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Fire Hazard Evaluation of BART Vehicles

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Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

March 1978

Final Report

Prepared for
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A fire hazard evaluation of the subway cars used on the San Francisco Bay Area Rapid Transit District was performed. After analyzing the cars' interior and exterior design, five recommendations were made that, if implemented, would improve passenger safety by decreasing the probability of developing a hazardous fire situation. Among these recommendations were the upgrading of current upholstered urethane seat assemblies and the need for the development of a fire detection system appropriate for rapid rail transit vehicles. Those system improvements would not only provide passengers a safer traveling environment but would also provide a modest level of protection for the heavy investment in rail vehicles.

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FIRE HAZARD EVALUATION OF BART VEHICLES

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Abstract

A fire hazard evaluation of the subway cars used on the San Francisco Bay Area Rapid Transit District was performed. After analyzing the cars' interior and exterior design, five recommendations were made that, if implemented, would improve passenger safety by decreasing the probability of developing a hazardous fire situation. Among these recommendations were the upgrading of current upholstered urethane seat assemblies and the need for the development of a fire detection system appropriate for rapid rail transit vehicles. Those system improvements would not only provide passengers a safer traveling environment but would also provide a modest level of protection for the heavy investment in rail vehicles.

Key words: BART; fire accidents; fire hazards; fire safety; fire scenarios; mass transportation; material fire performance; rail vehicles; subway car design; UMTA.

1. INTRODUCTION

At the request of the Urban Mass Transit Administration (UMTA), the National Bureau of Standards (NBS) conducted a limited fire hazard analysis of the subway cars used on the San Francisco, California Bay Area Rapid Transit District (BART). The purpose of this investigation was to ascertain if any aspect of the design details or the material specifications relating to the subway car could result in an environment that has a high probability for developing into a hazardous fire situation. Throughout this analysis, primary consideration has been given to passenger safety under various fire scenarios and only secondarily to the protection of the rail vehicles. The analysis relies on material evaluations supplied to NBS by BART, with the testing being done by laboratories other than NBS.

Any transportation system presents both the occupants and operators with a certain level of fire risk which depends in part on the fire characteristics of the materials used in constructing and furnishing the vehicle. In addition, since mass transportation systems confine large numbers of people in small areas, evacuation may be difficult in a fire situation. This is especially true in subway systems, which present unique problems, such as the evacuation of passengers and personnel from a car made untenable by fire and located not at a station, either above or below the ground. The BART system is made up of approximately 73 miles of mainline track and 38 stations. About 25 percent of mainline track is below ground while nearly 42 percent of the stations are underground. These underground stations represent unique evacuation problems that must be recognized in any overall fire safety analysis, but that will not be discussed here, since this paper is devoted to the potential fire hazards in the rail vehicles.

2. SUBWAY CAR DESIGN

BART vehicles come in two configurations, an A-car and a B-car (see figure 1) [1][1]. Except for the attendant's cab, which is mounted on the front of an A-car, both configurations are identical. An operational train is made by coupling up to eight B-cars between two A-cars. Since A-cars contain all train controls, the smallest train that can operate on the BART system is two A-cars coupled back-to-back.

When the cars are mechanically coupled to each other, the cars are also automatically coupled electrically. The lead A-car automatically receives traffic information from a central computer system that monitors the overall system. The train computer system is completely interactive to the extent that the train operator's primary function is that of monitoring an annunciator panel in the attendant's cab of the lead car. Also, the train operator controls the door closure override to insure that all patrons are clear of the doors before they close.

2.1. Interior Car Design

Figure 2 illustrates the seat placement in the A-car and B-car configurations [2]. Each configuration provides sufficient seating for 72 passengers and a maximum "crush load" of an additional 216 standing patrons. There are eight longitudinal seats located behind modesty screens adjacent to each door. The remaining 28 seats are divided into three sections separated by the side entrance doors.

Each seat assembly consists of a molded urethane foam bottom and back encased in an upholstery fabric. The fabric is a combination vinyl/nylon assembly (figure 3) [1]. The outer edges of both bottom and back cushions are vinyl with the center section made of a nylon fabric. The seat cushions snap into the seat frame which, in turn, is attached to the sidewall.

The sidewall and ceiling liners are made of molded, glass fiber reinforced, polyester resin. The ceiling liner is riveted to the roof panel and has recessed molded inserts for lighting and speakers. The sidewall liner also forms the interior plenum for the heating and air

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[1] Numbers in brackets refer to the references listed at the end of this paper.

conditioning system. The air handling system has outlets along the bottom sill of each window, while the returns are located along the bottom of the sidewall, below the seat assemblies.

The floor panels, throughout the passenger compartment, are covered with a latex foam pad and wool carpet, except over the bolsters. In these areas, the standard latex foam pad is replaced by a vinyl-covered polyester urethane pad, Baryfol (TM). This special pad is intended as a sound barrier against under-car noises emanating from the track areas.

2.2. Exterior Car Design

The car exterior is made of extruded aluminum sheet stock. The car is designed such that all train controls and machinery are located below the car floor. The only exceptions are the electrical wires for lighting and inter-car communications. While some of the subfloor wiring is confined to conduits, the majority of the wiring is strapped at convenient intervals to the under-floor beams and completely exposed to the under-car environment.

The under-car equipment, which is attached to floor beams and bolster plates, includes:

a) the heating and air conditioning equipment,
b) the trucks subsystem motors and braking system (dynamic and friction brakes),
c) the air suspension system,
d) the starting and braking resistors,
e) the third rail shoe (1000 VDC).

The floor that separates this equipment from the passenger compartment is constructed of an aluminum ((6061-T6) .15 cm (.060 in)) sandwich with a 2-inch core of polyurethane foam. This extends throughout the length of the car.

2.3. Communication System [3]

There are two interrelated communication systems in each train. One is for intra-train communications and the other is for communications between the train operator and central control. Switching also exists on the train operator's console to permit public address announcements to be made directly by central control to the passengers.

2.3.1. Intra-Train Communications

There are two types of intra-train communications. One is a general public address system that allows the train operator to simultaneously key on all of the speakers in each car. Under standard operating conditions, this is used to announce station names. However, in the event of an emergency, it is intended to be used to direct passenger movement away from hazardous locations.

The other mode of intra-train communications is the passenger-to-attendant intercom located at the ends of each car. The intercom is activated by the passenger when he depresses a button located next to the speaker/microphone.

2.3.2. Inter-System Communications

Two-way communications, via the train radio system, exist between central control, trains and maintenance vehicles. In addition, a system of telephone lines is installed along mainline tracks. There are two types of telephone lines, maintenance telephone lines and emergency telephone lines. Maintenance telephone lines are brought out as plug-in jacks at each maintainable piece of equipment. Portable phone handsets can be plugged in and communications can be established with the Central Communications Controller.

The emergency telephone lines are an independent system that provides emergency call boxes within line of sight of not more than 1,000 feet apart in all tunnel and subway sections. It is possible to remove power from the third rail by a trip button located in these telephone boxes.

3. FIRE PERFORMANCE OF EXISTING BART MATERIALS

Table 1 is a list of the flame exposure tests that were required to be performed on the synthetic components in the BART vehicle. Table 2 is a summary of the results of tests performed on the seat cushions and upholstery fabric according to the records on file by BART [4]. The test results for the other materials were not in BART files, however, upper flammability limits were specified in the original specifications and BART personnel stated that all of the materials used in BART vehicles met or exceeded these limits. These limits are listed in table 3. All of the specified test methods except for ASTM E-84 utilize a small and localized ignition source.

3.1. Test Methods

3.1.1. ASTM D 1692

This test determines the rate of burning or extent of burning of cellular plastics using a horizontal screen to support a 15 x 5 x 1.3 cm (6 x 2 x .5 in) specimen. A propane bunsen burner with a flame spreader attached is the ignition source. It is applied to one end of the specimen for 60 seconds.

BART requires that materials tested by this test method "self-extinguish." This term, which was used prior to the 1973 revision but is no longer considered meaningful, was used to classify materials which did not propagate a flame under these test conditions.

3.1.2. ASTM D 635

This test is intended for the measurement of the rate of burning or extent of burning of self-supporting plastics. A 12.7 cm x 1.3 cm (5 x .5 in) specimen in its end-use thickness is clamped with its long dimension in the horizontal direction. A bunsen burner flame, fueled with "laboratory gas," is applied to the unclamped end of the specimen for 30 seconds. All materials tested by this method must "self-extinguish" (that is, the specimen must not propagate a flame under these test conditions) in order to meet BART acceptance criteria. However, as in ASTM D 1692, this term is no longer considered meaningful.

3.1.3. FS 5906/CCC-T-191

This test method is intended to determine the horizontal burn rate of various materials. Like the previous test methods, this one also applies a bunsen burner flame to the lower surface of a 33.0 cm x 11.4 cm (13 x 4.5 in) specimen. Upholstery fabrics tested by this method must not have a flame spread rate in excess of 12.2 cm/min.

3.1.4. ASTM E-84

The purpose of this test is to determine the surface burning characteristics of various materials. A specimen 51 cm wide by 7.3 m long (20 in x 25 ft) is mounted and supported on the ceiling of a long test chamber. Two gas burners pointing up at one end of the chamber impinge flame on the exposed surface of the specimen. The test evaluates a material's flame spread, fuel contribution, and smoke development. BART's primary concern is with flame spread and, therefore, the acceptance criteria for flame spread is 75 on a scale where red oak is 100 and asbestos-cement board is 0.

3.2. Small Scale Flame Exposure Tests-Discussion

Small scale flame exposure tests are designed to measure a particular physical characteristic of a material in a given environment. The degree to which this evaluation is related to real world performance depends on the scenario that was used to develop the test method and the degree to which the test exposure simulates a real world fire situation. With the exception of ASTM E-84, all of the test methods used to evaluate component materials in the BART vehicle assume that the material will be exposed to a small ignition source and that it will be the first item to ignite. The ASTM E-84 test was designed to evaluate mainly wood-base interior finish building materials under more severe fire conditions than a small bunsen burner. This test was used to evaluate BART floor coverings. The carpeting, therefore, is tested under flame exposure conditions that are significantly more severe than used on the other components. There is a question as to whether the ASTM E-84 test is meaningful for testing floor coverings such as carpeting [5].

4. FIRE PROTECTION SYSTEM

No active fire detection and suppression system exists on the BART system. Fire suppression takes two forms. For interior car fires, one fire extinguisher is located at each end of every car. In A-cars, one fire extinguisher is behind the attendant's seat, while the other is in a compartment behind seat number 1 (figure 2). In the B-car, the fire extinguishers are behind seats 1 and 36 (figure 2).

Fire suppression for under-car fires is accomplished by a series of sprinkler heads located between tracks at grade level at all underground stations. The line to the sprinklers is dry and must be activated from the platform. The sprinklers are capped with plastic shields that are ejected at 15 psi water pressure. In addition, there are dry standpipes at each station to facilitate fire fighting.

5. FIRE INCIDENTS ON BART [6]

From March 1975 until November 1976, there have been 27 fire or smoke incidents on subway cars of the BART system. All but three of these incidents occurred below the car floor and did not penetrate into the passenger compartment. The remaining three cases involved interior car fires that produced only minor damage, primarily because the fires were detected at an early stage of development and quickly extinguished. Two involved smoldering or burning trash that was extinguished by BART personnel. The third was an aborted arson attempt to ignite a seat cushion with a pile of matches.

In addition to these incidents, there have been two serious fires involving BART transit vehicles: one in November 1974 and the most recent in November 1976. In the former incident (car 618) the fire originated in the under-car areas and, before it could be contained, penetrated into the passenger compartment. The cause of the fire was a locked brake.

The 1976 incident (car 120) originated in the passenger compartment of the last car in a nine car train. The fire began in the center of the car, at seat number 21, and caused varying degrees of damage throughout the car. The cause of the fire has been attributed to an "external agent" [6].

6. FIRE SCENARIOS IN BART CARS

Based on BART's fire accident records and from a knowledge of fire experience in other transit systems, one can develop a series of fire scenarios that are applicable to BART. These scenarios are a description of the system's response to a given thermal input. An analysis of the probable sequence of events contained in the scenarios should point out those areas that must be protected or altered in order to reduce the risk to life safety.

6.1. Interior Ignitions

If we assume that we are dealing with a transit vehicle in mainline service and which is fitted and furnished in the same manner as current BART vehicles, there are two primary parameters that need to be defined to permit a determination of the effect of an interior ignition fire:

1) a description of the ignition source (the rate of energy release and the total amount released, and
2) the location of the ignition source.

In a rapid transit vehicle, except for electrical fires, there are three probable locations for an interior ignition source. They are:

1) on the floor - in the aisle
2) on the floor - beneath a seat
3) on a seat.

The ignition sequence assumes that the first item ignited will be either the wall, ceiling, or seat cushions. In order for the ceiling to be the first item ignited, the ignition source, located in the aisle, would have to produce flame heights approximately equal to the floor to ceiling distance of the car (2.06 m). This would require an inordinately large amount of fuel. It is, therefore, highly unlikely that this has a high probability of occurrence. No consideration will be given to this specific scenario.

For the remaining two ignition locations, probable flame spread patterns can be postulated. Consider the case of a floor ignition source. If the ignition source is below the aisle seat, there are two possible modes of flame spread. One is along the carpet and the other is along the seat cushions. Flame spread initially along the carpet (of the type in current use) is not probable based on carpet compartment tests, full-scale tests in mass transit vehicles, and an actual fire incident (car 120). This would be true even if the ignition source were reasonably large (e.g., 0.5 - 1.0 kg of newsprint). Based on the specified flammability characteristics of the seat cushions (section 3), ignition of the seat cushion is the most likely path for fire growth. At this point, the fire would probably grow in intensity until the back of the seat, the ceiling, and the wall liners were ignited. Without actual testing, it is not possible to determine if adjacent seat assemblies would ignite prior to the ignition of the wall and ceiling liners.

For floor ignition sources near the wall, primary fire growth would still be due to the seat cushions. However, the wall liner would ignite at a much earlier stage of fire development and contribute to the total evolution of heat and smoke.

For fires originating on a seat, critical fire stages would be reached sooner in comparison to floor fires. There would be nearly simultaneous involvement of back and seat cushions. At a given stage of fire growth, sufficient feedback energy would exist to permit the lateral spread of the fire to an adjacent seat cushion in the same seat assembly. From this point on, the growth and spread of the fire would resemble a floor ignition.

So far, we have postulated fire growth patterns assuming an ignition, but have not considered the characteristics of the ignition source and the minimum energy necessary to cause ignition. Probable ignition sources range from smoldering cigarettes to flammable liquids. They differ only in the rate of energy release and the total energy released. The total energy in turn depends on the mass of combustible material in the ignition source. Figure 4 shows the relationship of energy release rate for various ignition sources to the total heat released for a given mass of material [7]. Based on previous experimental work [8,9], ignition levels for various seating materials are indicated. These minimum values were arrived at empirically in a series of experiments conducted on subway and bus seat assemblies currently in use. Strictly speaking, these results pertain to the physical constraints present and the materials employed at the time of these tests. Nevertheless, it can be inferred that a significant improvement in ignition resistance can be realized by changes in the materials used in constructing the seat assemblies.

6.2. Exterior Fires

Since a majority of the fire incidents occurring on the BART system have originated below the floor, consideration must also be given to the probable results of sub-floor ignitions. In addition, sub-floor fires are the most difficult to handle because detection usually comes late in the development of the fire. Sub-floor fires may be caused by a variety of sub-system failures. The brake failure in car 618, described in section 5, is but one example of the consequences that may follow a mechanical or electrical failure. One of the reasons this incident ended with no injuries to passengers and crew can be attributed to the above ground location of the train at the time of the failure. Above ground failures that stall a train do not represent the same degree of risk to passengers that similar below ground failures do. For example, if this train had been in the Trans-bay tube, passengers would have had a more difficult time evacuating the train and fire fighting personnel would have also encountered special difficulties in suppressing the fire. The greatest hazard of such an incident would occur if the train were located between stations. Simple scenarios can be described for sub-floor failures and their consequences. The critical parameters that enter into the description are:

1) the location of the train at the time of detection,
2) the condition of the train as a result of the failure (i.e., is the train moveable),
3) the intensity of the fire.

While the first two items determine the nature of the response that BART must initiate, the third determines the effective time available for evacuation and suppression. The fire penetration resistance of the floor assembly becomes critical. If, at the time of detection, a sub-floor fire has spread over all appreciable areas of the floor assembly, the floor will fail sooner than if a fire is detected at a much earlier stage of development.

7. SYSTEM IMPROVEMENTS

There are several areas that can be upgraded to reduce the level of risk to life safety in the BART vehicles. While several different improvements will be suggested, some may represent technological and economic hardships that will effectively rule them out as viable. Since it is virtually impossible to completely harden a system against the occurrence and subsequent spread of a fire, two types of improvements will be discussed; those that inhibit the growth of a fire (i.e., changes in vehicle furnishings) and those that provide early detection of a fire.

7.1. Furnishing Improvements

Based on the scenarios postulated in section 6.1, initial fire growth from an interior fire source can be inhibited by improving the fire resistance of the seat assemblies. As currently designed, the seat cushions represent the largest contribution to the hazard level of the vehicle. There are several options available for upgrading the seat cushions. If we set aside, for the moment, the added problem of vandalism, the replacement of the nylon fabric in the upholstery design with a more fire resistant material would go a long way towards lowering the hazard from small incidental fires (i.e., a trash bag). An example of such a replacement is the use of a complete vinyl covering over the urethane cushions. If, however, one is concerned with vandalism, which may be the case in any subway system, or is concerned with larger ignition sources (i.e., newspaper), serious consideration must be given to replacing the existing cushions. It has been found that a fire-retarded neoprene cushion upholstered with a vinyl fabric is quite resistant to fire growth from larger ignition sources [9]. As a seat assembly, it has the added advantage of retaining fire retardant properties when the cover fabric is penetrated.

7.1.1. Wall and Ceiling Liners

The wall and ceiling liners present the most difficult problems in terms of improving their fire characteristics without sacrificing other material properties. Since the expense of replacing the installed liners is prohibitive, one must seek acceptable alternatives. The use of a special surface coating for the wall covering, such as an intumescent paint, may be a quite acceptable form of fire protection. However, any proposed product must first be tested before specific recommendations can be made. This testing should include an examination of properties other than fire, e.g., permanency. In addition, careful thought should be given to its maintenance and how its wear life affects the flammability characteristics.

7.1.2. Carpeting

Based on past experience and accident data, it appears that commercial floor coverings do not greatly affect the growth of a fire in a compartment, except during flashover conditions.

7.2. Floor Assembly

Not only does the floor assembly support passengers in a car, but it also acts as a barrier between passengers and any hostile environment that may develop beneath the car. The actual fire penetration resistance of the BART floor assembly described in section 2.2 is not known, but a ply-metal floor assembly (plywood-aluminum sandwich) has been estimated to have a 10-minute endurance under a given fire load [9]. It can be anticipated that the BART car floor assembly (aluminum-polyurethane sandwich) would have an appreciably shorter endurance time under the same fire load conditions. However, a retrofit at this time does not seem possible nor do any practical means appear to exist to harden the floor assembly against sub-floor fires. It may be possible to partially protect the floor assembly by shielding critical floor areas. However, the nature of the shielding material cannot really be described without an analysis of sub-floor fires.

7.3. Fire Detection

Because of the problems encountered in dealing with the wall and ceiling liners, serious consideration was given to the installation of fire detectors. With the upgrading of the seat cushions, fire detectors should provide the means necessary to detect a fire in its early stages of development and permit BART personnel to initiate appropriate fire suppression procedures. Two problems, however, are encountered in the use of fire detectors:

1) what type to use,
2) where to install them.

The type of detector to be installed is dictated by the environment in which it will be used and its tolerance for false alarms. The location of the detectors in the vehicle also poses some problems. An investigation of flow patterns in a vehicle that is in use must be made in order to properly determine correct placement of the detectors. In addition, care must be exercised to insure that communication lines between detectors, train operators and central control are compatible with existing or new hardware. This is beyond the scope of this study, but such an investigation must be performed to insure effective utilization of the detectors.

8. RECOMMENDATIONS

Based upon a review of the design and materials used in the BART subway cars, and analysis of potential fire situations, it is recommended that:

1. BART upgrade the flame resistance of the seat assemblies, e.g., by introducing all vinyl upholstery. In order to further increase evacuation time, serious consideration should be given to incorporating neoprene cushions with the vinyl upholstery.
2. BART investigate the technological and economic feasibilities of using an intumescent coating on the wall and ceiling liner.
3. BART develop a means for hardening the floor assembly against sub-car fire penetration at least in those areas most vulnerable to fire exposure.
4. BART, after additional study of detector types and locations, install a fire detection system to indicate the presence of a fire on board a train.
5. BART, in the interim, provide walk-through inspection after passing the terminal stations and/or prior to entering storage facilities.

9. REFERENCES

[1] BART Operations and Maintenance Manual, Car Body and Interior Components Manual, Vol. 12 (December 1974).

[2] BART Operations and Maintenance Manual, Transit Vehicle Manual, Vol. 1 (March 1972).

[3] BART Operations, Rules and Procedures Manual.

[4] BART Train Safety File (Flammable Materials).

[5] Cellular Plastics Products - Disclosure of Combustion Characteristics and Certification, 40 FR 30842, Federal Trade Commission.

[6] Personal Communications - BART Personnel

[7] Personal Communications - Philip Oglesby, Nat. Bur. Standards.

[8] Braun, E., Report of Fire Test on an AM General Metro Bus, Nat. Bur. Standards (U.S.), NBSIR 75-718 (June 1975).

[9] Braun, E., A Fire Hazard Evaluation of the Interior of WMATA Metrorail Cars, Nat. Bur. Standards (U.S.), NBSIR 75-971 (December 1975).

Table 1. List of Fire Tests for Synthetic Components Used in BART [4]*

Application	Material	Specified Test
Side Wall and Ceiling Liner	Glass Fiber Reinforced Plastic	ASTM D635-63
Floor Sound Barrier and Insulation	Baryfol 10M	ASTM E84-61
Windscreen Panel	Micarta (TM) Laminated Melamine	ASTM D635-63
Seat Cushions	Molded Polyurethane	ASTM D1692-59T
Seat Arm Rest Supports	Vinyl	ASTM D635-63
Seat Trim	Acrylic/Polyvinyl Chloride	ASTM D635-63
Side Wall and Door Insulation	Polyurethane	ASTM D1692-68
Seat Upholstery	Nylon/Vinyl	FS 5906-53 of Fed Spec CCC-T-191
Carpet	Wool	ASTM E84-61
Carpet Pad	Latex Foam	ASTM E84-68

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[*] More specific information on physical characteristics of these materials was not available.

Table 2. Test Results of Seat Cushions and Upholstery Fabric Tests Conducted by BART [4]

Material	Test Method	Burn Length (cm)	Burn Rate (cm/min)
Polyurethane Foam	ASTM D-1692	11.2	3.23
Upholstery	MVSS 302**		
Fabric - Warp		24.1*	2.64
- Fill		22.9*	3.45

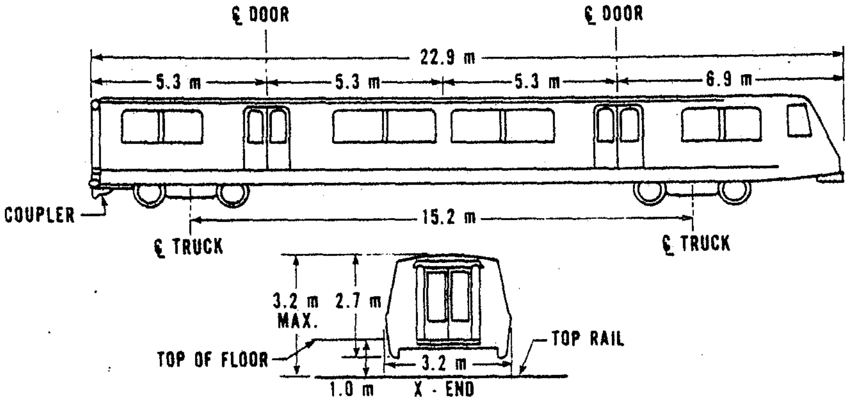
*1 out of 4 burned this length, the others self-extinguished

**Similar to Method 5906 of Federal Specification CCC-T-191

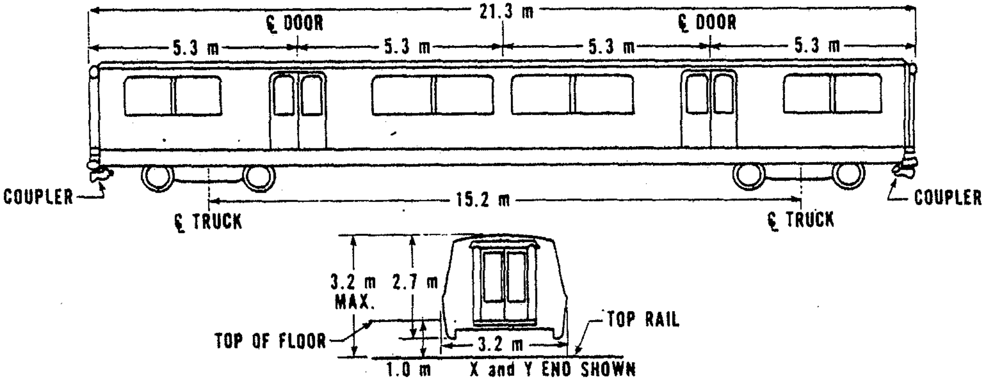
Table 3. Acceptance Criteria for Test Methods Used in Qualifying BART Materials

Test Method	Acceptance Criteria
ASTM D-1692	Self-extinguishing*
ASTM D-635	Self-extinguishing*
FS 5906	Max 12.2 cm/min - flame spread rate
ASTM E-84	Max 75 flame spread index

*Since the 1973 ASTM revisions, this term is no longer used for any fire tests.

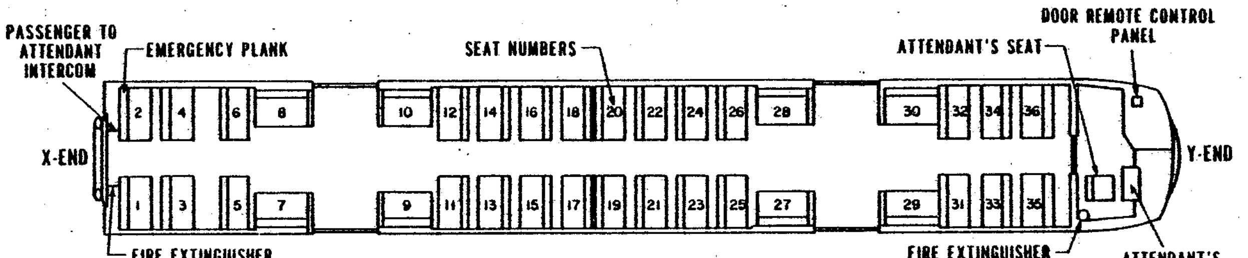


A - CAR

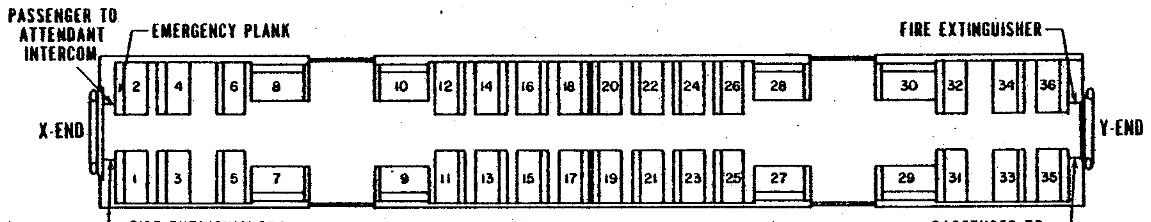


B - CAR

Figure 1. Exterior views of A-car and B-car configurations



A-CAR CONFIGURATION



B-CAR CONFIGURATION

Figure 2. Seat placements in A-car and B-car configurations

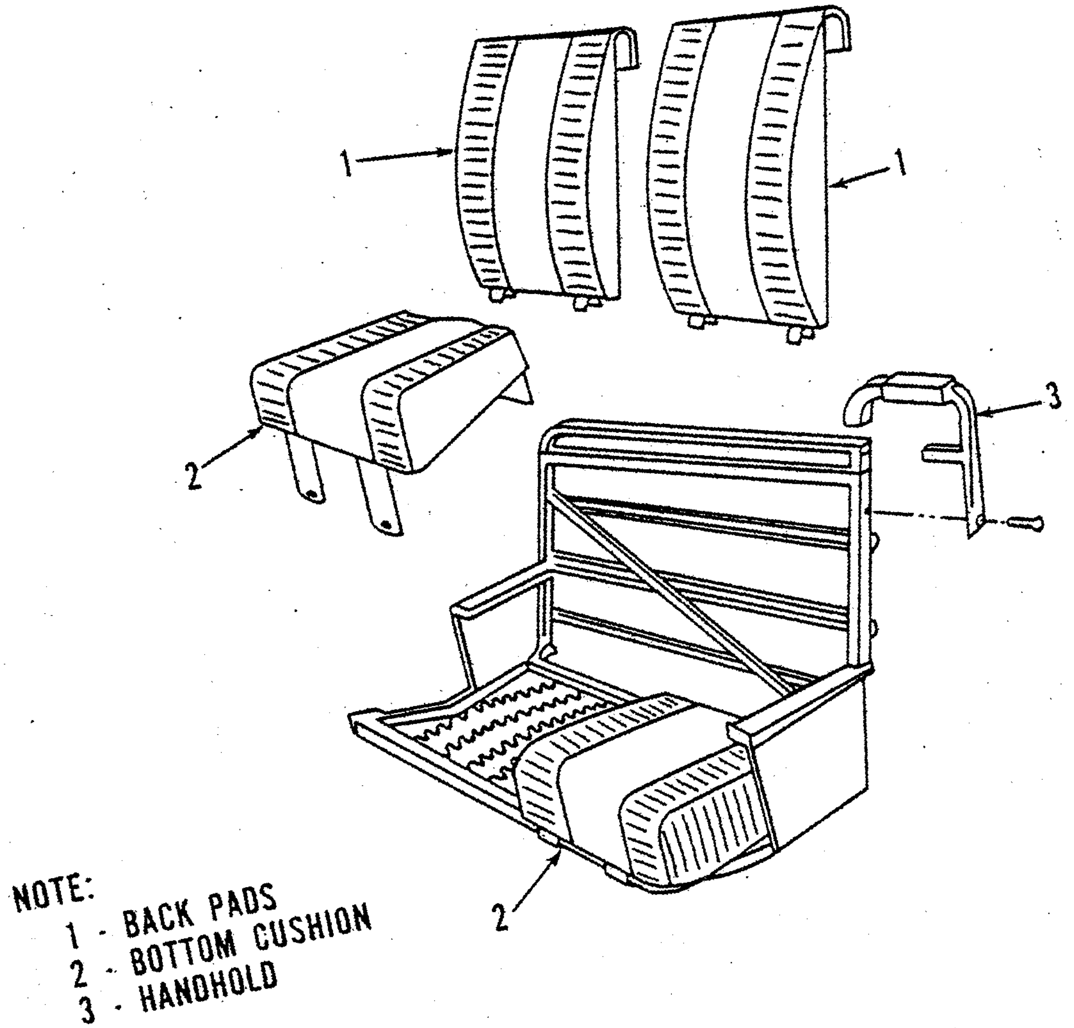
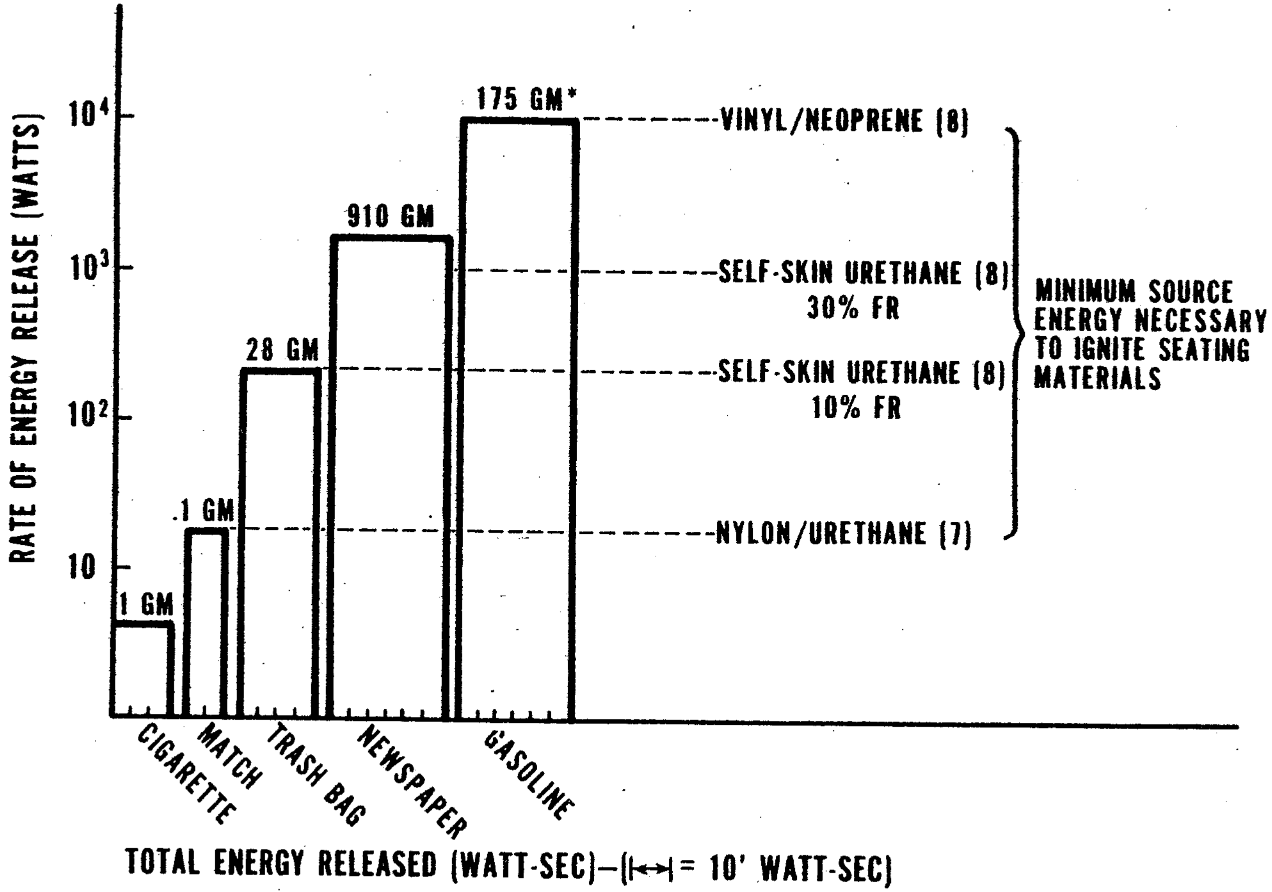


Figure 3. Seat assembly - cushions and frame



*Mass of original material

Figure 4. Comparison of ignition source characteristics and minimum ignition energies for various seat assemblies