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Aluminum Tank Car Puncture Resistance Evaluation

Office of Research and Development
Washington, DC 20590

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Experimental studies to maintain the safety of transporting hazardous material by rail have been extended to evaluate the effectiveness of steel head shields for the protection of the contents of DOT Type 111 aluminum tank cars. These studies comprised a series of full- and 1/5-scale model tests based on prior tests conducted on DOT Type 105A500W (chlorine) tank cars and DOT Type 112J340W tank cars. Design parameters were varied to establish the sensitivity of puncture resistance to head and tank head shield thicknesses, internal pressure, and temperature.

The test to demonstrate puncture resistance, specified in Title 49, Part 179, section 179.105-5 of the Code of Federal Regulations, requires a threshold speed of 18 mph. The tests conducted in this study were intended to demonstrate the puncture resistance of various head configurations of a standard DOT Type 111 aluminum tank car, the puncture resistance of DOT Type 112/114 (propane) tank cars and DOT Type 105 (chlorine) tank cars and to investigate the relationship between the 1/5- and full-scale impact models.

The results of the full-scale tests showed that bare aluminum heads had very low resistance to puncture and that heads protected by a 1/2-inch thick steel head shield had a puncture resistance of 16.5 mph. The 1/5-scale tests with steel chlorine and propane tank car heads demonstrated a much greater resistance to puncture than the aluminum tank car heads. The 1/5-scale tests showed that puncture resistance is strongly influenced by shield thickness and internal tank pressure which is affected by the temperature of the gas within the tank car.

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PREFACE

The tests discussed in this report were sponsored by the Federal Railroad Administration's Office of Research and Development. The authors wish to thank Claire Orth and Jose Pena of that Office for their direction and guidance during the preparation of the report. Tests were conducted by the Association of American Railroads acting as operations and maintenance contractor for the U.S. Department of Transportation Test Center. Thanks are due to the personnel of the Association of American Railroads at the Transportation Test Center for their consultation throughout the planning, testing and analysis process.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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EXECUTIVE SUMMARY

In a continuing effort to maintain safety in transporting hazardous materials by rail, the Federal Railroad Administration is conducting programs to investigate the vulnerability of tank cars to puncture and fire, and to evaluate the effectiveness of head shields to protect their contents. Part of that effort includes an evaluation of DOT Type 111 aluminum tank car heads, with and without head shields, and DOT Type 112/114 and DOT Type 105 steel tank car heads subjected to specific ambient temperature (-20°F and +32°F) conditions. This report describes a series of (1/5) scale and full-scale model tests conducted from March 1989 to March 1990 at the Transportation Test Center near Pueblo, Colorado.

One-fifth scale model tank car head configurations were tested in a laboratory drop test fixture. Design parameters were varied to establish the sensitivity of puncture resistance to tank head and head shield thickness, internal pressure, and temperature. Full-scale tank heads were tested employing a pressurized tank fixture mounted on a railroad flatcar. These tests were intended to establish the puncture resistance of the various tank car head configurations and to investigate the relationship between the 1/5-scale and full-scale impact models.

Federal regulations require a demonstrated puncture resistance or head shield protection for high-volume tank cars carrying flammable liquids and gases at car impact speeds of 18 mph. The test to demonstrate puncture resistance is specified in 49 CFR 179.105-5 of the Code of Federal Regulations. The tests conducted in this study were intended to determine the puncture resistance of a standard DOT Type 111 aluminum tank car, and the puncture resistance of DOT Type 112/114 (propane) tank cars (covered by the specification) and DOT Type 105 (chlorine) tank car head designs at specific cold temperatures. Baseline tests of the propane and chlorine tank car heads were conducted according to the specification at a pressure of 100 psi. DOT Type 111 aluminum heads are used in nonpressurized tank cars and were tested at a typical operating pressure of 4 psi.

In full-scale model tests a 5/8-inch thick aluminum head without the protection of a steel shield showed an estimated puncture resistance of 4 mph. With a 1/2-inch steel head shield the estimated value of the puncture resistance increased to 16.5 mph. For a 5/8-inch head shield the puncture resistance increased to 17.5 mph. It may be desirable to confirm this result by repeating the test, since some of the energy at impact may have been dissipated in the coupler and draft gear with the result that the energy delivered by the impacting ram to the tank head may have been reduced.

Results of the 1/5-scale tests show that increasing shield thickness and decreasing internal tank pressure are most effective in increasing puncture resistance. Lower temperatures decrease the vapor pressure of both chlorine and propane and were expected to increase puncture resistance significantly. The low temperatures used in these tests were not low enough to change the mechanical properties (ductility, yield strength, ultimate tensile strength) of the aluminum or the steel specimens and hence did not have a significant effect on the puncture resistance. Tests demonstrated that DOT Type 112/114 and DOT Type 105 steel tank car heads had a much greater resistance to puncture than DOT Type 111 aluminum tank car heads. Tests of the aluminum heads, increased in thickness by 50% from 5/8-inch to 15/16-inch, showed a minor increase in puncture resistance of about 1 mph.

1 BACKGROUND

In 1976, full-scale tests were conducted at the Federal Railrod Administration (FRA) Transportation Test Center (TTC) near Pueblo, Colorado to investigate the mechanism of coupler override. This mechanism was believed to be the cause of several accidents that occurred during train makeup operations in switch yards [1]. These tests demonstrated that under certain circumstances the coupler on an adjacent car could override a tank car's coupler and impact the tank head with sufficient force to cause puncture. The tests investigated the use of shelf couplers to reduce the potential for override and of 1/2-inch thick steel head shields to blunt the impacting coupler. The results of these tests and other investigations were used to establish ~~minimal~~ minimum safety standards requiring that DOT Type 112/114 tank cars designed to carry certain flammable liquids and gases be equipped with shelf couplers and head protection sufficient to withstand an 18 mph impact.

As a result of incidents involving chlorine tank cars and general concern over the commodity, the FRA considered requiring that these cars also demonstrate an ability to withstand impacts as described in the Code of Federal Regulations (CFR). To provide background data for these considerations, a series of tests were conducted comparing the puncture resistance of DOT 112J340W tank cars which carry liquefied propane gas and DOT 105A500W tank cars which carry chlorine [2].

The test specified in 49CFR 179.105-5 to demonstrate puncture resistance calls for a 263,000 pound impact car to strike a reaction car at 21 or 31 inches above the sill along the centerline of the tank head. The reaction car is required to be filled to a 6% outage with water and backed up by three cars with a total weight of 483,000 pounds. If the tank car withstands an impact of 18 mph without leaking for 1 hour, the car passes the specification.

The propane tank car equipped with a head shield is known to pass the test for puncture resistance. The design parameters of the chlorine tank car are similar enough to indicate that protection of its tank head would be sufficient to pass the specification. The propane tank car has a volumetric capacity of 33,000 gallons and an inside diameter of 120 inches with a wall thickness of 11/16-inch, and is covered externally with a 1/2-inch insulating coating to protect its contents from heating if the vehicle is involved in a fire accident. A 1/2-inch thick steel head shield placed in front of the tank head acts as a means of protection in the event of accidental impact. The load capacity of the chlorine tank car is limited to 90 tons, restricting its volumetric contents to 17,390 gallons. Its inside diameter is 102 inches and its wall thickness is 13/16-inch. The outside of the tank is covered with 4 inches of urethane foam to prevent the commodity from heating and building up excessive internal pressure. Jacketing with 11 gauge steel covers and protects the foam. Since the chlorine car has a thicker tank head, the puncture resistance threshold was expected to meet or exceed the required value of 18 mph. Actual tests of chlorine tank cars at impact velocities up to 17.5 mph did not produce puncture.

Through concern for the safety of hazardous materials transported by rail, the investigation was extended to the vulnerability of aluminum tank cars to puncture. Tests similar to those conducted for the chlorine tank car were performed to evaluate the effectiveness of head shields to protect DOT Type 111 nonpressurized aluminum tank cars from puncture. Some comparative tests were performed with the propane and chlorine tank cars in specific ambient temperature (-20 °F and +32 °F) conditions. To comply with the intent of the test, the aluminum heads were tested at a typical operating pressure of 4 psi.

Table 1.1 summarizes the characteristics of the car designs and distinguishes between the pressure and nonpressure designs as a function of their internal tank pressure.

TABLE 1.1 TANK CAR PARAMETERS

Parameter	PROPANE	CHLORINE	ALUMINUM
Tank Head Thickness	11/16 in	13/16 in	5/8 in
Capacity	33,000 gal	17,390 gal	Various
Inside Diameter	120 in	102 in	102 in
Insulation Thickness	1/2 in	4 in	4 in
Head Shield or Jacket Thickness	1/2 in	1/8 in	1/8 in
Internal Pressure	100 psi	100 psi	4 psi
Vehicle Weight (Loaded)	263,000 lb	263,000 lb	263,000 lb
Lading Density (@ 85 ° F)	44 lb/ft.^{3}	85 lb/ft.^{3}	Varies
Tank Car Specification	112/114 J340W	105A500W	111A100ALW1

2 OBJECTIVES

The tests described in this report deal with the safety of tank cars that carry hazardous material. The objective of the tests is to evaluate the puncture resistance of DOT Type 111 aluminum tank cars carrying hazardous materials, in absolute terms and in comparison with the DOT 112J340W tank cars which carry liquified propane gas and DOT 105A500W tank cars which carry chlorine.

The specific objectives are:

1. To determine the puncture resistance of a DOT Type 111 aluminum tank car relative to the intent prescribed in 49 CFR 179.105-5[3].
2. To evaluate the influence of parameters affecting the puncture resistance of an aluminum tank car: such as head thickness, head protection, material type, and internal pressure.
3. To evaluate the effects of low temperature on the puncture resistance of steel and aluminum tank cars.

3 TEST IMPLEMENTATION

The series of engineering tests conducted were intended to provide data to support analyses for fulfilling these objectives. Two types of tests were used:

1. One-fifth scale drop tower tests of the tank head to investigate the influence of parameters affecting the puncture resistance of the aluminum car.
2. Full-scale model tests with a tank head attached to a pressure vessel on a flatcar to estimate the behavior of actual aluminum tank cars and to provide a lower bound on puncture resistance of actual aluminum tank cars.

The determination of puncture resistance involving tests of actual tank cars is costly and time consuming. Testing with rolling stock results in damage to and possible destruction of the tank cars. Substituting for the actual cars a full-scale test model that consists of a reusable pressure vessel mounted on a flatcar provides a means of estimating the behavior of an actual tank car at a reduced cost and of conserving railroad stock. After each full-scale model test, only the detachable tank head and, when used, the test head shield require replacement. On account of the smaller tank volume and the lower rigidity of the full scale model, the results will differ slightly from actual tank car test results and will provide a lower bound on the puncture resistance of actual tank cars. Scale models, which are a more approximate representation of the behavior of an actual tank car, can reduce costs as well as the time necessary to conduct tests. The reduced scale model and test fixture used in tests for this report represent a compromise between the degree of model simplification and the tolerance for inconsistencies in behavior of the model and were useful in the study of trends with changes in tank car design parameters.

In previous full-scale tests with propane and chlorine tank heads, results were compared with test results of actual tank cars. Examination of those test results indicated that full-scale model tank car puncture resistance values were lower and more conservative than actual tank car puncture resistance values. Therefore, no actual tank car tests were performed for the present series of tests.

Results from previous tests also indicated that the choice of insulation, whether it was urethane foam, glass fiber, or ceramic fiber, did not affect puncture resistance significantly; consequently, its effect on puncture resistance was not considered in these tests.

In the CFR specification defining the required puncture resistance for DOT Type 112/114 tank cars, the impact location above the sill is specified as either 21 or 31 inches, whichever is more severe. Previous 1/5-scale tests indicated that 21 inches above the sill location produced the more severe test condition and it was selected as the impact location for this series of tests.

3.1 1/5-SCALE TESTS

The 1/5-scale parametric study was performed to evaluate factors affecting puncture resistance of tank cars and included the effects of tank car material, head thickness, head protection, internal pressure, and head temperature. The study included fifteen test series, nine simulating a DOT Type 111 tank car, three corresponding to the DOT 105A500W tank car, and three corresponding to the DOT 112J340W tank car. Three additional low temperature test series, DC-03A, DC-05A, and DC-07A, were included to determine whether lower temperature or decreased pressure has the greater effect on puncture resistance, and to determine if rounding of the coupler face could affect puncture threshold velocities determined by previous tests. The test matrix was designed to provide the range of values for each of the parameters and is summarized along with the respective test series in Table 3.1. A summary of the scale factors which relate the parameters of the 1/5-scale test model to the full-scale test model is found in Table 3.2.

The DOT Type 111 tank car heads were fabricated from 5052-O aluminum alloy which is a more compliant, lower strength material than the steel used in the propane and chlorine tank car heads. Stock thicknesses of 0.100-, 0.125- and 0.190-inch aluminum were used to hot-press form the test heads. Stock steel was unavailable in the desired thicknesses and required grinding to 0.163 inch for the chlorine heads and 0.138 inch for the propane heads prior to forming.

Combinations of these parameters were chosen and the speed of impact was varied to determine the puncture velocity and dent depth for each case. A new head was used for each impact.

TABLE 3.1 TEST MATRIX SUMMARY - 1/5-SCALE MODEL IMPACT TESTS
(ALL DIMENSIONS ARE FULL SCALE)

Test Series	Inside Diameter (in)	Head Material	Head Thickness (in)	Jacket Thickness (in)	Insulation Type* (in)	Head Temperature** (° F)	Internal Pressure (psi)
112J340W	120	ASTM A612 (AAR TC 128, Grade B) Steel					
DA-01			11/16	1/2	1/2 C	A**	100
DC-06			11/16	1/2	1/2 C	+32	40
DC-07			11/16	1/2	1/2 C	-20	10
DC-07A			11/16	1/2	1/2 C	-20/-1	10/10
105A500W	102	ASTM A612 (AAR TC 128, Grade B) Steel					
DA-02			13/16	1/8	4 F	A**	100
DC-04			13/16	1/8	4 F	+32	20
DC-05			13/16	1/8	4 F	-20	20
DC-05A			13/16	1/8	4 F	-20/+37/+37	20/20/100
111A100ALW1	102	ASTM B209 (5052-O) Aluminum					
DA-03			5/8	None	None	A**	4
DA-04			1/2	3/4	4 G	A**	4
DA-05			15/16	None	None	A**	4
DA-06			5/8	1/8	4 G	A**	4
DA-07			5/8	1/2	4 G	A**	4
DA-08			1/2	1/2	4 G	A**	4
DC-01			5/8	None	None	+32	4
DC-02			5/8	None	None	-20	4
DC-03			5/8	1/2	4 G	-20	4
DC-03A			5/8	1/2	4 G	-20	4

* Insulation materials are coded as follows:
C-Ceramic Fiber, F-Foam (polyurethane), G-Glass Fiber
** A - Normal Temperature (63 ° - 74 ° F)

TABLE 3.2 SCALE FACTOR SUMMARY - 1/5-SCALE MODEL IMPACT TESTS

Physical Parameter	Symbol	Scale Factor Symbol/Function	Scale Factor Value
Length	L	K_L	1/5
Diameter	D	K_D	1/5
Area	A	$K_A = K_L^2$	1/25
Volume	V	$K_V = K_L^3$	1/125
Speed	S	$K_S = 1$	1
Acceleration	a	$K_a = 1/K_L$	5
Time	T	$K_A = K_L$	1/5
Mass	M	$K_M = K_L^3$	1/125
Density	δ	$K_\delta = 1$	1
Force	F	$K_F = K_L^2$	1/25
Pressure	P	$K_P = 1$	1
Stress	σ	$K_\sigma = 1$	1

3.2 1/5-SCALE TEST APPARATUS

A drop test fixture (drop tower), shown in Figures 3.1 and 3.2, was installed in the Components Test Laboratory (CTL) at TTC to perform the tests in a controlled environment. The fixture had a maximum drop height of 18.5 feet with a scale tank head assembly in place.

Impact body mass was adjusted to 2,104 pounds during fabrication to simulate an impacting car weighing 263,000 pounds. This scale factor provided for a 1:1 scaling of velocity.

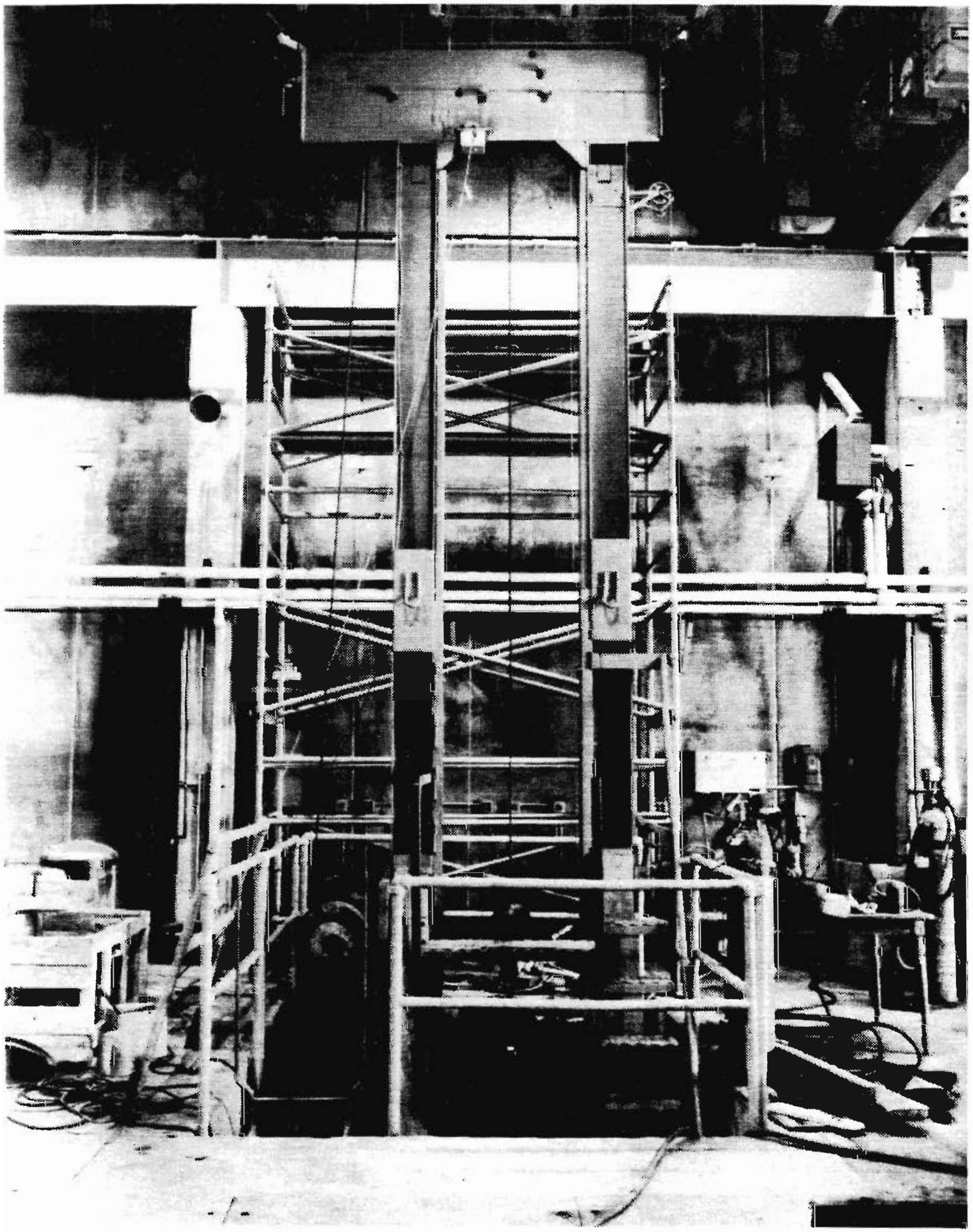

FIGURE 3.1 DROP TEST FIXTURE, UPPER SECTION - 1/5-SCALE MODEL IMPACT TESTS

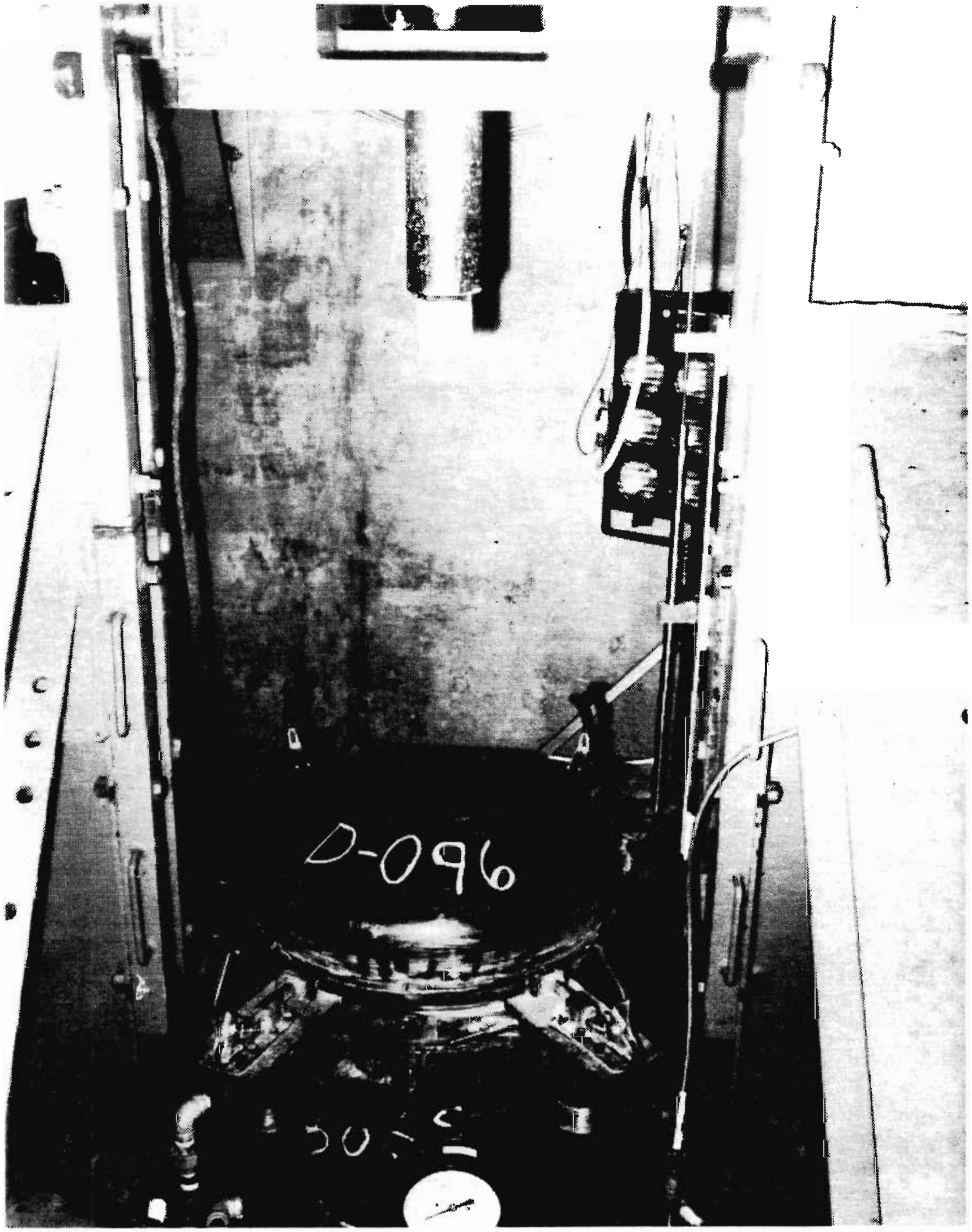

FIGURE 3.2 DROP TEST FIXTURE, HEAD ASSEMBLY IN TEST PIT - 1/5-SCALE MODEL IMPACT TESTS

The impact mass was capable of developing 24 mph theoretical free-fall velocity. Contact at impact was made with the test head assembly by a coupler mounted rigidly to the bottom of the impacting mass.

The test head assembly was attached to a pressure vessel which was secured at the test facility floor. Positioning the vessel permitted the point of impact to be scaled to the equivalent of 21 inches from the outside surface of the tank head to the impacting coupler centerline.

The test heads were manufactured with coupling flanges to facilitate attachment with clamps. An empty inverted container placed inside the pressure vessel acted as a pressure accumulator. The vessel was filled with water and pressurized. Air was purged from the vessel with the exception of the space inside the inverted container, where air representing a 10% outage condition was maintained. A schematic of the test setup is shown in Figure 3.3.

3.3 FULL-SCALE TESTS

The full-scale tests were intended to determine the approximate puncture resistance of the cars in a realistic rolling impact test. A summary of the standard configuration parameters used for the full-scale models is found in Table 3.3. The test matrix of the full-scale aluminum models is summarized in Table 3.4.

Six tests were conducted with DOT Type 111 aluminum tank heads made from 5/8-inch plate. Three tests employed a bare-head configuration, and three were designed with steel-head shields covering 4 inches of glass fiber insulation. Two shields were fabricated from 1/2-inch steel plate and the third shield from 5/8-inch steel plate. Conditions for testing followed the requirements specified in 49 CFR 179.105-5 for steel tank cars except that the internal pressure was reduced from 100 psi to 4 psi.

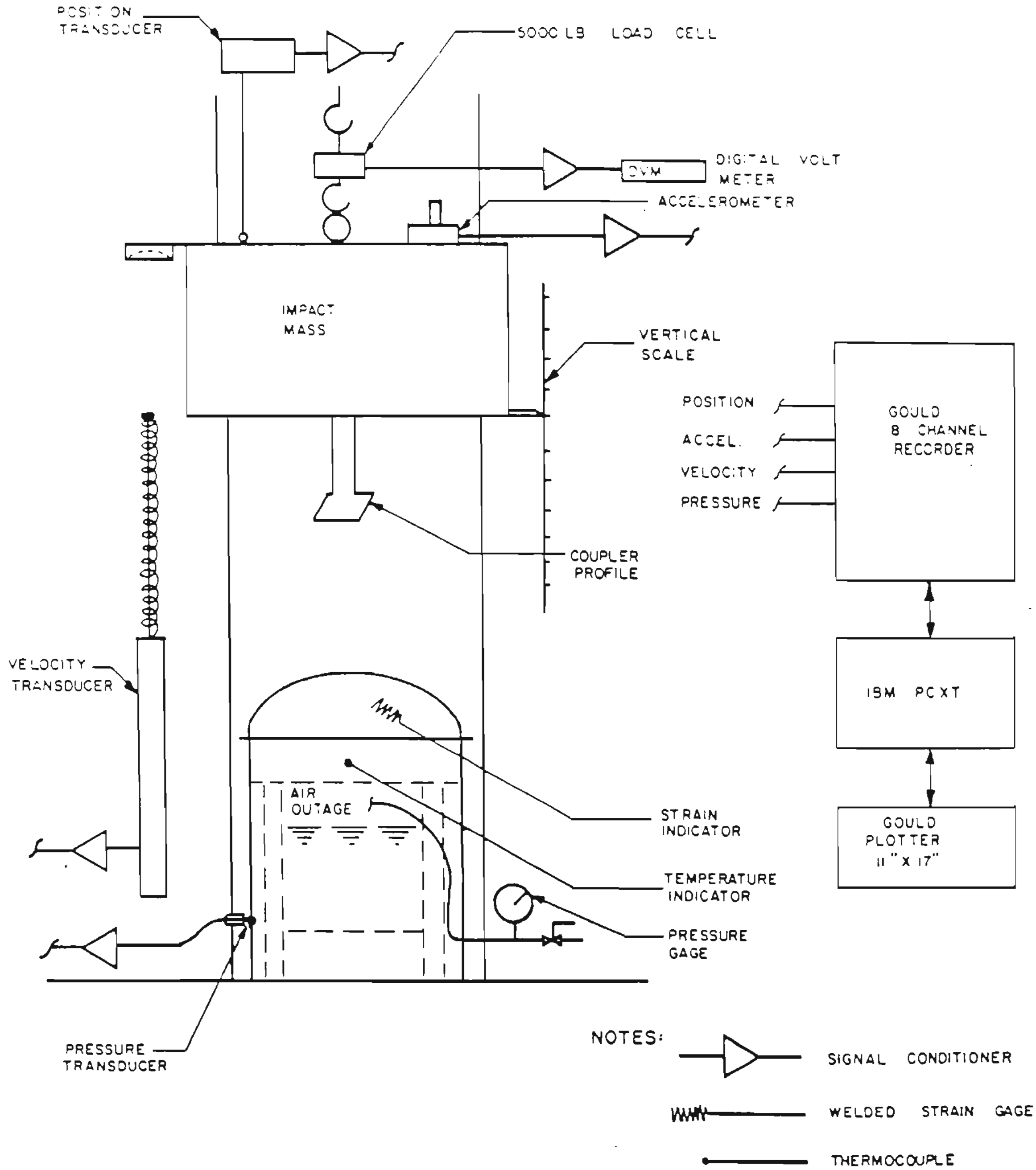

FIGURE 3.3 TEST INSTRUMENTATION SCHEMATIC - 1/5-SCALE MODEL IMPACT TESTS

TABLE 3.3 STANDARD CONFIGURATION SUMMARY - FULL-SCALE MODEL IMPACT TESTS

Parameter	111A100ALW1	112J340W	105A500W
Head Thickness	5/8 in	11/16 in	13/16 in
Head Diameter	102 in	120 in	102 in
Insulation Material	none[1] glass fiber[2]	ceramic fiber	foam
Insulation Thickness	4 in [2]	1/2 in	4 in
Insulation Jacket (Steel)	none	none	1/8 in
Head Shield (Steel)	none[1] 1/2 in [2] 5/8 in [2]	1/2 in	none
Impact Height (Nominal)	20 5/8 in	21 in	20 in
Internal Pressure	4 psi	100 psi	100 psi -
Tank Volume	5,268 gal	7,975 gal	5,268 gal
Outage	10%	10%	10%

[1]Bare head configuration

[2]Shield and insulation configuration

TABLE 3.4 TEST MATRIX SUMMARY - FULL-SCALE MODEL IMPACT TESTS

Test Series	Car Type	Number of Heads/Impacts	Head Thickness
FA-10	Aluminum (bare head)	3	5/8 in
FA-20	(0.500 in head shield)	2	5/8 in
FA-30	(0.625 in head shield)	1	5/8 in

3.4 FULL-SCALE TEST APPARATUS

Impact tests were conducted on full-scale tank head assemblies as produced for commercial tank cars. These assemblies were attached to a pressurized vessel mounted on a railroad flatcar as shown in Figure 3.4. The reaction car was a 100-ton flatcar with added structural modifications and supports for the pressure vessel. An adapter ring mounted on the pressure vessel to accommodate DOT 112J340W tank car heads was removed to permit direct attachment of DOT Type 111 tank car heads. Concrete blocks were mounted on the flat bed of the car to bring the total car weight, as set up for a test, to 254,000 pounds and to compensate for the weight loss by removal of the adapter ring.

Tank heads were made of 5052-O aluminum, hot press formed from standard plate to meet the minimum thickness requirement of 49 CFR 179.200-6 for DOT Specification 111A100ALW1 and 111A100ALW2 tank cars. Flanges welded to the tank head provided a means of attachment to the reaction vessel and room for a pressure seal.

The reaction car was backed up by three loaded freight cars as depicted in Figure 3.5. The reaction backup cars were 100-ton hopper cars loaded with track ballast material to a total weight for the three cars of 508,300 pounds. The effective mass of the simulated tank car used in the test was not the same as for actual tank cars. Previous tests had produced results that were conservative (i.e. puncture in the tests occurred at lower velocities than in the actual tank car tests).

The impactor car, shown in Figure 3.6, was a donated scrap locomotive. A support structure for a ram fixture was installed on the main frame. Total car weight was adjusted to 263,000 pounds. The traction motors were disconnected from the axles to reduce rolling friction.

The ram fixture consisted of the ram which was a simulated rail car center sill with a coupler and the draft gear assembly mounted on one end. The ram was mounted on a structural reaction frame on the front of the impactor car with height adjustment in increments of 2 inches. The coupler was a standard AAR Type E 60 CE with rotary operation mechanism removed and knuckle welded in the engaged position. Couplers were replaced as they became distorted from repeated impacts. The draft gear was a Westinghouse Mark 50.

Testing was performed on a track with constant downward gradient of about 1 percent, allowing the impactor car to accelerate from selected stationary starting points by gravity towards the reaction car to the desired impact speeds.

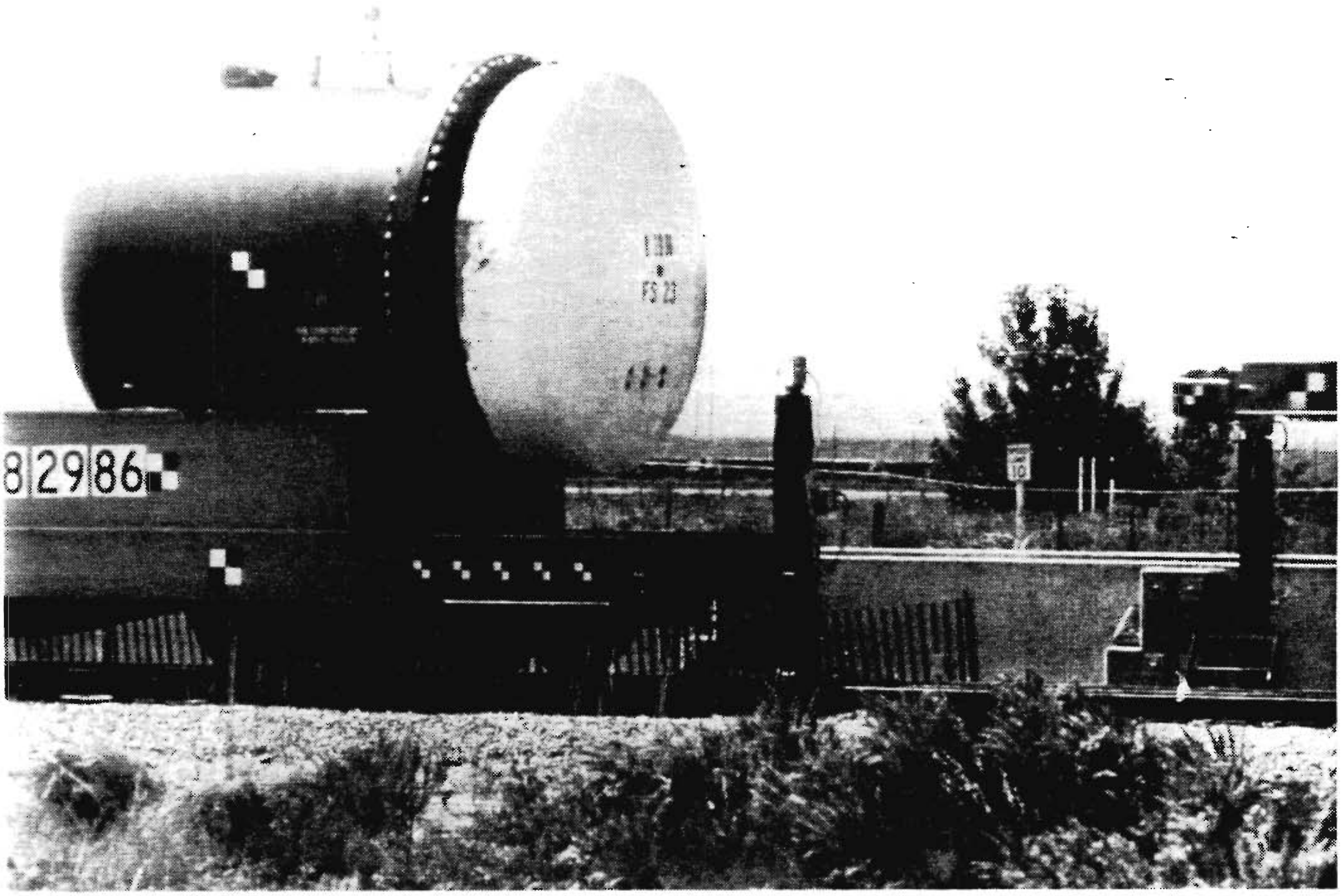

FIGURE 3.4 REACTION CAR - FULL-SCALE MODEL IMPACT TESTS

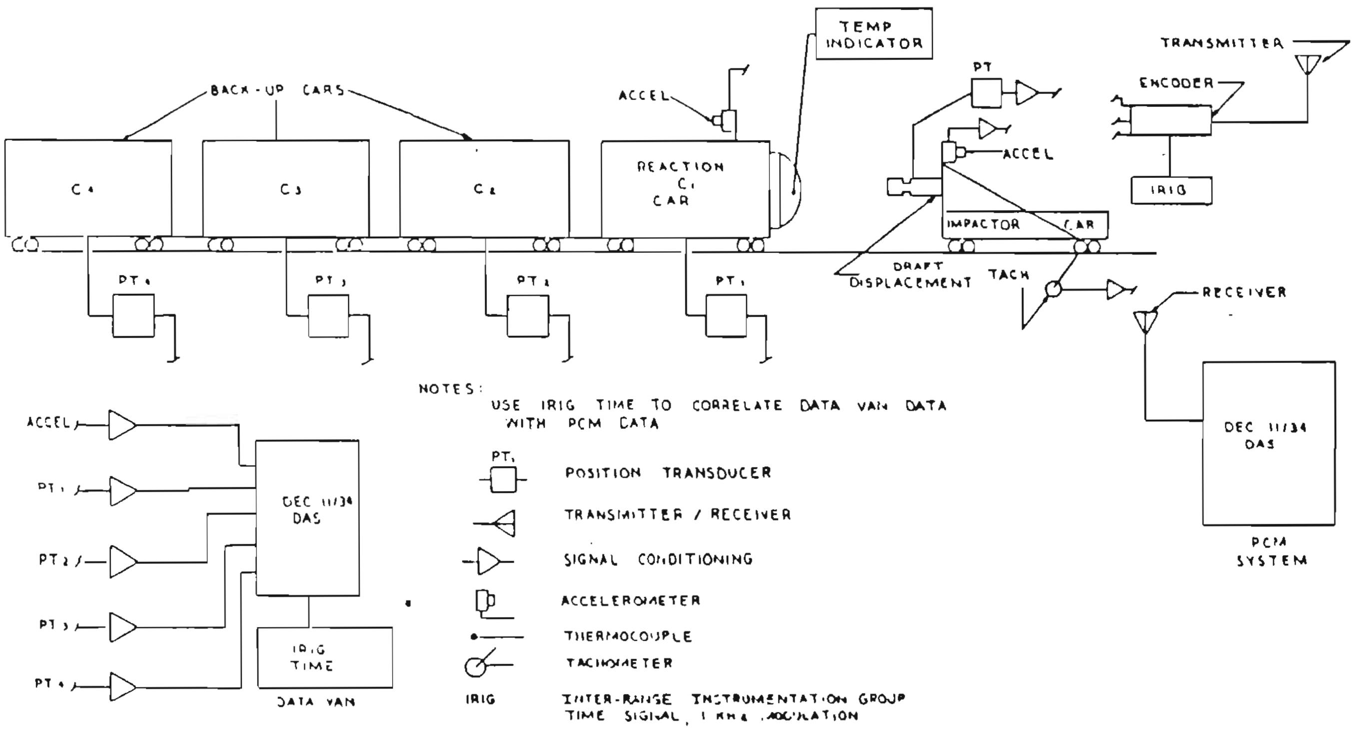

FIGURE 3.5 TEST INSTRUMENTATION SCHEMATIC - FULL-SCALE MODEL IMPACT TESTS.

FIGURE 3.6 IMPACTOR CAR AND RAM FIXTURE - FULL-SCALE MODEL IMPACT TESTS.

4 1/5-SCALE PARAMETER TEST RESULTS

The parameters studied in individual 1/5-scale model tests were tank car material, head thickness, head protection, internal pressure, and head temperature. The test results, the maximum dent depth without puncture and the velocity required for puncture as functions of the various parameters, are summarized in Table 4.1. The values of the parameters for each test series are given in Table 3.1. The individual test values are presented in Appendix B. To relate the summarized results to the individual test results, the values are identified by comparably numbered test series. Mechanical properties of the steel and aluminum used in the 1/5-scale test models are summarized in Table 4.2. Note that the properties of aluminum used for the full-scale tests shown in Table 5.2 differ from the values in Table 4.2. The lower elongation of the 1/5-scale model aluminum indicates a higher degree of work hardening that may have produced the higher strength. The low value of the post-test tensile strength was reported for steel material taken from a batch shipment with mechanical properties at the low end of the material specification. Elevated temperatures during the head forming process may have stress-relieved the material and resulted in a value of tensile strength outside the range of the specification.

4.1 TANK CAR MATERIAL

Tests of bare aluminum tank heads showed that unprotected aluminum provides little resistance to puncture. Baseline test series DA-03 with 5/8-inch thick heads exhibited a very low puncture velocity of less than 1.5 mph when compared with the 6.8 mph puncture velocity of previously tested 13/16-inch thick 1/5-scale bare steel chlorine tank heads. Even greater differences were indicated when representative propane and chlorine tank car heads of baseline tests series DA-01 and DA-02 were compared with the representative Type 111 aluminum tank car heads of baseline test series DA-03.

TABLE 4.1 DENT AND PUNCTURE RESULTS SUMMARY - 1/5-SCALE MODEL IMPACT TESTS

Test Series	# of Heads	Parameter	Dent Depth (in)	Puncture Velocity (mph)
112J340W				
DA-01	7	Baseline	5.1	10.5
DC-06	5	32° F	5.5	14.0
DC-07	4	-20° F	6.5	18.0
DC-07A	2	-1° F	6.8*	18.0
105A500W				
DA-02	6	Baseline	4.5	13.0
DC-04	5	32° F	6.8	18.0
DC-05	5	-20° F	6.9	18.0
DC-05A	3	+37° F (100 psi)	4.3	13.0
111A100ALW1				
DA-03	3	Baseline	2.1	<1.5
DA-04	4	Thin w/3/4 in Shield	6.5*	16.0
DA-05	5	Bare Head Thick	0.9	1.5
DA-06	6	Insulated w/Jacket	4.1	5.0
DA-07	4	Insulated w/1/2 in Shield	5.7*	12.0
DA-08	3	Thin w/1/2 in Shield	6.1	12.0
DC-01	4	Bare Head at 32° F	2.7	1.6
DC-02	4	Bare Head at -20° F	3.0	2.5
DC-03	5	Insulated w/1/2 in Shield -20° F	6.4*	13.0
DC-03A	3	Insulated w/1/2 in Shield -20° F	5.7	13.0
1125340W				
01	9	Baseline	2.8**	10.6**
105A500W				
03	6	Baseline	2.7**	10.2**

* Failure occurred as crack at pinched perimeter flange weld/sill area; visible leakage.

** See Reference 2

TABLE 4.2 MECHANICAL PROPERTIES OF MATERIALS - 1/5-SCALE MODEL IMPACT TESTS

Material	Mechanical Property	Specification	Post Test
ASTM A-612 (AARTC-128, Grade B) Steel			
	Tensile Strength	81-101 Ksi	70.9 Ksi
	Yield Strength	> 50 Ksi	51.9 Ksi
	Elongation in 2 in.	> 22%	27.5%
ASTM B-209 (5052-O) Aluminum			
	Tensile Strength	25-31 Ksi	34.2 Ksi
	Yield Strength	> 9.5 Ksi	27.5 Ksi
	Elongation in 2 in.	> 19%	12.8%

4.2 HEAD THICKNESS

The effect of increasing the bare aluminum head thickness was considered by comparing test series DA-05 with the baseline test series DA-03. The 1.5 mph puncture velocity of the thicker 15/16-inch head was not much greater than the less than 1.5 mph value of the 5/8-inch thick head of the baseline model. The 50 % increase in the bare-head thickness resulted in a minor increase in the puncture velocity. Based on the comparison of test series DA-07 and DA-08, increasing the aluminum head thickness from 1/2-inch to 5/8-inch did not change the puncture resistance measurably.

4.3 HEAD PROTECTION

Four test series, DA-04 and DA-06 through DA-08, were conducted to determine the effectiveness of varying the thickness of steel head shields protecting the aluminum tank car heads. Results showed that the puncture velocity increased with increases in the value of the thickness of the steel shield. Significant increases in puncture velocity from 5 to 12 to 16 mph occurred for the respective values of shield thickness of 1/8-, 1/2-, and 3/4-inch.

4.4 INTERNAL PRESSURE

Contents of DOT Type 111 nonpressure tank cars generally are subjected to low pressures. Propane and chlorine are normally kept cold and shipped in pressurized tank cars typically at less than 100 psi. Occasionally, all of these cars can experience temperature increases which cause the tank pressure to rise.

Regardless of the test temperatures (which did not affect the vapor pressure of the water substituted for the lading), puncture resistance of the chlorine and propane tank car heads showed a consistent decrease with increasing pressure. Data to indicate this behavior is found in Tables 3.1 and 4.1. DOT105A500W tank heads subjected to 20 psi in cold test series DC-04 and DC-05 survived impact velocities of 18 mph as compared to the heads subjected to 100 psi in baseline test series DA-02 and cold test series DC-05A , both of which punctured at 13 mph. The decrease in puncture resistance from 18 to 14 to 10.5 mph with increases in pressure from 10 to 40 to 100 psi, was also evident in the results of the cold test series DC-07 and DC-06, and the baseline test series DA-01 for the propane tank heads. The value of puncture resistance for cold test series DC-07 was the same as test series DC-07A and confirmed the same trend.

4.5 HEAD TEMPERATURE

The lower test temperatures did not have enough effect on the material properties of the aluminum head or the steel shield to increase their strength and to affect puncture resistance significantly. Baseline test series DA-03, and cold test series DC-01 and DC-02 with bare aluminum heads were compared to evaluate the effect of lower temperatures which may be encountered in DOT Type 111 tank cars. The puncture resistance showed a minor increase of 1 mph at the lower temperatures. Results of test series DA-07, DC-03, and DC-03A of the aluminum heads with steel head shields also showed a small increase of 1 mph in the puncture resistance at the lowest temperature. The effect of lower temperatures was to produce minor changes of 1 mph in the values of puncture velocity for both the bare and shielded aluminum tank head cofigurations.

5 FULL-SCALE TESTS RESULTS

Six impact tests were conducted with full-scale aluminum tank car heads attached to a special pressure vessel mounted on a flatcar. Three tests used the bare-head baseline configuration and the remaining tests used insulated heads protected by external head shields. Heads with a 5/8-inch nominal thickness were tested, each at different impact velocities. Prior to testing, a new coupler was installed on the ram to prevent impact velocity readings from being affected by differences in the contact surface as a result of repeated impacts. A summary of the full scale model impact test results is presented in Table 5.1. Mechanical properties of the aluminum used in the full scale test models are summarized in Table 5.2.

TABLE 5.1 DENT AND PUNCTURE RESULTS SUMMARY - FULL-SCALE MODEL IMPACT TESTS

Test Series	Car Type	Maximum Dent Depth	Puncture Velocity
FA-10	Aluminum (bare head)	15.4 in	4 mph
FA-20	(with 1/2 in steel head shield)	30.4 in	16.5 mph
FA-30	(with 5/8 in steel head shield)	NA[1]	17.5 mph

[1]Interference of ram penetration by wedging of closed couplers

TABLE 5.2 MECHANICAL PROPERTIES OF MATERIALS - FULL-SCALE MODEL IMPACT TESTS

Material	Mechanical Property	Specification	Post Test
ASTM B-209(5052-0) Aluminum			
	Tensile Strength	25-31 Ksi	27.6 Ksi
	Yield Strength	> 9.5 Ksi	16 Ksi
	Elongation in 2 in.	> 19%	35.5%

5.1 BARE TANK CAR HEADS

The puncture velocity of the full-scale bare aluminum tank head was estimated to occur at 4 mph and to produce a dent depth of 15.4 inches. The comparable 1/5-scale test series, DA-03, produced a puncture at less than 1.5 mph and a scaled dent in the head of 10.5 inches. Relative motion between the coupler and the head during individual full scale tests FA-12 and FA-13 caused the point of maximum dent depth to move radially toward the knee of the tank head. The point of impact was located above the neutral axis of the reaction flatcar tending to cause flexing of the flatcar, thereby raising the tank head above its normal location relative to the track. Contact between the tank head and the knuckle of the impacting ram also may have introduced a force component to promote sliding of the knuckle toward the knee of the tank head. Combined with compression of the draft gear, the more gradual loading at impact may have contributed to a higher value of full-scale puncture resistance and to the differences with results of the 1/5-scale tests. Greater yield strength and tensile strength of the aluminum used in 1/5-scale models, evident from Tables 4.2 and 5.2, did not produce a measurable increase in puncture resistance. The dent size, as in other tests, was larger than predicted by straight scaling of the 1/5-scale results.

5.2 TANK CAR HEADS WITH HEAD SHIELDS

Results of the full scale aluminum tank car heads with head shields for test series FA-10 through FA-30 exhibited some of the same behavior as the full-scale steel tank car heads with shields from previous tests. The earlier tests, which included full-scale chlorine tank car heads with 1/8-inch steel jackets, gave a puncture velocity of 15.1 mph. Tests of full-scale propane tank car heads with 1/2-inch steel shields reached impact velocities of 23.4 mph without puncture. The results of the full-scale tests for the DOT Type 111 aluminum tank cars also indicated increases in puncture resistance with increased head shield thickness. The puncture resistance of the bare aluminum tank car head in test series FA-10 was increased from 4 mph to 16.5 mph by the use of a 1/2-inch thick steel head shield in test series FA-20. Comparison of the DOT Type 111 aluminum tank car heads and the steel propane tank car heads, each equipped with 1/2-inch steel head shields, showed a significantly larger value of puncture resistance in the propane tank head. The effect of the greater yield strength and tensile strength of the steel tank head material is believed to be responsible for the increased puncture resistance.

The third test series FA-30 with a 5/8-inch steel head shield resulted in an estimated puncture resistance of 17.5 mph. In testing, puncture of the head did not occur. Part of the impact energy may have been transmitted to the coupler and the draft gear, thus dissipating the energy of the impacting ram. Because of the questionable value of the puncture resistance, it may be desirable to confirm this result by repeating the test.

The 16.5 mph value of puncture resistance determined in full scale test series FA-20, as expected, exceeded the comparable 12 mph value of the 1/5-scale model test series DA-07. A significant difference in the puncture resistances amounted to 27% of the full scale value. The full-scale dent depth of 30.4 inches, also, was greater than the 1/5-scale value of 28.5 inches. The difference in the dent depths amounted to an acceptable value of 6% of the full scale value. Severe folding and pinching of the aluminum tank car head with a steel head shield occurred at the sill bottom area. This was common to these full-scale and 1/5-scale model tests. Failure of the full-scale aluminum tank car with head shield in individual test FA-21, occurred as a full puncture of the head shield. With the 1/5-scale tests, the mechanism of failure was different. A crack occurred in the weld seam at the bottom sill area and no puncture was evident in the impact area.

6 DISCUSSION OF TESTS

Simulation of an actual tank car with full-scale and 1/5-scale models is always an attempt to duplicate the behavior of the actual tank car and results in some error. Differences, observed in previous testing, between actual chlorine tank cars and the full-scale test fixture were reviewed and compared with the differences found in the present series of tests. Differences observed between the modeling of the 1/5-scale tests and that of full-scale tests were also examined.

6.1 ACTUAL AND FULL-SCALE TESTS

The pressure vessel used in the full-scale fixture was smaller than the tank on an actual tank car. Most of the mass of an actual loaded tank car consists of fluid, free to slosh about within the tank. Impact loading has the effect of generating relative motion of the fluid contents, resulting in an effective mass that is significantly less than the mass of a loaded tank car, thereby reducing the impact force from what would occur with a rigidly mounted cargo of the same weight. In the reaction vehicle used for this series of tests, the fluid mass was less than about 25% of the total car mass. The smaller fluid mass results in a greater effective mass for the full-scale test fixture than would exist for an actual tank car and will cause a reduction of the puncture resistance of the full-scale test car. In previous tests with chlorine tank cars, the 17.5 mph impact velocity of the actual chlorine tank car as compared to the 15.1 mph threshold puncture velocity of the full scale model showed an error of about 14%. Using the same full-scale test fixture and a similar error for the aluminum tank car tests, the values of the full-scale aluminum model puncture resistance were assumed to provide a lower bound for the puncture resistance of the actual aluminum tank car.

6.2 FULL-SCALE AND 1/5-SCALE TESTS

In theory, the use of 1/5-scale tests can provide an economical and versatile means to study trends in the response of puncture resistance and dent depth of tank cars to variations of their design parameters. The comparative advantages over full-scale testing can result in lower model fabrication and test costs, shorter model delivery and test times, an adaptable low cost test fixture, and a readily controlled environment encompassing a less extensive test area.

Balanced against these advantages is the limitation of inexact scaling which affects the reproduction of the response to impact. The 1/5-scale drop tower tests do not predict full-scale performance directly because the impact mechanics are not scaled exactly. For the drop tower test, the head is attached to a vertically oriented tank secured firmly to the floor of the test facility. This leads to an energy and momentum transfer mechanism different from full-scale rolling tank car tests. In addition, the tank head mounting connections, variations in the head formation procedures, restricted coupler angle, restricted relative deflection, and different strain rates make direct comparisons between 1/5 and full-scale model tests difficult. The inability to scale up test results directly limits their use to the prediction of trends in parametric studies of design characteristics.

Tests with 1/5-scale models of bare aluminum heads and models of steel protected aluminum heads confirmed the trends of full-scale test results that puncture resistance and dent depth increased with increases in the thickness of aluminum and of steel. Discussion relating to these trends is found in sections 4.2, 4.3, and 5.2.

Comparisons also confirmed that the puncture resistance and dent depth of the 1/5-scale tests were less than the full scale values and illustrated the degree of proportionality, or lack of it, between the different scaled tests. Comparison of the 1/5-scale values of 5.1 mph and 10.5 inches, shown in Table 4.1, for bare aluminum heads with the full-scale values of 4 mph and 15.4 inches, shown in Table 5.1, indicated a difference in the puncture resistance of 28% of the full-scale value and a difference in the dent depth of 32% of the full-scale value.

A comparison between test series DC-03 and DC-03A showed the influence that attention to details had on the accuracy of the 1/5-scale test results. With the exception of the reprofiled coupler in test series DC-03A, the tests were identical. Puncture with the reprofiled coupler occurred in the impact area instead of the sill area. The puncture threshold velocities were estimated to be the same and the difference in dent depths was about 5%. Closer attention to details and reduction of discrepancies, which should result in a closer reproduction of full-scale behavior and should provide a more accurate indication of the trends with parametric studies, resulted only in minor changes of puncture resistance and dent depth with the use of a reprofiled coupler. In this case, the reprofiled coupler had a pronounced effect on the failure mechanism and a negligible effect on the puncture resistance and the dent depth.

Tests conducted with propane and chlorine tank car heads provided an opportunity to check the consistency with previous results of 1/5-scale tests. Results of test series DA-01 showed a puncture resistance of 10.5 mph for the propane tank car which was smaller by 0.1 mph than the value found from previous testing and represented an acceptable 1% difference between the two values. The puncture resistance of 13.0 mph of test series DA-02 for the chlorine tank car was found to be greater by 2.8 mph than results of previous testing and represented a significantly greater difference of 22%. Results of test series DA-01 and DA-02 show that the puncture velocity decreased with increasing thickness of protective steel covering, while earlier tests suggested no such trend. In addition differences in the depth of the dents with the previous series of tests were found to be much greater. The dent depths, estimated in the present 1/5-scale test series for both steel tank head types, were approximately 100% greater than in the previous tests. These inconsistencies in the results bring into question the applicability of the 1/5-scale test as presently conducted.

7 CONCLUSIONS

1. Full-scale tests indicate that steel shields for aluminum tank cars are capable of providing protection from coupler impact.
2. Full-scale aluminum tank car heads will require steel shields greater than 1/2-inch to survive an impact velocity of 18 mph.
3. Full-scale tests also indicate that 5/8-inch bare aluminum tank car heads cannot sustain impact velocities above 4 mph.
4. The results of 1/5-scale tests are valid for the prediction of gross behavior of full-scale model tank cars but cannot be extrapolated directly to full-scale results. The predicted trends with the 1/5-scale tests are consistent with the behavior of the full-scale model tests but have lower values of puncture velocity and dent depth than found with full-scale model tests.
5. Although 1/5-scale tests show that increasing the bare aluminum head thickness from 5/8-inch to 15/16-inch will increase the puncture velocity from less than 1.5 mph to 1.5 mph, that change is negligible.
6. In tests with 1/5-scale steel heads, the effect of lower tank pressures to increase puncture resistance is very significant. Decreases in pressure from 100 psi to a 10-20 psi range should produce increases in puncture resistance from about 10 mph to 18 mph. Lowering temperatures of propane and chlorine will decrease their vapor pressure and therefore can increase the puncture resistance of the tank car which carries those commodities.
7. Based on 1/5-scale tests, the effect of temperatures lowered from ambient to -20 °F have only a slight effect on the mechanical properties of aluminum, resulting in an increased puncture resistance of 1 mph or less.

8 RECOMMENDATIONS

The use of steel head shields should be considered as a means to increase the puncture resistance of aluminum tank cars.

Increasing the thickness of an aluminum head produces only a small effect on its puncture resistance and is not recommended.

Due to the sensitivity of puncture resistance to internal tank pressure, the value of the maximum operational pressure should be used for the evaluation of head shields for aluminum tank cars.

Temperature should be considered for its effect on the vapor pressure of the lading. Chlorine and propane are two examples of lading which have a pressure sensitivity to temperature. The mechanical properties of aluminum and steel, however, are only slightly affected by the temperature variation possible within the range likely to occur in service; hence temperature should not be considered for its effect on these properties.

APPENDIX A: 49 CFR 179.105-5, 179.106-2, and 179.200-6

Code of Federal Regulations, Title 49, "Transportation," Part 179, "Specification for Tank Cars," October 1987.

§ 179.105-5 Tank head puncture resistance.

(a) *Performance standard.* Each specification 112S, 112T, 112J, 114S, 114T, and 114J tank car shall be capable of sustaining, without loss of contents, coupler-to-tank head impacts within the area of the tank head described in § 179.100-23 at relative car speeds of 18 miles per hour when:

(1) The weight of the impact car is at least 263,000 pounds;

(2) The impacted tank car is coupled to one or more "backup" cars which have a total weight of at least 480,000 pounds and the hand brakes are applied on the first car; and

(3) The impacted tank car is pressurized to at least 100 psi.

(b) *Test verification.* Compliance with the requirements of paragraph (a) of this section shall be verified by full scale testing or by the alternate test procedures prescribed in paragraph (c) of this section. However, protective head shields that meet the requirements of § 179.100-23 or full tank head jackets that are at least ½-inch thick and made from steels specified in § 179.100-23(a)(1) need not be verified by testing.

(c) *Tank head puncture resistance test.* A tank head resistance system shall be tested under the following conditions:

(1) The ram car used shall weigh at least 263,000 pounds, be equipped with a coupler, and duplicate the condition of a conventional draft sill including the draft yoke and draft gear. The coupler shall protrude from the end of the ram car so that it is the leading location of perpendicular contact with the standing tank car.

(2) The impacted test car shall be loaded with water at six percent outage with internal pressure of at least 100 psi and coupled to one or more "backup" cars which have a total weight of 480,000 pounds with hand brakes applied on the first car.

(3) At least two separate tests shall be conducted with the coupler on the vertical centerline of the ram car. One test shall be conducted with the coupler at a height of 21 inches, plus-or-minus one-inch, above the top of the sill; the other test shall be conducted with the coupler height at 31 inches, plus-or-minus one-inch above the top of the sill. If the combined thickness of the tank head and any additional shielding material at any position over the area described in § 179.100-23 is less than the combined thickness on the vertical centerline of the car, a third test shall be conducted with the coupler positioned so as to strike the thinnest point.

(4) One of the following test procedures shall be applied:

	Minimum velocity of impact (in miles per hour)	Restriction
Minimum weight of ram car plus attached cars (in pounds):		
263,000	18	1 ram car only.
343,000	16	1 ram car or 1 ram car plus 1 rigidly attached car.
	Minimum velocity of impact (in miles per hour)	Restriction
686,000	14	1 ram car plus 1 or more rigidly attached cars.

(5) A test is successful if there is no visible leak from the standing tank car within one hour after impact.

[Amdt. 179-19, 42 FR 46314, Sept. 15, 1977]

§ 179.106-2 New cars.

(a) Each Specification 105A tank car built after February 28, 1981, shall be equipped with a coupler restraint system that meets the requirements of § 179.105-6.

(b) Each Specification 105S tank car built after August 31, 1981, shall be equipped with:

(1) A coupler restraint system that meets the requirements of § 179.105-6; and

(2) A tank head puncture resistance system that meets the requirements of § 179.105-5.

(c) Each Specification 105J tank car built after August 31, 1981, shall be equipped with:

(1) A coupler restraint system that meets the requirements of § 179.105-6;

(2) A tank head puncture resistance system that meets the requirements of § 179.105-5;

(3) A thermal protection system that meets the requirements of § 179.105-4; and

(4) A safety relief valve that meets the requirements of § 179.105-7.

(d) Each Specification 105 tank car shall be stenciled as prescribed in § 179.106-4.

[Amdt. 179-27, 46 FR 8012, Jan. 26, 1981]

§ 179.200–6 Thickness of plates.

(a) The wall thickness after forming of the tank shell, dome shell, and of 2:1 ellipsoidal heads must be not less than specified in § 179.201-1, nor that calculated by the following formula:

$$t=Pd/2SE$$

where:

d=Inside diameter in inches;
E=0.9 Welded joint efficiency; except E=1.0 for seamless heads;
P=Minimum required bursting pressure in p.s.i.;
S=Minimum tensile strength of plate material in p.s.i. as prescribed in § 179.200-7;
t=Minimum thickness of plate in inches after forming.

(b) The wall thickness after forming of 3:1 ellipsoidal heads must be not less than specified in § 179.201-1, nor that calculated by the following formula:

$$t=Pd/2SE\times 1.83$$

where:

d=Inside diameter in inches;
E=0.9 Welded joint efficiency; except E=1.0 for seamless heads;
P=Minimum required bursting pressure in p.s.i.;
S=Minimum tensile strength of plate material in p.s.i. as prescribed in § 179.200–7;
t=Minimum thickness of plate in inches after forming.

(c) The wall thickness after forming of a flanged and dished head must be not less than specified in § 179.201-1, nor that calculated by the following formula:

$$t=5PL/6SE$$

where:

E=0.9 Welded joint efficiency; except E=1.0 for seamless heads;
L=Main inside radius to which head is dished, measured on concave side in inches;
P=Minimum required bursting pressure in p.s.i.;
S=Minimum tensile strength of plate material in p.s.i. as prescribed in § 179.200–7;
t=Minimum thickness of plate in inches after forming.

(d) If plates are clad with material having tensile strength properties at least equal to the base plate, the cladding may be considered a part of the base plate when determining thickness. If cladding material does not have tensile strength at least equal to the base plate, the base plate alone must meet the thickness requirements.

(e) For a tank constructed of longitudinal sections, the minimum width of bottom sheet of the tank must be 60 inches measured on the arc, but in all cases the width must be sufficient to bring the entire width of the longitudinal welded joint, including welds, above the bolster.

(f) For a tank built of one piece cylindrical sections, the thickness specified for bottom sheet must apply to the entire cylindrical section.

(g) See § 179.200-9 for thickness requirements for a compartmented tank.

[Amdt. 179-10, 36 FR 21349, Nov. 6, 1971]