A RAILROAD TANK CAR SAFETY PROGRAM

The project outlined here will reveal much about the dynamics of railroad tank car accidents, information that can be applied toward reducing some of the hazards they present.

E. A. Phillips
Association of American Railroads
Chicago, Ill.

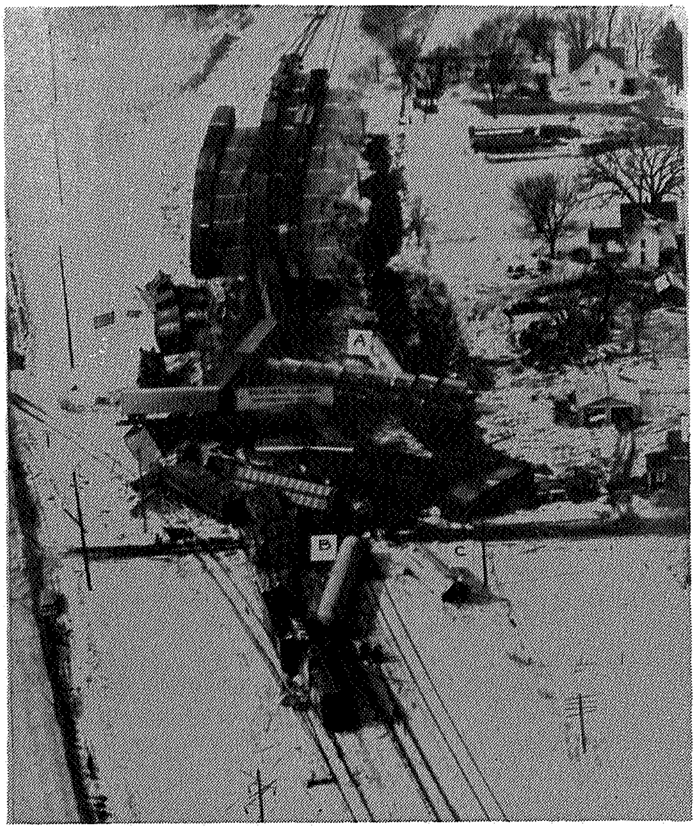


Figure 1. Tank car derailment in Crete, Neb.

I would much prefer that this article followed the format of most technical presentations in which the problem is stated, and then the method of solution, the solution itself, the results, and, finally, the conclusion(s). Unfortunately, at this time we only have a clear picture of our problem; viz., railroad tank car safety in accidents, and a rather ambitious plan for its method of solution.

In order to provide a clearer picture of this problem, first I will review the autopsy of an ammonia tank car which was ruptured at Crete, Neb. on February 18, 1969, and then I will discuss some of the particulars of our project and the background that led to its establishment.

Autopsy of the Crete accident

Following the accident, practically the entire tank car tank was recovered and shipped to the AAR Research Laboratory in Chicago for analysis. A comprehensive metallurgical and fracture mechanics study was made and reported on in July 1969 (**1**).

Figure 1 shows an aerial view of the derailment scene which is taken from this AAR report. As brief background, a derailing freight train struck a group of cars standing on a siding, among which were three adjacent tank cars of approximately 33,000 gal. capacity loaded with anhydrous ammonia. The loaded cars, each weighing roughly 250,000 lb., were of underframeless, non-insulated design and constructed of TC-128-B steel (**2**). The thickness of the tank steel and head plates ranged from 5/8 to 11/16 in. Two of the cars were displaced a considerable distance by the impact of the collision, but did not rupture. The third car, which was in the center of the group of three, was struck by one of the derailing cars so severely that it ruptured. Slightly less than one-half of the tank at the struck end fractured into numerous fragments. The remainder of the tank that did no so fracture is labelled C in the figure. The two cars that did not rupture are labelled A and B.

Figure 2 shows the tank partially reassembled by the AAR. The segment on the right side includes a portion of the tank head and is upside down, comprising the top half of the segments in the center and on the left. The fracture analysis showed that the car received severe blows on its side near the center and also on this head, and that the head blow caused initial fracture. Later, we will review a

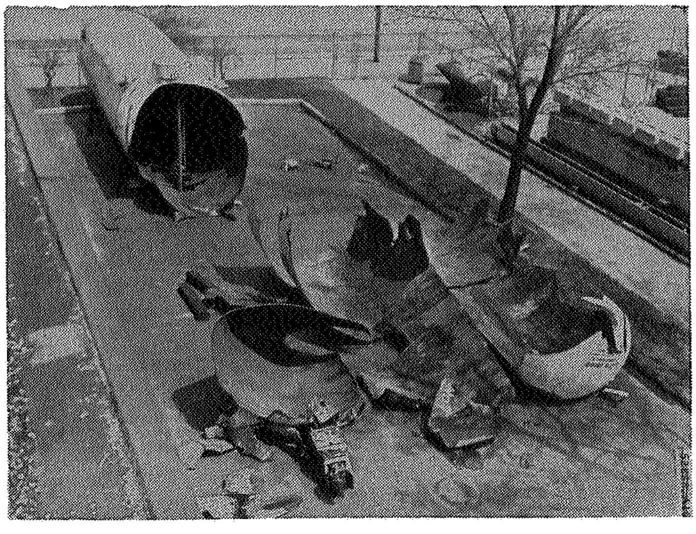


Figure 2. Partly "reconstructed" tank car from the Crete, Neb. accident.

crack progression diagram to follow subsequent events. While the head blow was considered severe enough to cause either a ductile or brittle rupture of the tank, the nature of the fracture surfaces, being predominantly brittle, became the main subject of study.

It is of interest to consider the state of affairs in the three tank cars just before the collision. Drawing from the regulations covering anhydrous ammonia loading in winter months, it can be calculated that at 4w F, the ambient temperature at the time of the accident, the three cars could have contained up to a maximum of 30,000 gal. of liquid and 3,500 gal. of vapor. The stresses in the cars were fairly low since, assuming thermal equilibrium with ambient temperature, the internal pressure would have been 19 lb./sq. in. gauge with a corresponding tank hoop stress of about 1,800 lb./sq. in. The design stress for this type car is 24,300 lb./sq. in.

Further, for an underframeless car of this type the "beam" stress in the center of the tank due to the dead weight under full load is approximately 2,400 lb./sq. in. A corollary to this low stress, and therefore high tank stiffness, is a fact not generally recognized: that in the case of an underframe type tank car it is primarily the tank that holds up the underframe.

Figure 3 is a sketch showing reassembly of the tank car. The fractures were of a brittle nature except for the portion labelled "shear" in the upper left. By following the chevron patterns, it was possible to establish the crack progression depicted by the arrows. The tank was struck at the lower portion of the head in the area labelled X in the lower left view, and the fracture origin was at the point labelled with an asterisk. Cracks propagated along the side and bottom of the tank toward its center, veered around circumferentially at several locations, and ended up in a rather confused array in the shell area adjacent the tank centerline, and at the location of the second point of external impact previously mentioned.

Tests on construction materials

Five steel samples were removed for study and are identified in Figure 3 as C1, C¼, C⅜, C½ and C⅝. The following tests and analyses were made on part or all of the samples: tensile, nil-ductility (NDT), bend, Charpy V-notch, hardness, micro- and macrographs, and chemistry.

The steel was found to meet the TC-128-B specifications, primary requirements of which are shown in Table 1. This steel is a close but slightly superior relative to ASTM A-515-70 having higher tensile and yield strengths and required to be manufactured to fine grain practice.

Metallographic examination of the fractured areas of the struck head contributed to the conclusion that the exact fracture origin was at the intersection of the head and a reinforcing structure connecting the stub-sill and head; however the fabrication in this area was not criticized on the basis that the extreme blow would have caused fracture somewhere in any case. Often, this is at a structural constraint nearest the location of impact.

The microstructure of the shell and head plate samples were considered normal for the steel and type of processing involved; viz., hot rolled low carbon steel plate cold rolled into shell rings and hot formed into tank heads. Finally, metallographic examination of the weld sample showed satisfactory welding practice.

Of particular interest in the AAR study was the attempt to correlate the laboratory fracture toughness tests with field behavior. It would be expected that the steel adjacent the ductile fracture in the one shell plate would exhibit the best toughness and that the steel adjacent the brittle fractures in the other shell plates and the head would exhibit the worst. As it turned out, there was little correlation between either the longitudinal and transverse Charpy V-notch transition temperatures and sctual fracture behavior. A possible explanation of this is that the speed of impact

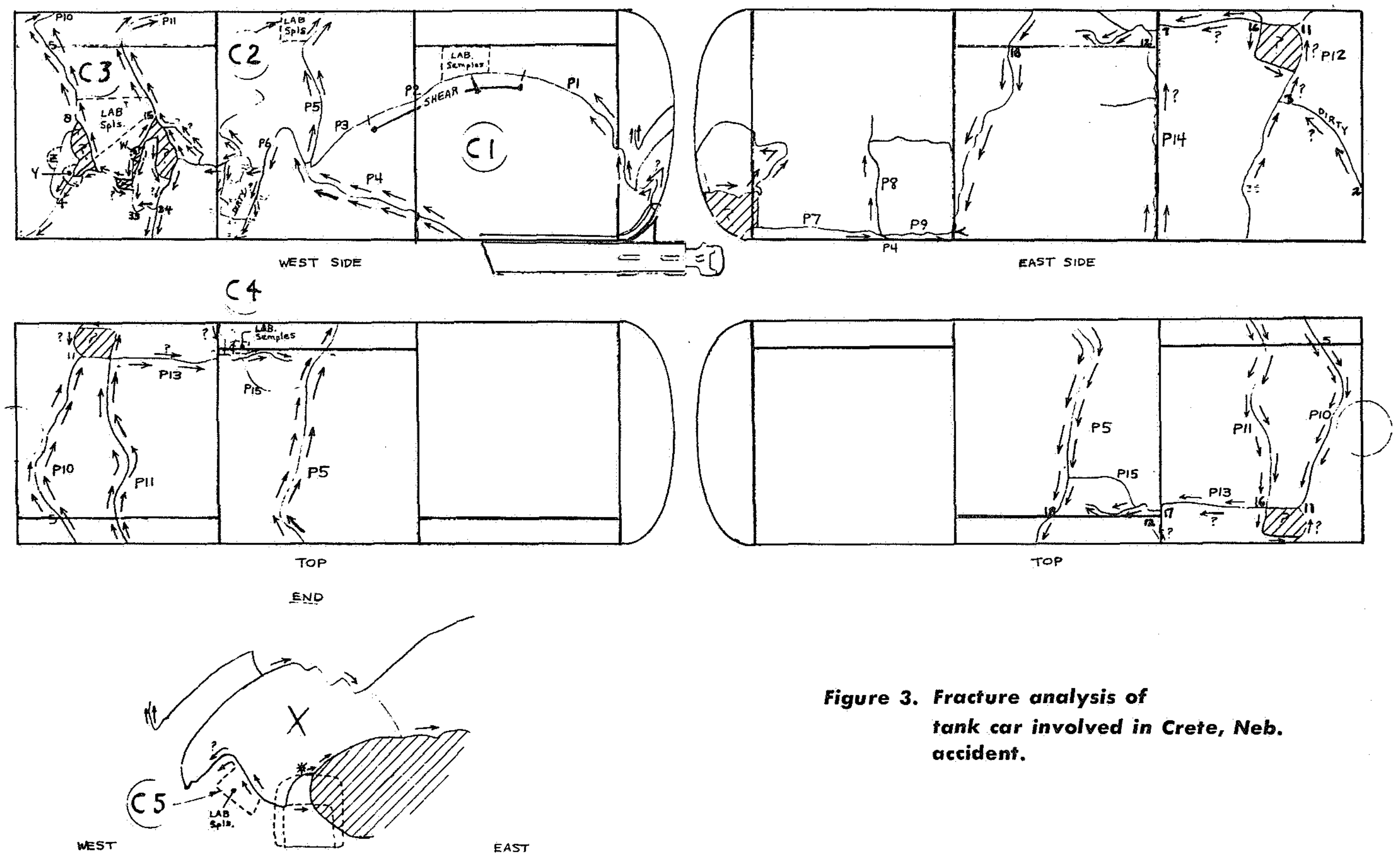


Figure 3. Fracture analysis of tank car involved in Crete, Neb. accident.

RPI-AAR RAILROAD TANK CAR SAFETY, RESEARCH AND TEST PROJECT ORGANIZATION

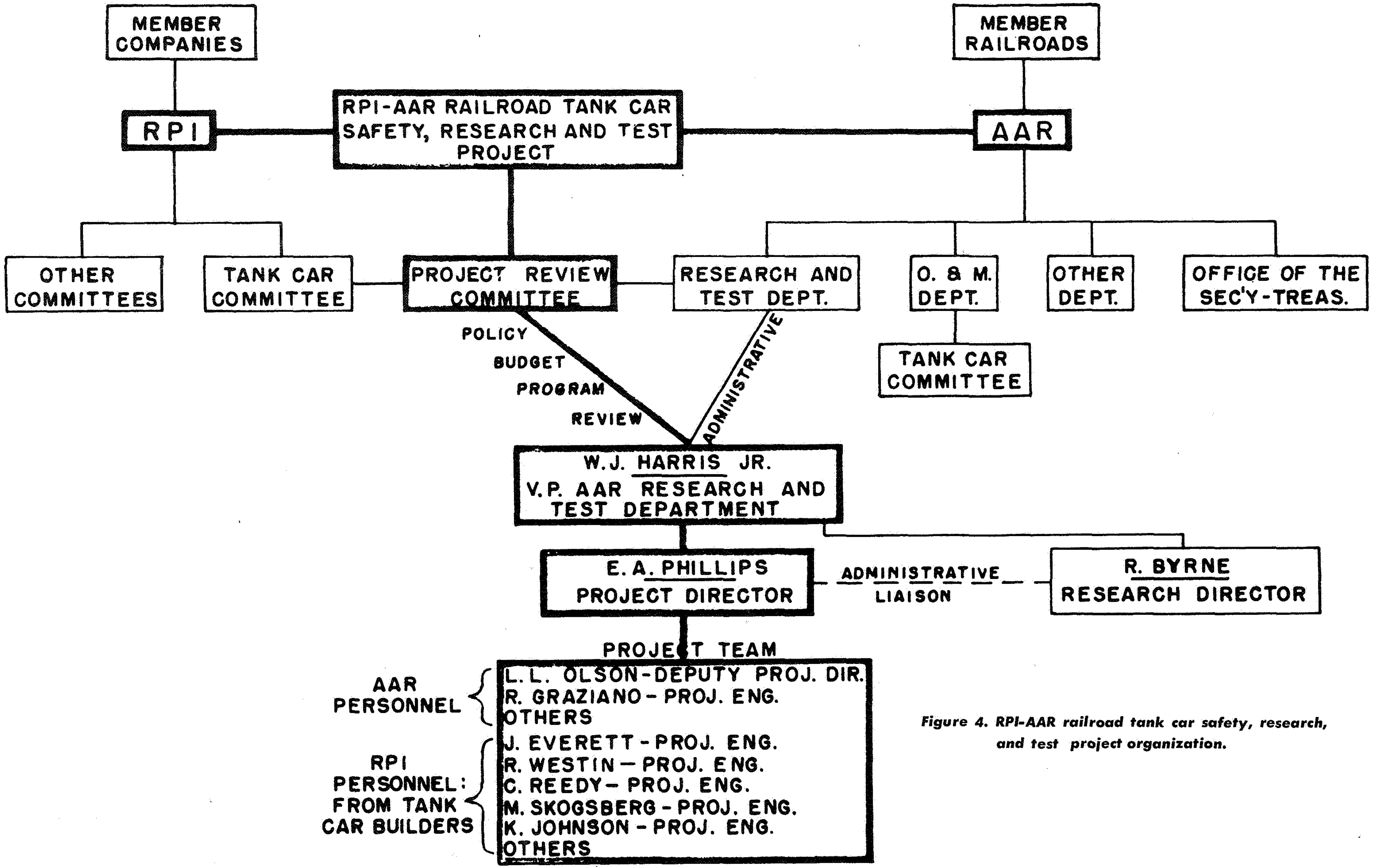


Figure 4. RPI-AAR railroad tank car safety, research, and test project organization.

precluded predictable fracture behavior. As we have seen in other instances where tank cars have been ruptured by mechanical blows, even at high ambient temperatures, there is often a mix of fracture surface patterns, some of high energy (ductile) and some of low energy (brittle) nature. The fracture appearance transition temperatures (FATT - or temperatures at which specimen fracture surfaces were 50% fibrous and 50% cleavage) correlated better, but the nil-ductility transition temperatures (NDTT) correlated best.

The results of the AAR investigation led to recommendations for further study in the areas of: steel toughness requirements, based primarily on NDTT tests, if feasible; fabrication procedures for tank heads; and the design of the head-to-sill juncture of stub sill type cars.

A historic parallel

Prior to 1900, tank cars carried rather innocuous products which did not badly misbehave in derailments; hence there was little impetus to develop tank car specifications. The picture changed when refined petroleum products, such as naptha, appeared in more quantity, and collisions, such as the one shown in Figure 4, began to occur. The problem became so severe that in 1903 the Master Car Builders' Association established a committee to review the need for certain specifications to cover tank cars. Following the committee's report proposing such specifications, it was stated, ". . . . THIS REPORT WAS PROMPTED BY . . . AN ACCIDENT IN WHICH AN ENTIRE SERIES OF OIL*-TANK CARS WERE IN COLLISION, AND WERE SUBSEQUENTLY IGNITED. During the fire which ensued, one or more tanks exploded . . . following which . . . a plan of experiments was . . . carried on . . . involving the destruction of at least seven tank cars and at least 60,000 gallons of naptha. These experiments were decidedly lively while they lasted and impressed everyone . . ."

The final outcome led to increases in tank car strengths to better resist collision forces and to the adoption of safety relief devices designed and tested to maintain safe internal tank pressure in the event of fire.

In subsequent years and to date, the specifications have been reviewed twice a year by the AAR Committee on Tank Cars, and in cooperation with such organizations as the Compressed Gas Asociation, Chlorine Institute, Manufacturing Chemists Association, and the American Petroleum Institute. Through this effort, changes have been made to keep pace with the increase in types and quantities of hazardous products shipped and with increases in tank car sizes, train sizes, and train speeds.

Following numerous tests and studies, the underframeless car was introduced in the late 1950's as was the domeless car and the non-insulated pressure car. Further specification additions and changes were adopted to improve the performance of tank cars in derailments, including the areas of overall car strength, safety releif devices, fail safe breakaway design of tank attachments and fittings, protective housings over fittings, and tank steel and aluminim specifications, the latter through considerable cooperative effort with the material producers. More recently, the Committee has required that:

couplers.

2. A breakaway design concept be employed for stub sills and body bolsters on underframeless cars wherein these components are to be attached to reinforcing plates in a manner which is no more than 85% as strong as the attachements of the reinforcing plates to the tank.
3. Stress concentrations associated with these reinforcing plates be reduced through the use of smooth contours.
4. High-temperature resistant gaskets be used on pressure cars.
5. All brackets above a specified minimum size be attached to the tanks through intermediate reinforcing pads which in turn are smoothly contoured to reduce stress concentrations.
6. The safety valve discharge port on pressure cars to be so sized and oriented that vertical discharge is assured so as to reduce the possibility of flame impingement on the tank.

In drawing from the pool of all possible improvements, the obvious ones are soon exhausted, and additional ones are found only through increasing study and research.

With the establishment of our Tank Car Safety Project, we see history repeating itself to an extent, but this time it is in relation to a broader and more complex problem.

Research and test project

Following several major derailments in 1969, attempts were made by the AAR, railroads, tank car builders and various shipper organizations to establish a framework for conducting research in the area of tank car safety. The subject project evolved from these efforts through an agreement between the AAR and five major tank car builders through the Railway Progress Institute (RPI).

The project organization is shown in Figure 5. The program is being administered by the AAR Research and Test Department under Dr. William J. Harris, Jr., and policy direction is being furnished by a Project Review Committee comprised of representatives of the tank car builders, the AAR, and the railroads. I am on leave from Union Tank Car Company to supervise the program technically as Project Director, and L. L. Olson of the AAR Research Center is the Deputy Project Director.

For the first six months of the program the sponsoring tank car companies are contributing five professional people and $100,000. The AAR is contributing two professional people and $30,000 during this period. Our present plan calls for a two-year program with additional manpower and funding to be provided on an "as requested and approved" basis for each successive six month period.

Our program objective is the broad one of "seeking means to improve tank car safety in accidnets". The term "accident" as used in our project includes derailments and other type catastrophies, such as the rupturing of a stationary tank car that has been enveloped in an unloading area fire. We intend to attack the problem on a deliberate and comprehensive basis, and to soundly justify all conclusions and recommendations.

The project scope covers all types of tank cars and hazardous products, but will emphasize the statistically more important, such as pressure cars that carry LPG, anhydrous ammonia, and vinyl chloride. We will give lower priority to accidents which occur with less frequency, as with ethylene oxide, and to less catastrophic accidents, as with many non-pressure flammable liquid products.

Table 1. Abridged specifications of TC-128-B steel.

Chemical*

C	0.25
Mn	1.35 (≤3/4 in.)
P	0.040
S	0.050
Si	).30 (≤3/4 in.)
V	0.08
Cu	0.35
Ni	0.25
Cr	0.25
Mo	0.08

*All are maximums

Tensile

T.S. - 81.000 to 101.000
Y.P. - 50.000 min.
ELONG. 2 in. - 19.0 min.

Importantly, our project scope does not include the intial cause of an accident unless a tank car tank, or a component peculiar to a tank car, is responsible. We thus treat tank car behavior immediately following the beginning of an accident. For example, at Crete, our starting point was when the car received the blow on its head.

Project planning was completed in April 1970. The first six months period of our program began May 1, 1970.

Activity has been divided into 12 technical phases. Eight phases are identifiable with particular portions of the tank car and with particular types of damage; the other four phases are of a data collection and advisory nature. These will be discussed now in more detail.

Phase 01 - accident review — This phase comprises the collection of detailed accident data and involves our major manpower expenditure. As is usually the case, the recovery of comprehensive and reliable data is extremely time consuming. We are employing three people full time in this effort and between one and two clerical personnel to log the data. The information is being collected from the nine sources shown in Figure 6. Our target is to cover every tank car damaged from 1965 to date, whether it be involved in a major accident or is only slightly damaged in a minor one. To be included, however, the damage must be to the tank or its attachements since damage to running gear or undercarriage components would not be peculiar to tank cars. For the period prior to 1965 we are collecting data on only major accidents.

On-site inspections of current accidents are made by one or more members of our Accident Review Team; and the data accumulated from this source is proving to be one of our most valuable inputs.

Phase 02 - derailment review — Under phase 02 we will assemble, classify, and analyze the collected data so as to statistically and technically define the problem with good accuracy and provide a sound basis upon which to evaluate project findings. As might be expected, we will computerize most of the data. Eight pages of data for each damaged

FIGURE - 7
PROJECT PHASES

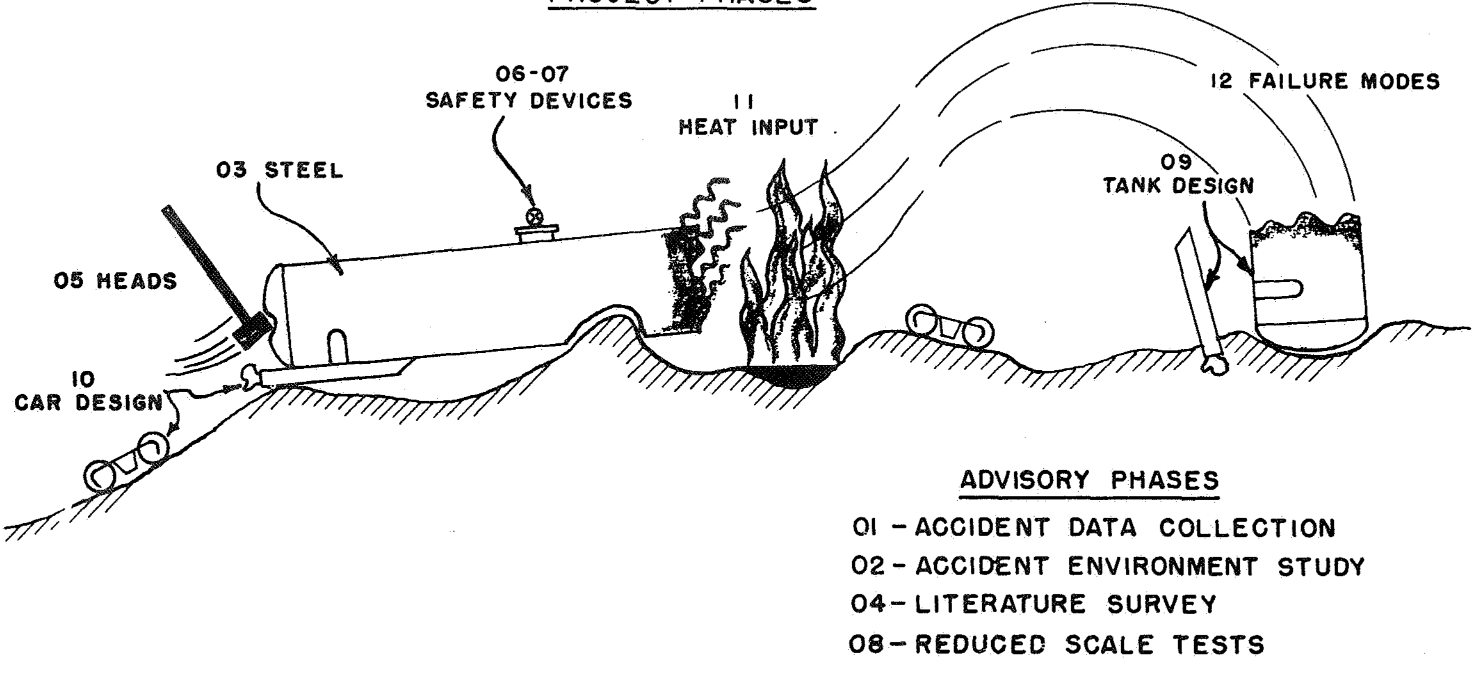


Figure 5. Project phases.

tank car and several pages of summary data for each major accident will be processed, and trhough computer programming, we will classify the data on various bases. This activity will begin in several months when sufficient phase 01 data is on hand.

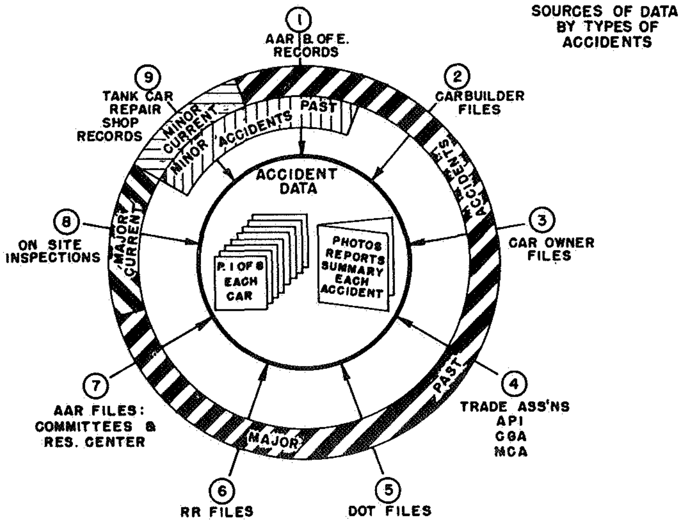


Figure 6, Phase 01 - accident review

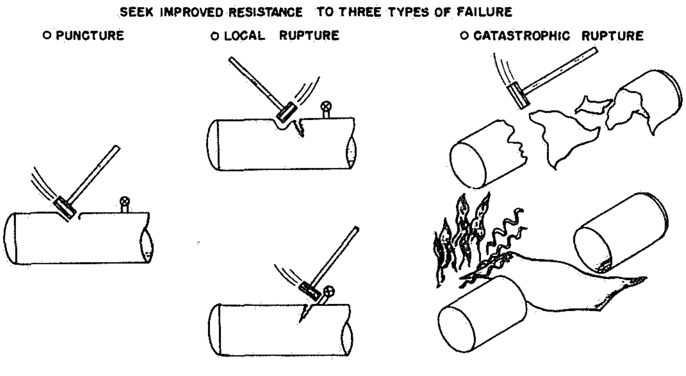


Figure 7. Phase 03 - materials study (steel).

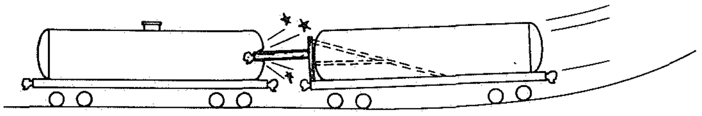


Figure 8. Phase 05 - head study.

Phase 03 - material study - steels — The objective of this phase is to seek improvements in steels that will reduce the severity of punctures and ruptures. We will be concerned primarily with toughness and strength properties at various temperatures as related to crack initiation and crack arrest. We have excluded other materials of construction on the bases that there are decidedly fewer non-steel tank cars and they generally carry less hazardous products.

Steel tank damage under which product can be released can be classified into three types, as shown schematically in Figure 7:

1. A puncture caused by a piercing object
2. A local rupture adjacent an area receiving a mechanical blow
3. A catastrophic rupture triggered by heat or a mechanical blow

One of the latter type rupture patterns characteristically involves a completely unfolded and flattened center section of the tank and two intact end tubs which are hurled distances up to several thousand feet. It appears that this pattern occurs only when the tank steel is weakened by heat impingement over the vapor space area. In contrast, we find a variety of rupture patterns when the trigger is mechanical impact, as for example, at Crete.

One approach toward reducing the frequency of catastrophic ruptures will lie in the reduction of the probability of occurrence of the first two types of tank damage. This is because the catastrophic ruptures are often found in chain reaction sequences initiated by minor punctures or ruptures.

Phase 04 - review of literature and related experience — Under this advisory phase we will review background experience and literature in our various technical areas of interest. We are accumulating much of this on our own and have set up a modest project reference library.

We also will contract with a research organization to review case histories of non-tank car pressure vessel failures and destructive tests of pressure vessels.

Phase 05 - head study — Mechanical damage to tank car heads occurs with sufficient frequency to warrant handling the matter under a specific phase. The objective of this phase is to seek means to increase the resistance of tank car heads to ruptures or punctures. Some reduced-scale tests already have been conducted, and a series of preliminary full-scale tests will commence shortly with the impacting of old tank cars using a ram car as shown in Figure 8. The ram car will be outfitted with a standard draft sill and coupler to simulate the condition of a tank head being struck by the coupler of an adjacent car. This sill and coupler arrangement will be adjustable vertically to permit striking heads at various heights. We have made the striker detachable so that the car can be moved in interchange to other test sites as our program needs dictate. Variables of head thickness, geometry of attachments, steel properties, and deflectors or shields will be examined as this work progresses.

Phase 06 - safety valve in liquid study — When a tank car carrying liquified compressed gas is heated in a fire, its liquid contents can expand to where the tank can become nearly shell-full at the safety valve pressure setting. The safety valve than may be called upon to maintain safe tank pressure by momentarily discharging liquid. It may also be called upon to do this in the event the tank is overturned and exposed to fire.

As in other pressure vessel codes, the tank car specifications require that safety valves be sized and tested on the basis of vapor discharge. There being no firm data on liquid discharge capacities, we will determine them under this pahse by means of full-scale tests, both in water (as a start), and then in propane.

Phase 07 - safety relief devices - general — This phase will treat the more general subject of safety relief devices for tank cars, and has the more general objective of seeking means to provide for safer containment or safer release of hazardous products in accidents. This activity is scheduled later for several reasons, one of which is the dependence on the phase 06 findings. Another is the continued experience we will be gaining on safety device performance and on modes and causes of tank failures under phase 01; for example, to date, we have found no evidence of tank ruptures attributable to excessive internal pressure caused by a malfunctioning safety device.

Phase 08 - reduced scale model studies — Under this advisory phase we have engaged a consultant to evaluate the feasibility of reduced-scale model tests that may be helpful under other phases. We will use model tests primarily to guide us in improving the efficiency of full-scale tests. As mentioned, this already has been done under phase 05 where we have completed a series of drop wieght tests on /12th scale model heads in preparation for the full-scale tests. Among the obstacles we face in scale model testing are primarily the inability to scale gravity and thermal radiation; however, these will be considered carefully since it does not take much imagination to visualize ehe costliness, not to mention the liveliness, of a series of meaningful full-scale tests.

Phase 09 - design study - tanks and attachments — Here we seek means to streamline the tank in order that it can better survive mechanical abuse while sliding along a track or rolling down an incline. Design studies are underway concerning the reduction in size and the streamlining of tank projections, and concerning improved breakaway performance of tank attachments. In particular, the underframeless stub sill car, which is the design predominantly produced today, will be studied from the viewpoint of achieving fail-safe breakaway performance of its stub sills and bolsters.

While we plan test work under this phase, we are finding here, as in many other phases, that our most important data derives from inspections of current accidents.

Phase 10 - design study - car — Under this phase we will study the influence on our problem of design elements of tank cars which are not associated with the tank or its immediate attachments. Of interest, for example, is the effectiveness of interlocking couplers in reducing catastrophies by virtue of their potential ability to maintain in-line configurations of derailed cars, and also, the effectiveness toward this end of locking center pins which have the potential to keep trucks attached to the cars in derailments.

Phase 11 - thermal effects study — The whole thermal question, including fire environement and thermally induced stresses, is covered under this phase. Extensive research and testing has been conducted over the years in these areas, particularly concerning heat input from fire and its relationship to the safety relief valve discharge capacity. Following an extensive review of this experience, we will consider the feasibility of conducting full-scale and/or model tests with full instrumentation. Here again, we have been able to accumulate vital information from our investigation of current and past accidents.

Phase 12 - vessel failure research — This is our basic research phase. Its primary objective is to explain a number of fundamental phenomena associated with the catastrophic type rupture. This includes the rocketing of tank sections by apparent continued thrust, the hurling of tank segments by apparent initial impulse only, the characteristic patterns involving unfolded and flattened center sheets and circumferentially separated end tubs, brittle failures, and the simultaneous rupturing of tanks at more than one location. This study will involve many areas of engineering mechanics and metallurgy, such as fracture mechanics, fluid dynamics, heat transfer, structural dynamics, shock, and thermodynamics. We have sought outside help to assist us in many of these areas.

Conclusion

As seen, our program attacks all fronts. We have assigned a Phase Leader to supervise and coordinate each phase. While staying within the bounds of our overall timetable and objectives, we maintain flexibility in planning and scheduling as dictated by current project findings and continued input from our accident data collection effort.

There are numerous questions to examine, a variety of suggested solutions to evaluate, and more still to uncover. No answer will solve the total problem, but we are confident that measurable improvements will be forthcoming.

Literature cited

1. "Report on a Study of Tank Cars Involved in a Collision at Crete, Nebraska." Report No. MR-454, AAR Research Center, Chicago, Ill.

2. "AAR Specifications for Tank Cars," Appendix M, Association of American Railroads, Chicago, Ill.

DISCUSSION

SAM STRELZOFF, Consultant; Tank ruptures such as described can happen with ammonia storage tanks. What amazes me is that the project just lists 12 phases, and nothing was mentioned about the transportation aspect. Just recently, a train with very dangerous material moved across the continent, and they had a pilot train in front to prevent any chance of collision. I believe very much that if you move a long train with many cars of ammonia and other similar products, serious consideration should be given to the matter such as was done for the dangerous materials that are being sent from the West Coast to the East Coast.

All project phases that you mentioned today seem to be concerned with action following the collisions on the railroad track. But the question in my mind, if you want to really be safe, is what do you do about railroad practices in order to prevent such collisions?

All the studies that you make relative to the cars, such as materials, etc., are attractive but if you don't prevent the collision, I doubt that you will really resolve the problem.

Secondly, in my mind, while we all hear about the railroad tank cars, what is being done about storage tanks that remain in a plant? Many years ago, I believe in 1929, we had a storage tank rupture wherein 35 people were killed.

PHILLIPS: Your points are well taken. It's simply a case of defining a project scope. We never at any time, since we began to outline and develop our program, considered getting into the area of railraod operation. I know that the railroads, through their own efforts and through the AAR Operating and Transportation Division, are doing a lot in this area.

They are considering the questions of train speed, car spacing, the use of buffer cars between cars carrying hazardous products; these are matters not included in our project scope. Our project is related to the technical matter of railroad tank car design. By the same token, we are not in the areas of permanent storage vessels or highway tank trucks. Our project, incidentally has a broad enough scope as it is.

IAN McFARLAND, ICI America: When you were discussing the results which I believe were published in MR454 on the Crete tank, you mentioned the correlation between fracture pattern on these plates and three types of tests, which are NDTT, - fracture appearance, which you said both agreed fairly well, and the Charpy results, which did not. I would like to make a comment on this, if I may, and that is that the values which I believe you compared in MR454 were 15 foot pounds. Now, this comes from ASME VIII, division 1, and historically goes back to the investigation of Liberty ships, I think, in World War II. The steel used in those ships was of relatively low strength and this Charpy value really doesn't have any meaning at all in this particular context. It really has to be tied in to the strength of the material, and I believe that the normal practice with ICI in England is to put in a Charpy value which should be applied according to a formula which I believe is ,066Y^2 where Y is the yield strengh in long tons per square inch, with a minimum of 15 and a maximum of 40 foot lb. Now, applying it to the steel in these tank cars we are referring to now, we find ourselves right on the maximu , and if we apply 40 foot lb. I think you will find that the Charpy values you get would suggest that you would expect brittle fracture.

PHILLIPS: I did not want to go into the details of this AAR report; it is available for anyone who wishes it. The AAR charges a nominal price for it, and it is quite extensive and covers the results of a log of work, and it is available throught the AAR office in Chicago.

W.D. CLARK, ICI Agricultural Division, England: We are of course very much involved in this, because we tank a lot of ammonia around the country ourselves. By and large we don't do it in such big tank cars as yours, and we have had no serious accident. But we have derailed quite a lot of tank cars, because for quite a time we couldn't really persuade the people to use the right sort of bearings on them.

I am particularly interested to hear from what we've been told today that the proposition of using model tank cars to investigate the brittle fracture properties — what would happen to a tank car in a collision — has been, I suspect, largely dropped.

One of the things that we are very clear about, and I'm sure the American Naval laboratory and so froth are equally clear about, is that doing tests on quarter size or half size thicknesses gives you no clue to what grade of steel you need in the full scale thickness. Obviously, model tanks - cars - can tell you a good deal about how the shape of things affect what happens. Referring to what McFarland said, we have set our plans on what we want do do on tank car steel, and that is to demand that the steel has, at the minimum operating temperature a Charpy V impact value of 0.66Y^2 where Y is the yield point in tons/in tons/in^2. At 55000 lb/in^2 yield this is 40 ft-lb, but for stronger steels we do not to ship plate, has no general significance.

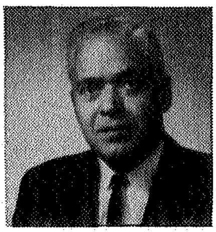
You want 20, 30, 40 foot pounds before you can get the equivalent resistnace to brittle fracture that was found necessary in the case of the Liberty ships and so forth. ASME 3 has requirements which are slightly less conservative than the ones we are trying to get. I say, "trying to get," because in England, just as in the States, you go to a steelmaker and you say, "I want some tough steel".

And he says, "Well, yes — we have tough steel. Oh, but we haven't it that tough! Don't ask for the impossible!" Well the impossible is a thing that we are steadily getting. If you push hard enough, you can get something remarkable. You may have to pay for it, and it's a pity - you will have a lot of tanks on the road which aren't as good as they ought to be, and you can't afford to scrap them all at once, but you've got to progress, because the ultimate in accidents is likely to happen at some time.

Tank cars will crash and split in more awkwards spots than Crete - which was unfortunate, but it could have happened in a much worse spot. We are trying to buy steel for our own tank cars to a drop weight test. In the States here you are in a better position than us, because you hav you have that test written as an ASTM specification, while in England, as yet, we haven't got such a specification, and steelmakers therefore can make it even more difficult for us.

But that's what I expect to find in a year or two you will be going. Thank you.

PHILLIPS: I guess that wasn't really a question, but I appreciate the comments. I noticed that at one point you referred to scale models and fracture toughness. We are not planning on using any of the scale models test to investigate the actual fracture phenomena. This is for the obvious reason that you do not get the same type of fracture behavior as you get in the full scale case. The scale models will be used to evaluate design features, such as structural constraints.



PHILLIPS