, or the evaporation rate exceeds the above figures, the car must be removed from service, the cause determined, corrective action taken, and the car retested.

(b) The shipper must retain for a period of two years records used in determining the average daily pressure rise for each shipment, the data used in determining and evaluating any tests made per (a), and the tank repair history of each car while in his service.

(4) Appropriate additions to 173.31 (c), Retest Table 1, should be made to cover the relief devices on the tank for the DOT 113C 120W and DOT 113D 120W tank cars. Product safety relief valves should be retested every two years (see footnote (a) covering chlorine cars).

PROPOSED ETHYLENE TANK CAR SPECIFICATION

The following recommended changes have been approved by the ad hoc committee on ethylene:

AAR 60-4

(a) The design of the insulation system shall be such that the total heat transfer from the atmosphere at 90°F to the lading at the average temperature between the maximum temperature at the time of shipment and the temperature at the safety valve start to discharge pressure does not exceed 2/3 of the value given in Table 61-1*. The insulation requirements are based on a 30-day holding time. The total heat transfer shall include the heat transfered through the insulation, support system, and the piping.

* For car built prior to January 1, 1973 use 1.0 instead of 2/3.

(e) Each tank car shall be tested while stationary to demonstrate that its heat transfer rate meets the requirements of Paragraphs AAR 60-4(a) and AAR 61-1. The test shall be conducted by measuring the normal evaporation rate of the cryogenic test fluid (preferably the lading, where feasible) maintained at approximately one atmosphere. The test period shall be sufficient to permit the normal evaporation rate to stabilize. The measured heat transfer rate shall not exceed 75% of the value listed in Table AAR 61-1,* and shall be calculated from:

* For cars built prior to January 1, 1973 use 100% instead of 75%.

AAR.60-4(d) Revise paragraph to read - "If the insulation consists of a powder having a tendency to settle, the entire top of the cylindrical portion of the inner container shall be insulated with a layer of glass fiber insulation of at least one-inch nominal thickness or equivalent, suitably held in position, and covering an area extending 25° to each side of the top center line of the inner tank."

AAR.60-17(b)(3) Vapor Phase Pressure Gage. A vapor phase pressure gage of approved design must be provided to indicate the vapor pressure within the inner container. The gage must be mounted so as to be readily visible to an operator. An additional fitting for application of a test gage must be provided, together with a manually operated shut-off valve located as close as possible to the outer shell and within a suitable housing.

Table 61-1 Revise per the attachment.

AAR.61 INDIVIDUAL SPECIFICATION REQUIREMENTS APPLICABLE TO LOW TEMPERATURE TANK CAR TANKS.

AAR.61-1 INDIVIDUAL SPECIFICATION REQUIREMENTS.
"A" (SIC: DELETE) IN ADDITION TO AAR.60 THE INDIVIDUAL SPECIFICATION REQUIREMENTS FOR THE INNER CONTAINER AND ITS APPURTENANCES ARE AS FOLLOWS:

DOT SPECIFICATION	113A60W[7/]	113A175W[7/]	113C120W	113D120W
LADING TEMPERATURE (MINIMUM F)	-423	-423	-260	-155
MATERIAL (SEE AAR.60-7(a))	AAR.61-3	AAR.61-3	AAR.61-3	AAR.61-4
IMPACT TESTS (WELDS AND PLATE MATERIAL[1/])	REQUIRED	REQUIRED	NOT REQUIRED	REQUIRED
IMPACT TEST VALUES	AAR.61-3(a)(1)	AAR.61-3(a)(1)	NOT REQUIRED	AAR.61-4(a)(1)
MAXIMUM HEAT TRANSFER (BTU PER DAY PER LB OF WATER CAPACITY MAX.) (SEE AAR.60-4(a))	AAR.62-1(a)	AAR.62-1(a)	0.4121[2/(SIC: 3)] 0.5100[6/]	0.3950[5/]
MINIMUM PLATE THICKNESS INCHES				
SHELL (SEE AAR.60-6(a))	3/16	5/16	3/16	3/16
HEADS (SEE AAR.60-6(a), (b), AND (c))	3/16	5/16	3/16	3/16
TEST PRESSURE PSI (SEE AAR.60-22(a))	60	175	120	120
SAFETY VENT BURSTING PRESSURE (MAX. PSI)	60	175	120	120
VALVE START-TO-DISCHARGE PRESSURE PSI (±3 PSI)	30	115	75	75
VALVE VAPOR TIGHT PRESSURE (MINIMUM PSI)	24	95	60	60
VALVE FLOW RATING PRESSURE (MAXIMUM PSI)	40	125	85	85
PRESSURE CONTROL DEVICE START-TO-VENT (MAXIMUM PSI)	17 AAR.62-1(b)	17 AAR.62-1(b)	NOT REQUIRED	NOT REQUIRED
RELIEF DEVICE DISCHARGE RESTRICTIONS (SEE AAR.60-18)	AAR.61-2	AAR.61-2	AAR.61-2	AAR.61-2
TRANSFER LINE INSULATION (SEE AAR.60-16(a)(1))	AAR.61-5	AAR.61-5	NOT REQUIRED	NOT REQUIRED

1/ IMPACT TESTS FOR TEST PLATE WELDS AND PLATE MATERIAL USED FOR INNER CONTAINER AND APPURTENANCES SHALL BE IN ACCORDANCE WITH AAR SPECIFICATIONS FOR TANK CARS, APPENDIX W.W9.00.

3/ DETERMINED FOR LIQUID METHANE AT A MAXIMUM SHIPPING PRESSURE OF 10 psig AND A START-TO-DISCHARGE PRESSURE OF 75 psig.

5/ DETERMINED FOR LIQUID ETHYLENE AT A MAXIMUM SHIPPING PRESSURE OF 20 psig AND A START-TO-DISCHARGE PRESSURE OF 75 psig.

6/ DETERMINED FOR LIQUID ETHYLENE AT A MAXIMUM SHIPPING PRESSURE OF 10 psig AND A START-TO-DISCHARGE PRESSURE OF 75 psig.

7/ FOR DOT 113A60W AND DOT 113A175W SEE DOT 179.401.

Review of Proposed Specifications Relating to the Shipment of Ethylene in Tank Cars at Cryogenic Temperatures, 1974, US DOT, FRA, FA Vassalo, DE Adams, WA Bullerdiek, 14-HazMat