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Urban Mass Transportation Administration

Review of BART "C" Car Fire Safety Characteristics

Transportation Systems Center
Cambridge, MA 02142

September 1987
Final Report

UMTA Office of Safety and Security

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16. Abstract

The report presents the results of a review of the fire safety characteristics of the prototype BART "C" Car. Initiated in response to a request from the Urban Mass Transportation Administration (UMTA) Region IX Administrator, the review has been structured to address the concerns expressed by the California Public Utilities Commission (CPUC). This review addresses the prototype "C" car fire safety characteristics, and it specifically highlights the ignition prevention and fire containment stages of a transit vehicle fire.

The review examines the BART fire experience, vehicle documentation (revisions available as of December 1986), materials, fire testing, and undercar equipment. Interior materials and undercar equipment are described, ignition sources identified, and an evaluation of BART's effort to address potential fire hazards is presented. The final section of the report presents the conclusions and recommendations.

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PREFACE

This report presents the results of a review of the fire safety characteristics of the Bay Area Rapid Transit District (BART) prototype "C" Car. This review was conducted for the Urban Mass Transportation Administration Office of Safety and Security in response to a request to the Associate Administrator for Technical Assistance from the UMTA Region IX Administrator.

The scope of this review has been limited to the fire safety characteristics of the "C" Car and, more specifically, the ignition prevention and fire containment stages of a transit vehicle fire. Elimination of all transit vehicle fires is not possible. However, this focus on prevention and containment should provide the highest practical degree of safety. This report, based on information available as of December 1986, discusses the approach taken in the review and presents the results of an examination of BART fire experience, a prototype "C" Car, vehicle documentation, materials, fire testing, and undercar equipment.

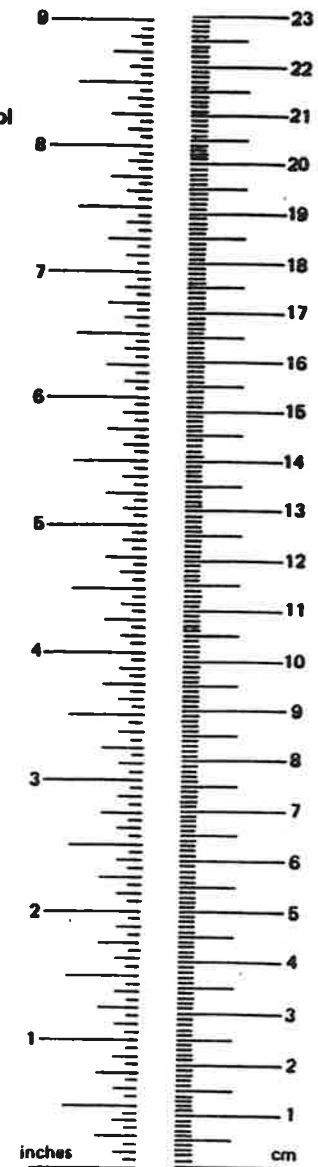
The authors wish to acknowledge the contributions of Dr. Phani K. Raj, and Professor Howard Emmons of Technology and Management Systems, Inc., for their review of the full scale and corner scale fire test results and assistance in the preparation of sections 3.2 and 3.3. The authors also wish to express their appreciation to Steven A. Barsony, Gwendolyn R. Cooper and Roy Field of UMTA, and George R. Grainger formerly of UMTA Region IX for their guidance and assistance in this project; Alex E. Lutkus, Haji M. Jameel and Donald Johnson of the California PUC for their guidance and helpful comments on the review draft; and BART staff members Kris V. Hari, Maury F. Clapp, Ralph S. Weule, James M. Kestler and their staffs, for their cooperation in providing information throughout the vehicle design phase. Finally, the authors wish to express their appreciation to James H. Kelley for his assistance in editing this report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

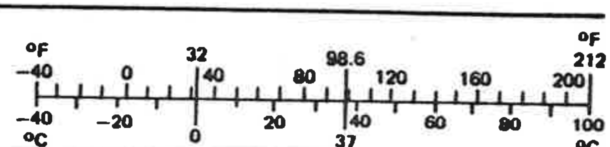
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 BACKGROUND

On January 5, 1984, the Urban Mass Transportation Administration (UMTA) Region IX Administrator requested that the UMTA Associate Administrator for Technical Assistance provide, through the Transportation Systems Center (TSC), technical support to review the fire safety characteristics of the Bay Area Rapid Transit District (BART) rail transit vehicle ("C" Car) presently being procured. This document presents the results of TSC's review of the fire safety characteristics of the "C" Car. The review effort has been structured to address the fire safety concerns expressed by the California Public Utilities Commission (CPUC). These CPUC concerns are presented in Appendix A.

The BART system presently operates a fleet of approximately 440 cars. This fleet is comprised of "A" and "B" Cars designed and built by the Rohr Company. To expand this fleet of "A" and "B" Cars, the BART system has contracted with the Raismes Division of Alsthom Atlantique (hereafter referred to as the carbuilder) to design and build 150 additional vehicles. Designated as "C" Cars, these new vehicles will be capable of operating in conjunction with, or independent of, the "A" and "B" Cars. In the United States, the carbuilder is known as Soferval Inc. The carbuilder is located in France, and has designed and built a variety of rail vehicles. In the United States, the carbuilder has designed and built 120 rail cars for the Metropolitan Atlanta Rapid Transit Authority.

1.2 SCOPE

The scope of this review has been limited to the fire safety characteristics of the "C" Car and, more specifically, the ignition prevention and fire containment stages of a transit vehicle fire. Elimination of all transit vehicle fires is not possible. However, this focus on prevention and containment should provide BART patrons and employees the highest practical degree of safety. This report, based on information available in December 1986, discusses the approach taken in the review and presents the results of an examination of BART fire experience, vehicle documentation, materials, fire testing, and undercar equipment, as well as from an inspection of a prototype "C" Car. Interior materials and undercar equipment are described, ignition sources are identified, and an evaluation of BART's effort to address potential fire hazard areas is presented. The final section of the report presents conclusions and recommendations.

1.3 REVIEW APPROACH

A new vehicle procurement, such as the BART "C" Car, should result in a vehicle in which the fire threat has been minimized. This can best be accomplished when, in the design of the new vehicle, the proper analyses are conducted to identify and resolve prospective hazards. This process of hazard identification and resolution is known as the system safety concept. With this concept, each identified hazard is eliminated or controlled in vehicle design, engineering and operation. Fire safety can not be adequately addressed unless the car designer has taken care to analyze and ensure that hazards identified in previous vehicle incidents are eliminated or controlled and that features introduced in the new vehicle design do not incorporate new hazards into the vehicle. Employing the system safety concept in the design, construction, and testing phases of vehicle procurement will assist in minimizing the fire threat in the vehicle.

The hazard identification and resolution process should be conducted throughout the vehicle procurement cycle. A major focus of this review of the BART "C" Car fire safety will be the hazard identification and resolution process utilized by BART and the carbuilder.

In reviewing the BART "C" Car fire safety characteristics, the initial effort was directed at a review of the following major elements of the vehicle procurement:

1. Vehicle Documentation Supporting the Procurement,
2. Vehicle Materials Selection,
3. Vehicle Equipment Selection.

Each of these three elements has a profound effect on the fire safety characteristics of the "C" Car. The documentation element outlines the vehicle performance requirements and what analysis and design efforts were performed by BART and required of the carbuilder. Section 2 describes the documents prepared in support of the "C" Car procurement. The materials selection and car equipment selection elements directly address the ignition prevention and fire containment characteristics of the new vehicle. Section 3 discusses materials selected and test results for the prototype "C" Car. Section 4 identifies and discusses the prototype "C" Car undercar equipment. Section 5 presents conclusions and recommendations.

1.4 BART FIRE EXPERIENCE

The initial task in the review of the BART "C" Car fire safety characteristics was an examination of the past fire experience of BART. The "C" Car incorporates many materials, components and undercar equipment that are similar to those used on the existing fire hardened BART "A" and "B" Cars. As a result, an examination of previous fire and smoke incidents involving "A" and "B" Cars could serve to identify potential fire hazards in the new "C" Car. This approach is limited, however, as the "C" Car is a new system and therefore may have hazards not identified by past incidents. To identify prospective fire hazards, BART fire experience was examined for the period March 16, 1975 to November 28, 1985. Two basic categories of vehicle fire and smoke incidents were identified:

1. Arson/vandalism related incidents, and
2. Equipment/mechanical related incidents.

Fire and smoke incidents relating to arson/vandalism are summarized in Table 1-1. Because such incidents are intentional, it is very difficult to eliminate them. However, the effects of such arson/vandalism may be minimized by quickly containing the fire. Such containment can best be achieved by careful materials selection and component placement.

Fire and smoke incidents resulting from equipment/mechanical problems are summarized in Table 1-2. Potential fire and smoke hazards associated with the equipment can be reduced through equipment design and selection as well as its placement.

TABLE 1-1. BART VEHICLE ARSON/VANDALISM FIRE AND SMOKE INCIDENTS (1975-1985)

COMPONENT INVOLVED	NUMBER OF INCIDENTS
Seats	5
Floor/Carpet	13
Under Seats/Floors	14
Between Cars	9
Smoke Bomb	1
Cigarette Extinguished at Vent/Duct	3
Miscellaneous	1
Unknown	1

TABLE 1-2. BART VEHICLE EQUIPMENT/MECHANICAL FIRE AND SMOKE INCIDENTS (1975-1985)

CAUSE COMPONENT	NUMBER OF INCIDENTS
Air Conditioning Evaporator	3
Air Conditioning Evaporator Motor	4
Air Conditioning Compressor	1
Dynamic Brake Resistor	7
Current Collector	2
Traction Motor	4
Motor Alternator	1
Brake Discs	4
Battery	3
Ruptured Capacitors	1
Hydraulic Fluid Leaks	2
Motor Controller Box	2
Propulsion Overload	3
Miscellaneous	8
Unknown	6

Source: California Public Utilities Commission

2. VEHICLE DOCUMENTATION SUPPORTING PROCUREMENT

Documentation is one of the elements of the vehicle procurement process. While it is essential, good documentation alone does not result in a vehicle in which the fire threat has been minimized.

The documentation supporting the "C" Car procurement includes the vehicle documentation BART developed in support of the procurement and the vehicle documentation prepared by the carbuilder. Documentation developed by BART consists of the BART "C" Car specification "Contract Book for the Procurement of Transit Vehicles"[1] and "Contract Drawings for the Procurement of Transit Vehicles."[2] BART also sponsored a report entitled "Fire Safety Report - BART C Vehicle"[3] prepared by Kaiser Engineers, Inc. The carbuilder prepared numerous documents in support of the vehicle design and construction. These documents, several of which have yet to be approved by BART, address the system safety engineering as well as the materials and equipment design and selection for the BART "C" Car. This section summarizes the TSC review of these documents (revisions available as of December 1986). A complete list of the "C" Car documentation reviewed is contained in the References.

2.1 BART DOCUMENTS

The BART "C" Car procurement process was initiated by BART in December 1979, with a solicitation of proposals from engineering firms to assist in the preparation of the "C" Car specifications. In January 1980, BART solicited proposals from fire-safety consulting organizations to help in the preparation of fire-safety requirements for the "C" Car specifications. On April 3, 1980, Kaiser Engineers, Inc. was tasked to prepare contract documents for the procurement of the new "C" Car vehicle and materials testing requirements.

2.1.1 Contract Book and Drawings (Specification)

The "C" Car specification was initially issued on October 3, 1980, when BART published an "Industry Review Copy" of the "C" Car specification. This copy was reviewed by government organizations, prospective carbuilders and members of the rail transit industry. Many comments were provided by these organizations and a revision was prepared in February 1981 taking these comments into consideration.

In February 1981, the revised specification was distributed to rail transit systems throughout the United States which had recently purchased rail transit vehicles, UMTA, CPUC, as well as to local fire departments, with the request that they review the specification and send representatives of their engineering staffs to a review meeting. Under UMTA sponsorship, a review meeting was held on July 22, 1981. Members of the CPUC staff, local fire departments, and rail transit system engineers attended.

Comments and suggestions from all sources were evaluated and considered in light of the BART operating requirements for the transit vehicle ("C" Car). The result was the bid document dated January 1982, which was made available to the rail transit carbuilders for bidding purposes. It was revised four times by addenda prior to the bid opening. Addendum 2 changed the bid opening date. Addenda 1, 3, and 4 were the result of industry comments on the bid documents (specification book and drawings). The specification development process culminated in the signing of a contract with the Raismes Division of Alsthom Atlantique on October 7, 1982.

From the fire safety perspective, the "C" Car specification provides performance and design requirements for the vehicle materials and the equipment/component selection and placement. According to the Kaiser report discussed in the following subsection, "the specification was written such that the design of the vehicle would reduce the potential fuel load to a minimum and provide features which would inhibit fire propagation." The materials requirements set forth in the Contract Book (Table 19-1 and Appendix G) require the use of materials with fire safety characteristics which meet or exceed the requirements of the UMTA Recommended Fire Safety Practices for Rail Transit Materials Selection. A full scale fire test was also specified. BART is the first transit system to take the initiative to require a full scale fire test. Section 3 contains a detailed discussion of the individual materials requirements, selection and test results.

Several areas of the undercar equipment which relate to fire safety and not directly addressed in the Contract Book are described in the following subsections. Section 4 describes the results of a detailed review of the documentation related to individual undercar equipment and components. That section describes the TSC review effort to identify ignition sources and equipment hazards and to assess the probability and severity of undercar equipment failure and potential contribution to a fire or smoke incident.

2.1.2 Kaiser Report

Prior to the completion of the final specification, BART contracted with Kaiser Engineers (Kaiser) to prepare the report "Fire Safety Report-BART "C" Vehicle." The purpose of the Kaiser effort was "to describe the requirements that have been incorporated in the C-Car specifications in order to provide a high level of fire safety." In scope, the report "presents the results of the studies, investigations, and other activities that produced the fire safety requirements incorporated in the Contract Book for the Procurement of Transit Vehicles for the San Francisco Bay Area Rapid Transit District." The report focuses on the "C" Car fire safety requirements from a materials and equipment design perspective. The result of this effort was to provide BART with additional insight, input, and information concerning the fire safety portion of the specification.

Fire safety requirements summarized by Kaiser include materials and large scale testing requirements, design requirements and reviews, and systems safety analyses. The Kaiser report identified arson and equipment failure as the most likely ignition sources. Furthermore, the report stated that "Using materials which are difficult to ignite and which do not encourage fire propagation reduce the likelihood and severity of arson." Materials and large scale testing requirements described by Kaiser (as specified in the "C" Car Contract Book) are consistent with UMTA's Recommended Fire Safety Practices for Rail Transit Materials Selection and are discussed in Section 3 of this report.

Potential equipment failures identified by Kaiser are the current collector assembly and 1000 volt cable; traction motors; dynamic brake resistors; friction brake assembly; heating, ventilation and air conditioning (HVAC) system; and batteries. Design requirements "chosen to eliminate potential ignition sources and prevent fire propagation" include the following features:

1. Electrical fault protection,
2. Equipment grounding,
3. Overtemperature sensing and local equipment shutdown, and
4. Floor fire integrity.

The report describes the application of the particular design feature(s) (with the exception of equipment grounding) selected to address each of the potential equipment failures. Equipment grounding requirements, although not discussed by Kaiser, are described in the Contract Book.

In summary, the report provided BART with an independent input into the fire safety of the "C" Car specification. The Kaiser report, although addressing the major fire safety issues of the "C" Car, left to BART the task of addressing several key undercar fire safety concerns. These concerns were:

1. The placement of equipment components relative to ignition sources or combustible materials. An inspection of the prototype "C" Car at BART facilities resolved this concern.

2. The basic criteria for the installation of wire and cable (even in conduit) under the vehicle was not established (nor mentioned in the Contract Book). Historically, wire and cable, even in conduit, is not installed over potential "hot spots" (such as the dynamic brake resistors) or explosion areas. In examining the final contractor drawings submitted for this review and the prototype vehicle itself, it was determined that the cables initially placed over the resistors had been relocated, resolving this concern. The cables over the battery box are only low voltage cables and have been shielded by the top of the battery box.

3. The propulsion controller as a potential source of ignition. A review of the carbuilder's Preliminary Hazard Analysis showed that the propulsion controller was identified as an ignition source. However, the analyses are limited to a few key propulsion items and do not consider, to its full extent, propulsion controllers as a potential source of ignition.

4. The potential for electrical creepage across the insulated mounting bracket of the current collector. Creepage across the insulated mounting bracket can result from damage to the mounting bracket or contamination of the bracket. The Operating Hazard Analysis lists contamination as a Category I hazard, while the FMECA classifies contamination as a Category III hazard. An expanded analysis of the current collector will resolve the category question.

5. The provision for heat shielding for undercar equipment. The BART Contract Book specifies that for braking resistors "Shielding shall be provided so that rejected heat shall not affect performance of adjacent equipment." Inspection of the prototype "C" car revealed that heat shielding was installed in such a manner that the heat from the braking resistors would have no effect on the performance of adjacent equipment.

2.2 CARBUILDER DOCUMENTATION

The carbuilder prepared numerous documents supporting the "C" Car design and construction. In this review of "C" Car fire safety characteristics, the following documents were examined:

1. Design Analysis Documents
2. Contract drawings
3. Fire Loading
4. Structural Description Report (pages 42-49)
5. Test procedures, test results and test program
6. System Assurance Plan
7. Quality Assurance Program Plans
8. List of Approved Change Proposals

Carbuilder prepared documentation has been an iterative process which is still underway. Several documents such as the System Safety Design Analysis and Safety Critical Items List (SSDASCIL) have yet to be approved by BART. In reviewing early drafts of this document, a number of shortcomings were noted. Recognizing this, the most recent revisions (available as of December 1986) of this document have resolved many of the items of concern identified in the previous revisions. The fire safety issues and concerns identified and discussed in the following sections should, as recommended in section 5, be resolved prior to BART approval of the system.

2.2.1 Design Analysis Documents

The "Design Analysis Documents"[4] present the results of hazard and failure analyses performed on the vehicle's major subsystems. Intended to identify and address vehicle hazards, the SSDASCIL lists the following as Safety Critical Items: car body, doors, friction brake, trucks, propulsion, and couplers. (Safety Critical Items are defined by BART as single point failures.)

The SSDASCIL document describes a series of analyses performed by the contractor. These analyses are: Preliminary Hazard Analysis (PHA), Subsystem Hazard Analysis (SSHA) including, Fault Tree Analysis, Operating Hazard Analysis, and Interface Analysis. Failure Modes and Effect Criticality Analyses (FMECA) were also performed for certain components. A detailed discussion and evaluation of the individual analyses which identify the fire hazards for particular undercar equipment as applicable, is contained in Section 4.

2.2.1.1 General Discussion of the Design Analysis Documents - The focus of the TSC review effort concerned fire hazards. The format and organization of the initial drafts of the documents presented considerable difficulties to TSC in its review. However, BART has worked closely with the carbuilder to resolve those problems.

2.2.1.2 Specific Equipment Hazards - The analyses presented in the documents address fire and mechanical hazards of the equipment specified for the "C" Car. As noted previously, the Kaiser report identified the six most common potential ignition sources due to equipment failure as: current collector assembly; traction motor; dynamic brake resistors; friction brake assembly; heating, ventilation, and air conditioning (HVAC); and battery. The carbuilder does address these potential ignition sources in the SSDASCIL. However, ignition sources that are identified by the carbuilder appear to be chosen in an arbitrary manner. Each vehicle system and subsystem should be examined to ascertain whether it may be a potential ignition source. For example, subsystems such as the side door subsystem should be examined. Ignition in side door subsystems has occurred in many transit systems in the country. Although side door ignition problems were not reported in the BART incident reports, the potential for ignition should be addressed in the PHA or SSHA.

Certain events within the fault trees are not developed completely. As an example, the sub-event "Faulty Equipment" (pg. III.52) leading to "Short Circuit/Arcing in High Voltage Equipment" was not developed completely and does not refer to other fault trees that describe faulty equipment such as traction motors hot (pg. III.56), braking resistors hot (pg. III.56), or battery/capacitor explosions (pg. III.55). A detailed fault tree "Faulty Undercar Equipment" should be developed which refers to specific equipment.

Although Propulsion/Pneumatics are addressed in the SSHA, no mention is made of fire safety issues concerned with rotary devices, or improperly adjusted or binding line switch armatures. Although these may be primarily maintenance issues, the carbuilder should address them in the failure and hazard analyses.

2.2.2 Contract Drawings

Contract drawings for undercar equipment layout, major cable and wire placement, and specific types of equipment[5] were examined during this review effort. This equipment included current collector, friction brake assembly, air compressor, traction motor, etc. Specific undercar equipment components will be discussed in Section 4.

2.2.3 Fire Loading and Structural Description Reports

The Fire Loading report[6] presents the results of an assessment of the caloric content in British thermal units (Btu) of each primary and secondary combustible material contained in the "C" Car. Based on the component and materials weight, the total caloric content of the "C" Car is estimated to be approximately 85,143,767 Btu. Such an estimate of the caloric content or Btu's in a vehicle is a purely physical value and is used primarily as a "Figure of Merit" for the vehicle.

The Structural Description[7] report describes materials used in the carbody components. In addition to the aluminum structure, these components include: floor panels, carpet and pad, car body and floor insulation, interior liners, windscreens, door insulation, and windows.

These two reports were used to assist in the identification of interior materials. Materials selection is further discussed in Section 3.

2.2.4 Test Procedures, Test Results and Test Program

The car builder prepared and submitted for BART review a series of reports which describe the test procedures to be used in the laboratory testing of materials[8]. More extensive test procedure reports were prepared and submitted to BART for the floor tests and full scale tests. As the test procedure for each material was completed, the results were submitted to BART for their review and approval for the prototype "C" Car. Full scale and corner test procedures were also developed. The results for individual materials, full scale, and corner tests are contained in Section 3.

2.2.5 System and Quality Assurance Program Plans

2.2.5.1 System Assurance Plan - Included in the Carbuilder's System Assurance Plan[9] is the Carbuilder's System Safety Program. This program's objective is the elimination of all Category I and II hazards and control of all Category III hazards associated with the car system and its testing, operation and maintenance. This application of the system safety concept to vehicle engineering should result in the identification and reduction of potential hazards. The contractor will also, in accordance with the BART specification, stress the fail safe concept. This program should assist in providing a vehicle in which the fire threat to the BART patrons and employees has been minimized. The program provides for the preparation of several hazard analyses and a critical/catastrophic items list (Category I and II, single point failure) to provide management visibility and assist in their resolution.

2.2.5.2 Quality Assurance Program Plan - The Carbuilders Quality Assurance Plan[10] describes the Quality Assurance Program to be employed in the "C" Car manufacture. This plan is quite detailed and demanding for a conventional industrial manufacturer (i.e., not space or military high reliability hardware). BART has approved this plan for production. As it is a "Plan" to control quality, it is important that it be properly implemented. Adequate quality control for all materials and equipment utilized in the vehicle construction will minimize the possibility of improper or defective materials or equipment being employed in the vehicle.

2.2.6 Approved Change Proposals

Each of the many change proposals[11] to the vehicle procurement was examined for its impact on the fire safety of the vehicle. Change order CO56A titled, "Revise Flame Spread Requirement for Light Diffusers and Destination Sign," was a no cost change to the flammability performance of this equipment. This change order provided for an increase in the materials flame spread index (I_s) from an I_s of 50 to an I_s of 100 or less. This change was necessary to allow for the use of a transparent polycarbonate material. As determined in the development of the Recommended Fire Safety Practices, there are no transparent plastic materials in which the flame spread index is less than 100.

A change order was also approved for the upholstery test criteria. The original specific optical density (D_s) of 100 at 4 minutes that was specified by BART was changed to a D_s of 150.

Therefore, with the exception of the upholstery, these change proposals maintain the BART specification within the limits of the Recommended Practices for these material functions.

3. MATERIALS SELECTION

Vehicle materials are a critical element in providing a vehicle in which the fire threat has been minimized. Materials selection influence both the ignition prevention and fire containment characteristics of the vehicle. BART has required the contractor to submit fire and smoke emission data for all flammable materials used in the prototype "C" Car. This has included all materials/components which weigh more than 10 pounds. The scope of the TSC review was directed at those components identified in the UMTA "Recommended Fire Safety Practices for Rail Transit Materials Selection." Requirements for laboratory and full scale tests of the vehicle materials are contained in Table 19-1 and Appendix G of the Contract Book. In addition to the laboratory scale tests and full scale tests required to be performed by the carbuilder, BART has conducted corner liner tests to evaluate on a larger scale, the liner materials selected for the prototype vehicle. It should be noted that the following review of materials selection and testing is applicable to the BART "C" Car prototype only and is based on the information available as of December 1986.

3.1 LABORATORY SCALE TESTS

The laboratory scale performance tests specified by BART in the Contract Book are consistent with the UMTA Recommended Practices. In several areas of the specifications, BART has indicated that previous experience from the "A" and "B" Car Fire Hardening Program has allowed BART to be more stringent than the Recommended Practices. Table 3-1 presents comparative data on the original BART "A" and "B" Car, the fire hardened "A" and "B" Car and the new "C" Car. Use of the Recommended Practices to assist in the selection of vehicle interior materials will serve to minimize the vehicle fire threat. The materials test experience from the BART Fire Hardening Program has demonstrated that with materials that meet the Recommended Practices, the fire should be contained within the area of origin.

The individual laboratory tests prescribed in the Recommended Practices are standard American Society of Testing Materials (ASTM) tests. The materials presently selected for the prototype "C" Car are also presented in Table 3-2. Individual materials are grouped into the categories of seating, panels, flooring, insulation and miscellaneous, and are discussed in the following paragraphs of this section.

TABLE 3-1. BART TRANSIT PROTOTYPE "C" VEHICLE CONSTRUCTION MATERIALS-COMPARATIVE DATA

COMPONENT	ROHR A & B CAR	FIRE HARDENED A & B CAR	SOFERVAL/AA C-CAR
ROOF	Urethane Foam Sandwich with Aluminum Skins	Same	Welded Aluminum Extrusions with Glass Fiber Batt Insulation
SIDEWALL	Extruded Aluminum Sections, Urethane Sandwich Deadlights, Glass Fiber and Foam Elastomer Insulation	Same	Welded Extruded and Plate Aluminum Structure with Glass Fiber Batt Insulation and neoprene foam
UNDERFRAME	Steel Bolster, Center Sill and End Sill - Aluminum Crossbeams and Intercostals	Same	Aluminum Bolster, Center Sill and End Sill - Aluminum Sub-floor and Equipment Brackets
FLOOR	Urethane Foam Sandwich Panels with Aluminum Skins	Balsa Core Sandwich Panels with Steel Skins	Aluminum Sub-floor plus Phenolic Foam/Nomex Honeycomb Core Sandwich with Phenolic Skins
A/C DUCTING	PVC/Acrylic Thermoplastic with Glass Fiber Batt Insulation	Same	Aluminum with Glass Fiber Batt Insulation Neoprene foam over aluminum sheet
LINING	Polyester Fiberglass Reinforced Plastic/ Polyester Gelcoat	Ceiling and Sidewalls - Phenolic FRP Ends and Doorways - Improved Polyester FRP/Polyester Gelcoat	Ceiling and Sidewalls - Phenolic and Honeycomb Composit Ends - Phenolic FRP/Polyester Gelcoat
DOORS	Urethane or Styrene Foam Core Sandwich with Aluminum Skins	Same	Aluminum Structure with PVC Foam Core
SEATS	Steel Frame - Urethane Foam Pads with Vinyl/Nylon Covers - PVC/Acrylic Thermoplastic Shroud	Same Frame and Shroud - Low Smoke Neoprene with Wool/Nylon Covers	Steel Frame - Low Smoke Neoprene Pads with Wool/Nylon Covers - Polyester FRP Shroud
CAB	Urethane Foam Core Sandwich Structure	Same	Welded Aluminum Structure with Glass Fiber Batt Construction
WINDOWS	Glass	Glass	Glass (Laminated Safety)
CARPET	Wool	Wool	Wool
WINDSCREEN PANELS	Urethane Foam/Melamine Sandwich	Same	Phenolic Foam/MelamineSandwich

TABLE 3-2. BART PROTOTYPE "C" CAR MATERIALS TEST REQUIREMENTS

	UMTA RECOMMENDED PRACTICES	BART SPECIFICATION 10-1982/3-83	MANUFACTURER/ MODEL/MATERIAL	PROTOTYPE TEST RESULTS*	COMMENT
SEATING					
Seat Cushions	ASTM D-3675: $I_s \leq 25$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' Test for Flaming or Non-Flaming depending on most smoke	ASTM E-162: $I_s \leq 8$ at 15' NFPA 258: $D_s \leq 75$ at 1.5' Flam $D_s \leq 50$ at 1.5' Non F $D_s \leq 150$ at 4' Flam $D_s \leq 100$ at 4' Non F $D_m \leq 300$ Pass U. of S.F. Toxicity test Procedure B"	1. Uniroyal SLS Koylon 228 B1 CM2 Neoprene Foam 2. Toyad LS-200 Neoprene Foam	1. ASTM E-162: $I_s = 4.1$ NFPA 258: D_s at 1.5 = 48 Flam D_s at 1.5 = 25 Non F D_s at 4 = 133 Flam D_s at 4 = 81 Non F 2. ASTM D-3675: $I_s = 1.03$ ASTM E-662: D_s at 1.5 = 72 Flam D_s at 1.5 = 42 Non F D_s at 4 = 146 Flam D_s at 4 = 89 Non F	1. Passenger Seats Ref: Alsthom "Fire Loading" Rev. D, Appendix B 2. Operator Seat
Shroud	ASTM E-162: $I_s \leq 35$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4'	ASTM E-162: $I_s \leq 35$ NFPA 258: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	Fiberglass/CTE Resin w/gel Special 14	ASTM E-162: $I_s = 29.8$ ASTM E-662: D_s at 1.5 = 70 Flam D_s at 1.5 = 12 Non F D_s at 4 = 163 Flam D_s at 4 = 77 Non F	
Seat Frame	Same as shroud	Same as shroud	Stainless Steel	Non-Applicable	
Upholstery	FAR 25.853: Vert Flame time ≤ 10 sec. Burn length ≤ 6 Inches ASTM E-662: $D_s \leq 100$ at 4' Uncoated $D_s \leq 250$ at 4' Coated	ASTM E-162: $I_s \leq 35$ FAR 25.853: Vert Flame time ≤ 10 sec. Burn length ≤ 6 Inches NFPA 258: $D_s \leq 100$ at 4' $D_m \leq 400$	Craftex 90% Wool 10% Nylon	FAR 25.853: Vert. Flame time: 0 Burn length: Warp 1.5" Filling 1.3" NFPA 258: D_s at 1.5 = 44 Flam D_s at 1.5 = 15 Non F D_s at 4 = 112 Flam D_s at 4 = 44 Non F	Contract modification: Ds requirement of 100 was changed to 150. 8/31/84 Passenger and operator upholstery is identical
Arm Rests	UMTA: Foam plastic arm rests to be tested as cushions	Not Specified	Teperman Closed Cell Neoprene	Tested as elastomers ASTM C-542 = PASS	ASTM E-162: $I_s = 50$

NOTES:
Non F: Non Flaming Flam: Flaming
NFD = No Flaming Dripping
ASTM 662 = NFPA 258
* Test Certificates are listed in Item 8 References

TABLE 3-2. BART PROTOTYPE "C" CAR MATERIALS TEST REQUIREMENTS (CONT.)

	UMTA RECOMMENDED PRACTICES	BART SPECIFICATION 10-1982/3-83	MANUFACTURER/ MODEL/MATERIAL	PROTOTYPE TEST RESULTS*	COMMENT
PANELS					
Wall and Ceiling Panels	ASTM E-162: $I_s \leq 35$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4'	ASTM E-162: $I_s \leq 35$ NFPA 258: NFD $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	1. Stratiform Fiberglass/ phenolic w/ gel coat Monolithic Composite 2. Aerospatial/Nate Phenolic FRP skins w/NOMEX core. Inner skin w/gel coat and polyurethane paint Composite NIDA 3. Alstom Aytre Fiberglass/Phenolic w/ gel coat and polyurethane paint Nonolithic Composite	1. ASTM E-162: I_s = 1.71 NFPA 258: D_s at 1.5 = 67 Flam D_s at 1.5 = 18 Non F D_s at 4 = 162 Flam D_s at 4 = 61 Non F 2. ASTM E-162: I_s = 17.62 NFPA 258: D_s at 1.5 = 23 Flam D_s at 1.5 = 13 Non F D_s at 4 = 54 Flam D_s at 4 = 38 Non F 3. ASTM E-162: I_s = 3.78 NFPA 258: D_s at 1.5 = 3 Flam D_s at 1.5 = 2 Non F D_s at 4 = 44 Flam D_s at 4 = 72 Non F	1. X end lining and door coffer assembly 2. Passenger side and ceiling panels Cab ceiling panels 3. Passenger seat shell behind transversal seat. Note: Window masks are brushed aluminum
Cab Area Liner	Same as above	Same as above	Alstom Aytre Fiberglass/Phenolic w/ gel coat	Same as item 3 above	Windshield mask, side panel Cab Ceiling Panel see item 2 above
Fire Extinguisher Access Panels	Same as above	Same as above	Polycarbonate: M3	ASTM E-162: I_s = 34.55 NFPA 258: D_s at 1.5 = 2 Flam D_s at 1.5 = 0 Non F D_s at 4 = 145 Flam D_s at 4 = 1 Non F	
Door Panels	Same as above	Same as above	Door Insulation: Klegecell Q40 PVC foam and aluminum sandwich	ASTM E-162: = I_s = .57 NFPA 258: D_s at 1.5 = 6 Flam D_s at 1.5 = 2 Non F D_s at 4 = 15 Flam D_s at 4 = 4 Non F	

NOTES: Non F: Non Flaming Flam: Flaming
NFD = No Flaming Dripping
ASTM 662 = NFPA 258

TABLE 3-2. BART PROTOTYPE "C" CAR MATERIALS TEST REQUIREMENTS (CONT.)

	UMTA RECOMMENDED PRACTICES	BART SPECIFICATION 10-1982/3-83	MANUFACTURER/ MODEL/MATERIAL	PROTOTYPE TEST RESULTS*	COMMENT
PANELS (cont.)					
Windscreens	ASTM E-162: $I_s \leq 35$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4	ASTM E-162: $I_s \leq 35$ NFPA 258: NFD $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	Aerospatial: Polyrey Melamine laminate Honeycomb core/aluminum	ASTM E-162: $I_s = 1.67$ NFPA 258: D_s at 1.5 = 27 Flam D_s at 1.5 = 1 Non F D_s at 4 = 122 Flam D_s at 4 = 49 Non F	
Windows	ASTM E-162: $I_s \leq 100$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4'	ASTM E-162: $I_s \leq 50$ NFPA 258: NFD $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	St. Gobain Windshield: tempered glass PVB tempered glass Side, end, cab: tempered glass/PVB/annealed	Non-applicable	
Diffusers	ASTM E-162: $I_s \leq 100$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4'	ASTM E-162: $I_s \leq 50$ NFPA 258: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	GE/Luminator Lexan 103 Polycarbonate	ASTM E-162: $I_s = 84$ (153) NFPA 258: D_s at 1.5 = 7.7 Flam (153) D_s at 1.5 = 0.5 Non F (103) D_s at 4 = 196.9 Flam (153) D_s at 4 = 1.5 Non F (103)	Contract modification: I_s requirement changed to ≤ 100 12/19/84 Lexan 153 = 103
HVAC Ducting	ASTM E-162: $I_s \leq 35$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4	ASTM E-162: $I_s \leq 35$ NFPA 258: NFD $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	1. Rigid: a. Rubatex/aluminum a. 1/8" b. 1/4" b. Glass wool and aluminum sandwich 2. Flexible hose: a. WTD Glass Fabric/ Silicone b. Mai-Weave polyethylene scrim	1. a. Results identical to thermal and acoustical insulation b. Non-combustible 2. a. ASTM E-162: $I_s = 1.89$ NFPA 258: D_s at 1.5 = 6 Flam D_s at 1.5 = 10 Non F D_s at 4 = 8 Flam D_s at 4 = 16 Non F b. ASTM E-162: $I_s = 1$ NFPA 258: D_s at 1.5 = 7 Flam D_s at 1.5 = 2 Non F D_s at 4 = 18 Flam D_s at 4 = 4 Non F	

NOTES: Non F: Non Flaming Flam: Flaming
NFD = No Flaming Dripping
ASTM 662 = NFPA 258
* Test Certificates are listed in Item 8 References

TABLE 3-2. BART PROTOTYPE "C" CAR MATERIALS TEST REQUIREMENTS (CONT.)

	UMTA RECOMMENDED PRACTICES	BART SPECIFICATION 10-1982/3-83	MANUFACTURER/ MODEL/MATERIAL	PROTOTYPE TEST RESULTS*	COMMENT
FLOORING					
Floor Structure (including Panel)	ASTM E-119: Pass Time calculation required. Not less than 15 min.	ASTM E-119: Pass 15 Min.	Aluminum SNIAS: Sandwich of Phenolic glass laminate skins w/NOMEX honeycomb core (filled w/Phen. foam)	ASTM E-119: 22 min ✚ Floor Panel alone : ASTM 162: I_s = 4.52 NFPA 258: D_s at 1.5 = 2 Flam D_s at 1.5 = 1 Non F D_s at 4 = 33 Flam D_s at 4 = 10 Non F	✚ Full Floor Structure
Floor Covering	ASTM E-648: CRF $\geq$ 0.5W/cm²	NFPA 253: Covering alone: CRF $\geq$ 0.5 W/cm² Cover W/Pad: CRF $\geq$ 0.6 W/cm²	Wool carpet, polyester backing, neoprene foam pad	NFPA 253: CRF = 1.1-Carpeting CRF = 1.0-Carpeting/Pad Burn length: 3.7 cm carpet 4.3 cm carpet/pad	ASTM E-648 = NFPA 253 Covering exempt in BART specification: "3. Smoke Emission Req., Item E"
THERMAL AND ACOUSTICAL INSULATION	ASTM E-162: $I_s \leq 25$ ASTM E-662: $D_s \leq 100$ at 4'	ASTM E-162: $I_s \leq 25$ NFD NFPA 258: $D_s \leq 100$ at 4' $D_m \leq 300$	1a. Glass wool and PB 256 and glass fabric facing 1b. PB 265 w/glass or foil face 2. Rubatex R 1800 FS a. 1/8" b. 1/4"	1a. Non-combustible 1b. Non-combustible 2. a. ASTM E-162: I_s = 6.09 NFPA 258: D_s at 1.5 = 26 Fla D_s at 1.5 = 23 Non F D_s at 4 = 34 Flam D_s at 4 = 25 Non F b. ASTM E-162: I_s = 1.92 NFPA 258: D_s at 1.5 = 45 Flam D_s at 1.5 = 62 Non F D_s at 4 = 77 Flam D_s at 4 = 98 Non F	1a. Ceiling insulation 1b. Side insulation 2. HVAC and various locations

NOTES: Non F: Non Flaming Flam: Flaming
NFD = No Flaming Dripping
ASTM 662 = NFPA 258
* Test Certificates are listed in Item 8 References

	UMTA RECOMMENDED PRACTICES	BART SPECIFICATION 10-1982/3-83	MANUFACTURER/ MODEL/MATERIAL	PROTOTYPE TEST RESULTS*	COMMENT
THERMAL AND ACOUSTICAL INSULATION (cont.)	ASTM E-162: $I_s \leq 25$ ASTM E-662: $D_s \leq 100$ at 4'	ASTM E-162: $I_s \leq 25$ NFD NFPA 258: $D_s \leq 100$ at 4' $D_m \leq 300$	3. Safety electric Fiberglass/aluminum foil N-670-6 4. Safety electric Flexible elasomeric N/1036	3. ASTM E-162: $I_s = 3.71$ ASTM E-662: D_s at 1.5 = 0 Flam D_s at 1.5 = 0 Non F D_s at 4 = 2 Flam D_s at 4 = 0 Non F 4. ASTM 162: $I_s = 1.93$ ASTM 662: D_s at 1.5 = 50 Flam D_s at 1.5 = 59 Non F D_s at 4 = 78 Flam D_s at 4 = 100 Non F	3. HVAC 4. HVAC: Duct, drain pan, and piping insulation
MISCELLANEOUS,					
Elastomers	ASTM C-542 - 71A: Pass NFD	ASTM C-542 - 71A: Pass NFD	Sociate: Heurteaux 477 CAFAC 927E Rubberia SA 543 Colman-Cuvelier Dn 2812 Teperman	All passed	Arm rests
Exterior shell	ASTM E-162: $I_s \leq 35$ ASTM E-662: $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4'	ASTM E-162: $I_s \leq 35$ NFPA 258: NFD $D_s \leq 100$ at 1.5' $D_s \leq 200$ at 4' $D_m \leq 300$	Aluminum	Non-applicable	
Box Covers	Same as above	Same as above	All steel except for APSE which is aluminum and battery box cover which is phenolic stratified w/paint	Battery Box: ASTM E-162: $I_s = 5.58$ NFPA 258: D_s at 1.5 = 6 Flam D_s at 1.5 = 1 Non F D_s at 4 = 32 Flam D_s at 4 = 6 Non F	
ELECTRICAL INSULATON	None, See Comment	IEEE 383 Without Mod. NFPA 258: $D_s \leq 50$ at 4' $D_m \leq 300$	Raychem Cable, Raychem 44 Precicable BIW, ITT	Not reviewed	See published UMTA Reports
PAINT	None	ASTM D-1360		Not reviewed	

NOTES: Non F: Non Flaming Flam: Flaming
NFD = No Flaming Dripping
ASTM 662 = NFPA 258
* Test Certificates are listed in Item 8 References

3.1.1 Seating Category

Contained in this category are the seat cushion, upholstery, frame, and shroud. The seat cushion material selected is a low smoke neoprene identical to that contained in the Fire Hardened "A" and "B" Cars. Seat upholstery is a wool/nylon material, the same as that used in the Fire Hardened cars. The test results for this material, as submitted to BART, indicate that the material meets the BART requirement criteria. The seat frame is stainless steel. The seat shroud material is CTE Resin/Fiberglass and the test results are listed in Table 3-2. According to the Fire Loading Report (Appendix B, Summary Data Table for Seats),[6] the Armrest/Handhold materials are classified as elastomers. Therefore, the applicable test criteria is ASTM C-542. The test results refer to the arm rest material as "closed cell neoprene" and are contained in Table 3-2. The test results submitted to BART for the prototype "C" Car show that, with the exception of the upholstery, these materials meet UMTA's Recommended Practices.

3.1.2 Panels Category

This category consists of wall and ceiling panels, partitions, windscreens, door panels, light diffusers, ducting, and windows. Wall and ceiling panels, partitions, and windscreens are one subcategory, while door panels, light diffusers, ducting, and windows are each described separately.

3.1.2.1 Wall and Ceiling Panels - Concern was expressed by the CPUC about the wall and ceiling panel performance criteria selection. Ideally, it is desirable to specify a material with as low a flame spread index (I_s) as possible. Both the UMTA Recommended Practices and the BART specification require an I_s of 35 or less. In this instance, specifying a lower I_s is of questionable value for several reasons. Most notably, the fire safety requirement is one of many factors which influence the liner selection process. Other influencing factors include:

1. Mechanical Properties - strength, flexibility, puncture resistance, and thermal expansion,
2. Formability to vehicle contours and shapes,
3. Resistance to graffiti and vandalism, and
4. Maintenance and repair.

Fire test data from the BART Fire Hardening Program supports the specification of a flame spread index of 35. Materials are available which satisfy both the fire safety and design criteria required. Therefore, it does not seem prudent to reduce the flame spread index requirement. Furthermore, without a costly and lengthy testing process, there is no known way to quantify the effect of such a change and what, if any, its magnitude would be.

Two types of phenolic materials are used for the prototype "C" Car wall and ceiling panels. Wall and ceiling panels consist of a phenolic sandwich panel, comprised of a honeycomb core (Nomex) and a top and bottom skin, each consisting of a phenolic glass laminate. Some wall panels consist of a molded reinforced plastic comprised of three layers of fiberglass, bonded together with phenolic resin (Norsophen) with a gel coat layer. The test results for both of these applications are listed in Table 3-2.

The material used for the window mask is brushed aluminum.

3.1.2.2 Windscreens and Partitions - Prototype "C" Car windscreen materials are composed of two-side laminate, high pressure Melamine (Polyrey) with a honeycomb aluminum core. Test results are listed in Table 3-2.

3.1.2.3 Fire Extinguisher Access Panels - Prototype "C" Car fire extinguisher access panels are composed of polycarbonate material. The test results are contained in Table 3-2.

3.1.2.4 Door Panels - Prototype "C" Car door panels consist of two aluminum sheets bonded to a foamed Polyvinyl Chloride (PVC) plastic panel. The test results are contained in Table 3-2.

3.1.2.5 Light Diffusers - The material selected for lighting diffusers for the prototype "C" vehicle is Lexan 103 polycarbonate. Test data are contained in Table 3-2.

3.1.2.6 HVAC Ducting - The prototype "C" Car HVAC air ducting consists of two different types: flexible hose and rigid ducting. Flexible hose materials are: (1) a glass fabric coated with silicone, and (2) an impregnated polyethylene, fiberglass cloth. Rigid ducting materials consist of: (1) a glass wool and aluminum sandwich, and (2) aluminum sheet metal covered with neoprene foam. The test results are contained in Table 3-2.

3.1.2.7 Windows - Prototype "C" Car windows consist of a sandwich of two layers of safety glass and a inner layer of Polyvinyl-butyral. As such, the windows inherently meet UMTA's Recommended Practices.

3.1.3 Flooring Category

Contained in this category are structural flooring and floor covering. The Recommended Practices specify that structural flooring be tested in accordance with the ASTM E-119 "Fire Tests of Building Construction Materials." For acceptance criteria, the "Structural flooring assembly should meet the performance criteria during a nominal test period determined by the transit agency. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete, safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal test period should not be less than 15 minutes." The BART specification requires a nominal test period of 15 minutes. The floor test time calculation is contained in Appendix B. The calculated test time period is 16.1 minutes.

The prototype "C" Car floor system consists of an aluminum substructure and a floor panel. The floor panel consists of phenolic foam-filled Nomex honeycomb with phenolic laminate skins. Floor system test results provided by BART are presented in Table 3-2. The floor system test consisted of the structure and panel assembly including openings and penetrations. Equipped with ventilation duct and floor panel, the system was loaded to simulate equipment and passengers and was tested twice according to the E-119 test method. Each test simulated a different section of the vehicle floor. The results of the two tests were:

1. floor collapse and fire penetration at 22 minutes 30 seconds, and
2. collapse and penetration at 21 minutes 30 seconds.

Because of its composition, the floor panel was also tested separately. The test methods used were the ASTM E-162 and ASTM E-662 test methods and criteria. The results were an I_s of 4.52 at 15 minutes and D_s of 2 at 1.5 minutes and 33 at 4 minutes in the flaming mode. In the non-flaming mode, the D_s values were 1 at 1.5 minutes and 10 at 4 minutes.

The prototype "C" Car floor covering tested consisted of a wool/nylon carpet with an underpad of neoprene. (Note: the Structural Description Report listed latex as the original carpet pad.) The test results for the floor covering both with and without pad are also contained in Table 3-2.

A prototype "C" Car floor specimen was also tested in an UMTA sponsored test program[12] to evaluate different floor materials and structures. The results of this test confirmed a test criteria failure time of approximately 22 minutes.

3.1.4 Insulation Category

Contained in this category is thermal and acoustic insulation. Prototype "C" Car ceiling and side insulation consists of "glass wool," a "non-combustible" material, with glass and/or aluminum facings of various thicknesses. Neoprene material of 1/4-inch and 1/8-inch thickness is used for insulation at various locations within the car (including HVAC ducting). (See section 3.1.2.6.) A flexible elastometric material is also used for thermal insulation.

Floor insulation consists of the floor panels described in subsection 3.1.3. Door insulation is reviewed in subsection 3.1.2.4. Prototype "C" Car insulation material test results are contained in Table 3-2.

3.1.5 Miscellaneous Category

Contained in this category are elastomers (such as in door edges), exterior shell and component box covers. Undercar equipment covers are made of steel with the exception of the APSE (Auxilary Power Supply Equipment) cover, which is aluminum. Battery box covers consist of stratified fiberglass/phenolic with polyurethane paint on one side and anti-flash epoxy paint on the other side. Prototype "C" Car material test results for elastomers and battery box covers are contained in Table 3-2.

3.1.6 Conclusions

The review of the test results for the materials which BART has used for prototype "C" car interior materials shows that these materials all meet the criteria contained in the BART Contract Book. These test results also fall within the criteria specified in the UMTA Recommended Fire Safety Practices for Rail Transit Materials Selection.

3.2 CORNER LINER TESTS

While the laboratory testing utilized the standard American Society of Testing Materials (ASTM) test method, the larger corner tests were not ASTM standard tests and will therefore be discussed in more detail. To date, BART and the University of California have tested numerous materials with this test method and have found that it produces reasonably consistent test results.

For the "C" Car, two corner tests were conducted by the University of California, Berkeley fire test facility. These tests[8] were conducted in a fireproofed room and are therefore called the Room Fire Screening (RFS) tests. The RFS tests are intended to evaluate the pre-flashover or fire growth characteristics of interior finish materials.

3.2.1 Test Facility and Test Procedure

The test facility used consisted of a 8 foot x 12 foot x 8 foot burn room provided with a forced ventilation system. This room was designed with fire resistant walls to test materials to flashover. The design included exhausting the combustion gases through a hood. The rate of heat released by the burning materials was measured by sampling the exhaust gases and using oxygen depletion calorimetry. The test specimens were ignited by a 1-foot square sand box burner located at one corner of the test room

The test consisted of "veneering" part of the wall and ceiling at a corner of the room with the BART "C" Car material to be tested and measuring the ignition, combustion and rate of heat release of the specimens. Because of the location of the test specimen at a corner of the room, this series of tests has been termed "corner tests".

Two major types of tests were conducted at two different burner heat output levels. These burner output levels were 40 kW (136 x 10^3 Btu/hr) and 160 kW (544 x 10^3 Btu/hr), respectively. In the 40 kW tests the test specimens used were the following:

- o Aerospatiale (Panel) — 4 mm (0.16") thick x 8' x 2' on the left side side wall and 2' x 2' of ceiling at the corner.
- o Stratoforite (Panel) — 3.1 mm (0.122") thick x 8' x 2' on the rear wall of the room at the corner.

In the 160 kW tests, the same materials were used in basically the same configuration. The major difference was that the ceiling (Aerospatiale) specimen size was 4 feet x 8 feet and there were border specimens at the top of the side walls. The test specimen arrangement for the two tests is shown, respectively, in Figures 3-1 and 3-2. Temperatures were recorded using thermocouples at 4 inches below the ceiling level (directly over the burner center) and immediately above the ignition source burner. Numerous other thermocouples were provided at several locations on the room ceiling and in the doorway plane.

3.2.2 Corner Liner Test Results

The test results with the above dual material corner wall paneling indicate that:

A. In the 40 kW tests:

1. The damaged areas of the Aerospatiale and Strateforite wall panels were limited to the areas of direct flame impingement. Minor damage, in the form of surface bubbling, was noticed immediately outside the area of direct flame impingement.
2. The ceiling panel was not damaged.
3. The peak rate of heat release was never above 100 kW and the mean value was close to 50 kW.
4. The highest temperature recorded directly above the burner center and 4 inches below the ceiling was 209°C (408°F).

B. In the 160 kW tests:

1. The entire side wall and ceiling panels were damaged. However, no flashover, as such, occurred.

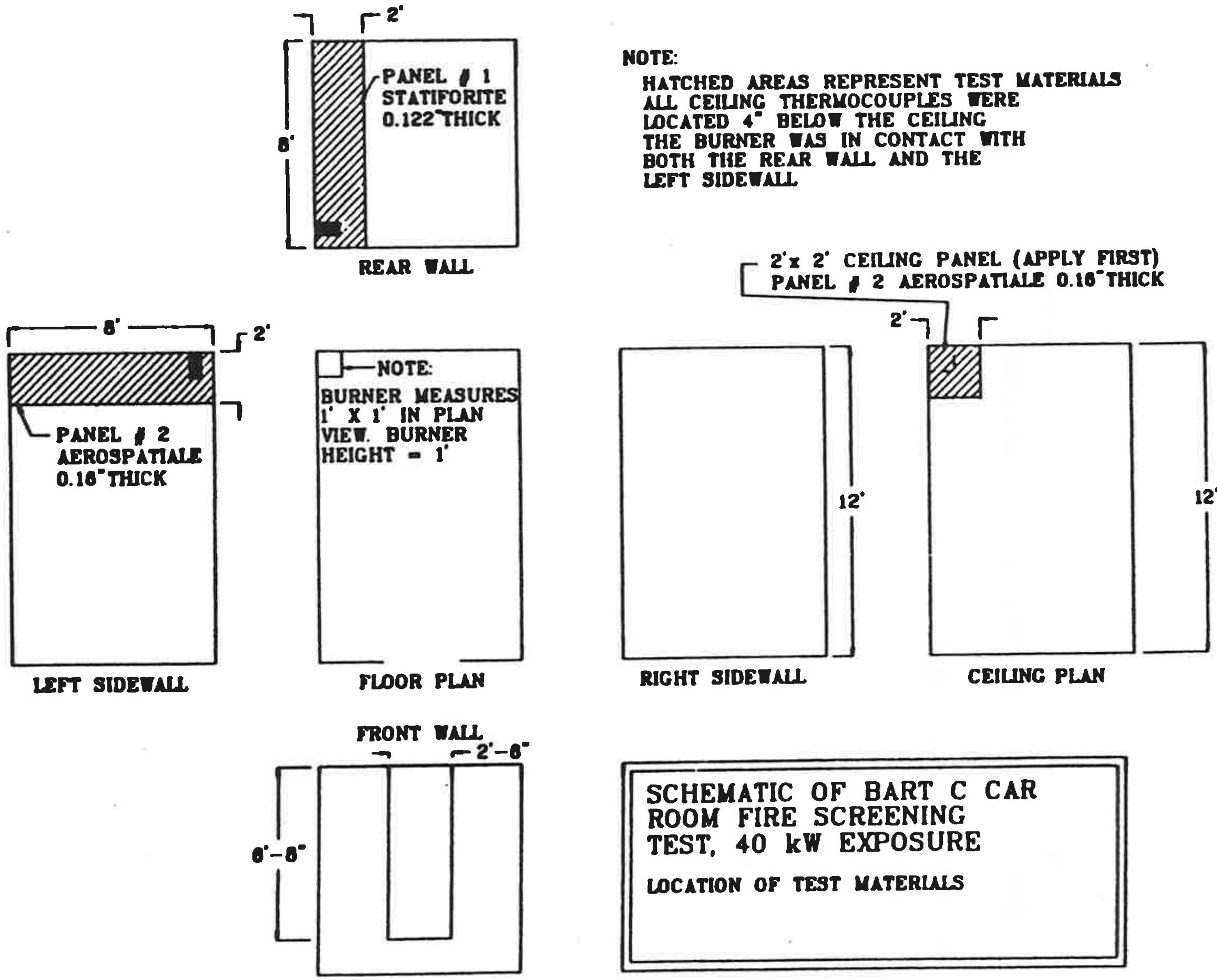

FIGURE 3-1. LOCATION OF THE TEST MATERIALS IN THE 40 kW ROOM FIRE SCREENING TEST

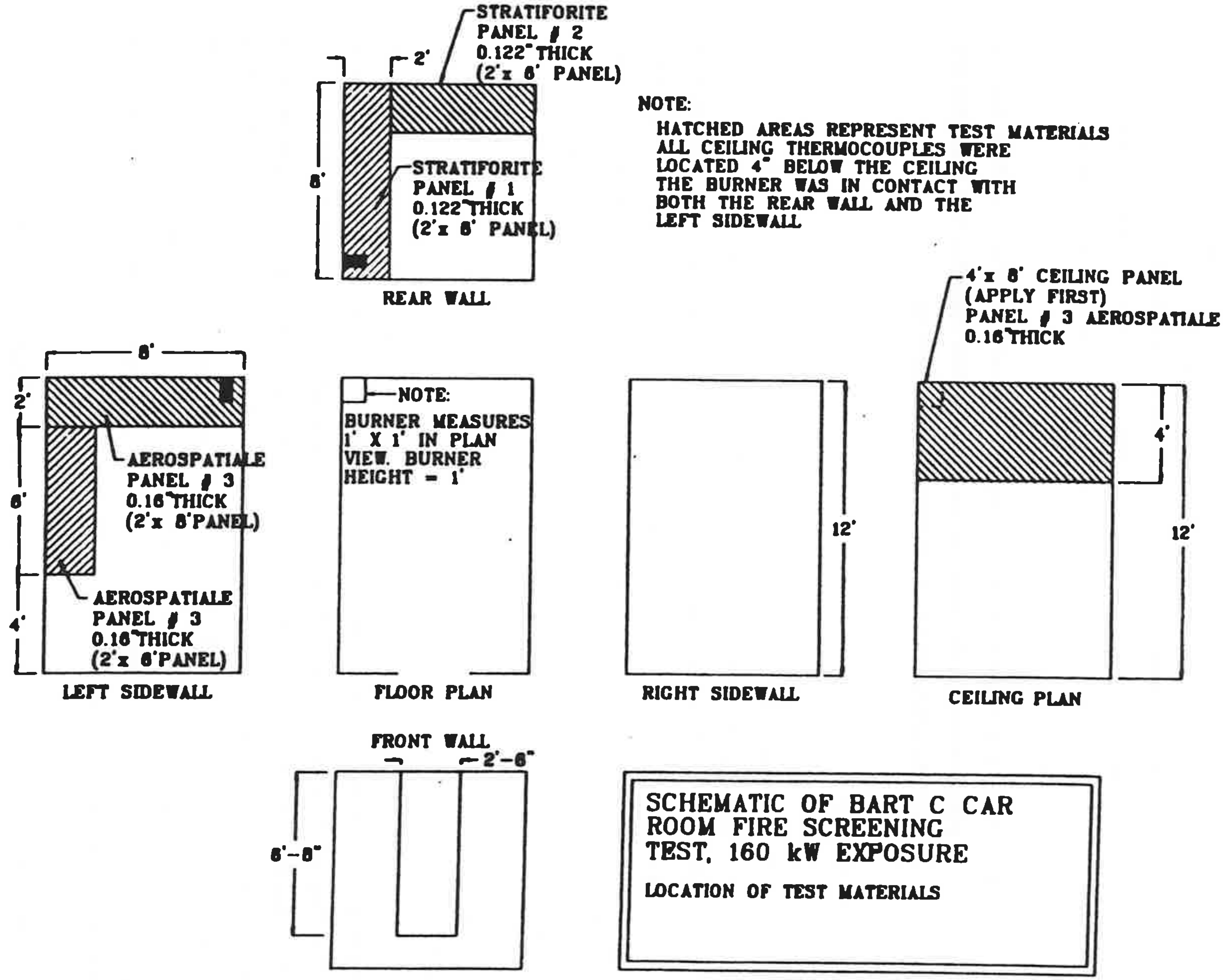

FIGURE 3-2. LOCATION OF THE TEST MATERIALS IN THE 160 kW ROOM FIRE SCREENING TEST

2. A peak heat release rate of 421 kW was measured. The net rate of heat release due to combustible wall materials was estimated to be 261 kW.

3. The maximum temperature recorded at a point directly above the burner center and 100 mm below the ceiling was 900°C (1650°F). The mean temperature level of 825°C was persistent for over 12 minutes - almost the entire time the burner was on.

4. Post test inspection of the ceiling material indicated a surface burning phenomenon of the resin in the Aerospatiale material had occurred but that the resin had not been completely consumed.

3.2.3 Conclusions

First, it must be noted that there are no well defined pass or fail criteria for this type of test. Secondly, the results indicated are based on only one test each with 40 kW and 160 kW burner levels. While one cannot always rely on a single test from which to draw firm conclusions, this particular test, as noted earlier, has produced reasonably consistent results in the fire hardening program. Furthermore, the results obtained from this test series confirm the test results obtained in both the laboratory tests and the full scale fire tests.

It cannot be concluded from these tests that because the corner test at 40 kW indicated no damage or flashover there will be no flashover at the same ignition load in a BART "C" Car. Flashover is a complex phenomenon initiated by pyrolysis of wall material and sudden gas combustion. Radiation interchange between the various pyrolyzing surfaces and ceiling smoke plumes is an extremely important factor in a system with a potential for propagating to flashover. Furthermore, the test specimens used in these tests did not form the entire wall surfaces of the room (as would be the case in a BART "C" Car). What the effect will be of lining the entire wall and ceiling of the room with Aerospatiale and/or Stratoforite is unknown because relatively low radiative interactions amongst the pyrolyzable wall materials may combine (non linearly) to exacerbate the potential for flashover at 40 kW.

In conclusion, the data obtained from the corner tests do provide guidance and confirm the results of the laboratory and full scale tests.

3.3 FULL SCALE TESTS

The carbuilder conducted two full scale fire tests inside a partially furnished, full size, BART "C" Car. The objective of these tests was to determine whether a small fire started under or on a seat, would grow and result in flashover in a BART "C" Car furnished with the wall, ceiling and seat materials which would be actually used in service.

The tests were conducted according to the BART contract specifications. The principal criteria, for acceptance of the materials used in the car as being fire safe, as specified by BART, included the following:

1. Seat materials, other than the double seat under/on which the ignition source is located and the double seat directly in front of the ignition source, should not burn.
2. Carpet on the floor outside a 2 foot radius from the ignition source should not burn.
3. The ceiling material directly above the ignition source and that above the side window should not burn actively.
4. There should be no flashover within the vehicle.
5. The smoke obscuration within the car at the normal eye level (6 ft.) should not be greater than 83 percent (or light transmission should not fall below 17 percent).
6. Flame tongues should not impinge on the ceiling in the test with ignition under the seat.

3.3.1 Description of the Test

A. Detail of the Car

A full size BART "C" Car was used in the tests. The rear half of the car was furnished with carpet, underpad, wall and floor liners. There were no active components inside the equipment lockers. All windows and doors were in the closed position. Only the aft end cubicle of the car had been furnished with seats (three sets of seats on each side). The materials furnished were as follows:

1. Wall material: fiberglass/phenolic (Nomex)
2. Ceiling material: fiberglass/phenolic Nomex/sandwich
3. Seat upholstery: wool/nylon
4. Seat cushions: Uniroyal SLS Koylon (neoprene)

The tests were conducted with natural car ventilation (without the aid of exhaust or forced fans). The test car, in effect, was almost identical to a BART "C" Car in normal passenger service.

B. Ignition Source for the Tests (Simulated arson)

Two types of tests were conducted. Both were identical except for the nature of ignition. In the first test, the ignition source was a polyethylene trash bag, located under the aft end seat on the carpeted floor, containing 0.8 kg of paper toweling and 0.2 kg of 4 oz. wax coated paper cups. In the second test, the same trash bag ignition source was used, except that the bag was on the seat across the aisle to the seat in the first test.

C. Instrumentation

The test results were recorded with a variety of instruments. Ten thermocouples recorded the temperature at various locations. These locations are indicated in Figure 3-3 and Figure 3-4. The wall and ceiling surface temperatures as well as gas temperatures close to the ignition source and 6 inches below the ceiling were measured.

Smoke obscuration was measured using a 50 watt halogen lamp (color temperature 3000°K) placed at the aft end of the car. The intensity of this light received at a position on the longitudinal axis of the car near the doorway was measured using a Photovoltaic Selenium Photodetector provided with a green filter. The light beam from the halogen lamps was concentrated into a narrow beam by a reflector-lens system provided at the halogen lamp location (such as in a projector). The percent transmissivity of the light through the smoke layer was expressed as the ratio of light intensities received at the detector with and without the smoke. Other instruments provided in the tests included a video camera, photographic equipment and timing devices. The tests were conducted by igniting the paper pieces on the open end of the trash bag and recording the data from thermocouples as well as on the video recorder.

- Point P is directly above the center of the seat

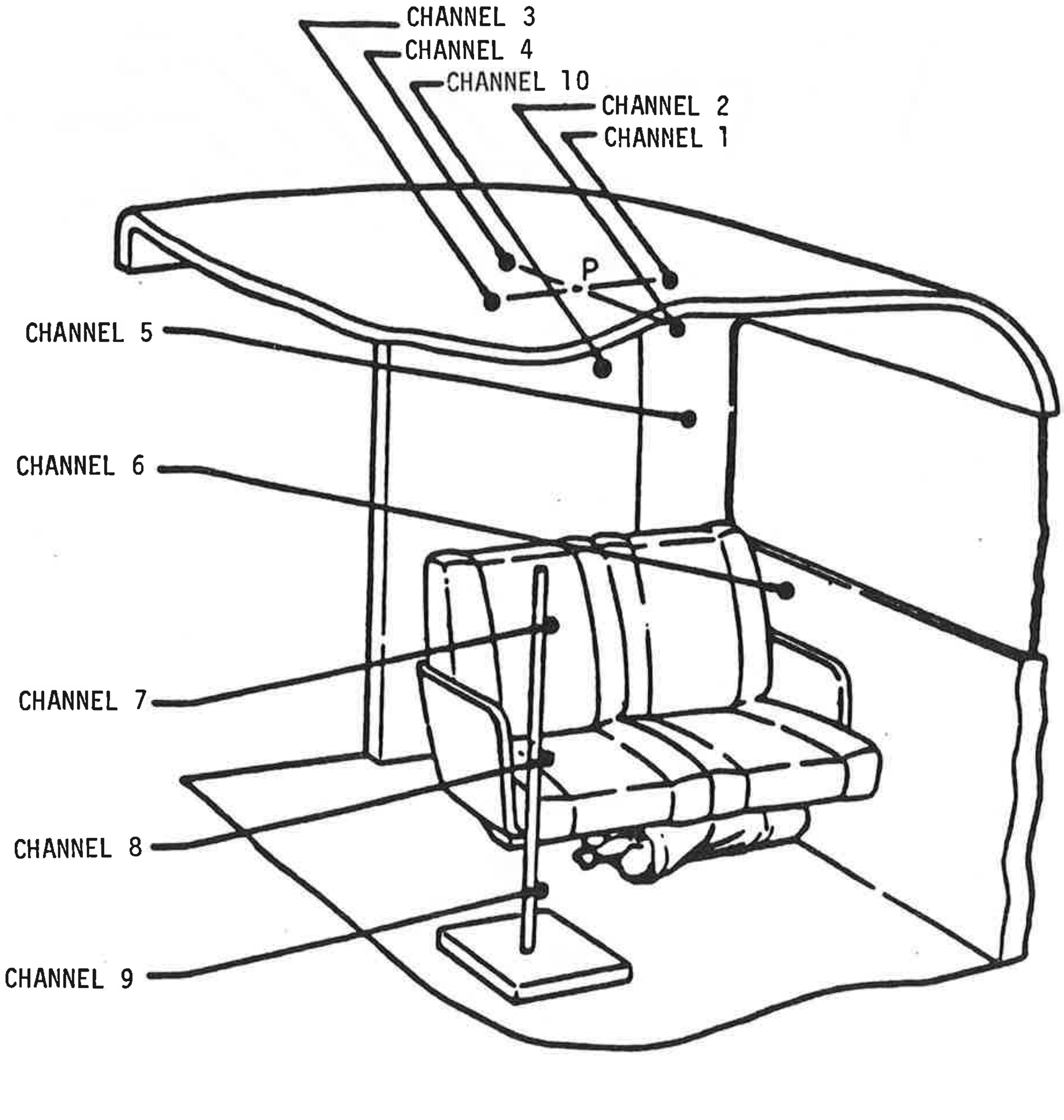

FIGURE 3-3. UNDER THE SEAT IGNITION AND THERMOCOUPLE LOCATIONS IN FULL SCALE FIRE TEST

o Point P is directly above the seat center

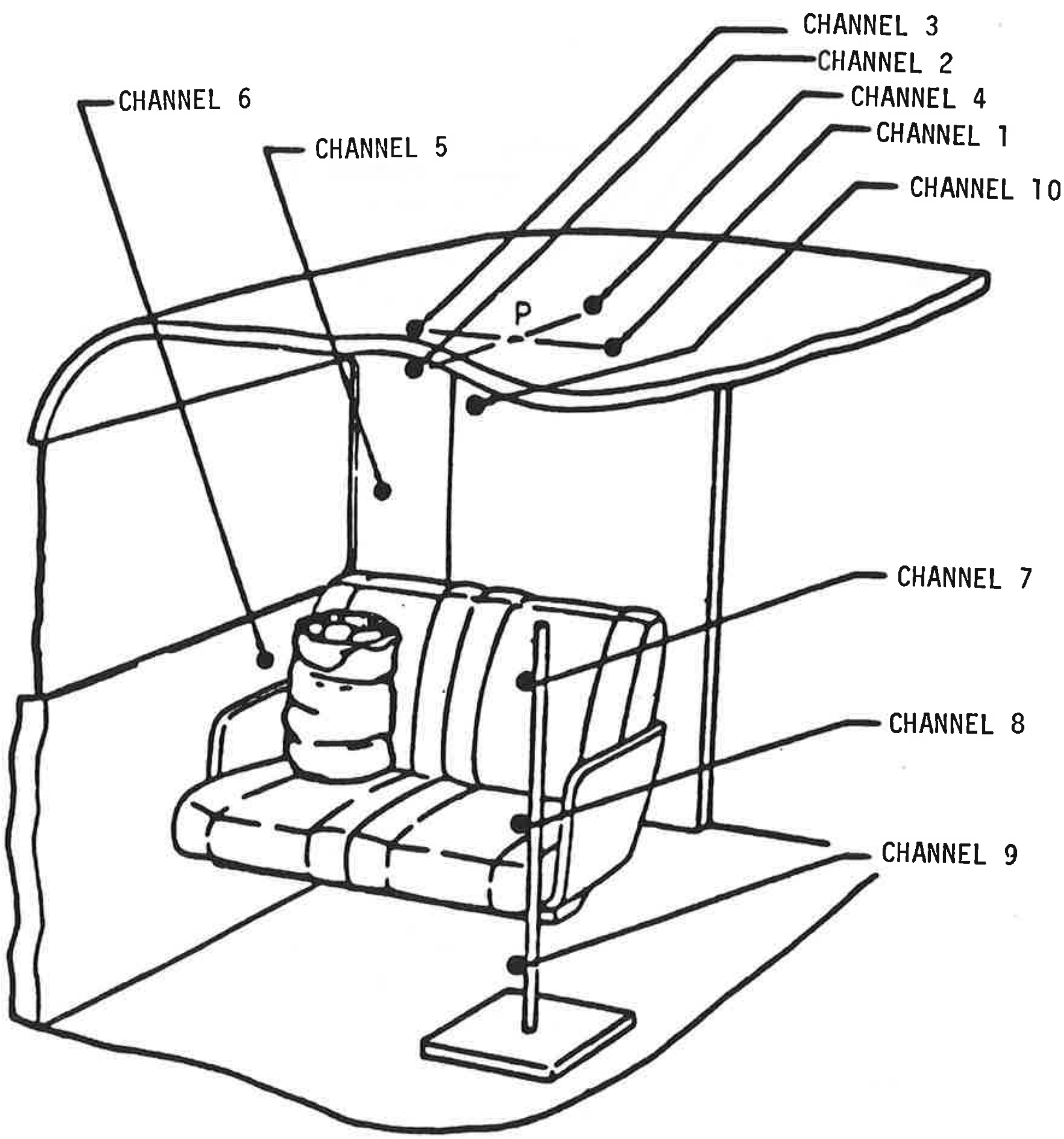

FIGURE 3-4. OVER THE SEAT IGNITION AND THERMOCOUPLE LOCATIONS IN FULL SCALE FIRE TEST

3.3.2 Test Results

Test #1: Ignition of Trash Bag Under the Seat

This test showed that fire damage was confined to the seat under which the ignition was effected. There was no flashover and the maximum temperature recorded was 104 °C (219 °F). The maximum smoke obscuration was 64 percent (transmission 36 percent). The maximum temperature was recorded, just under the window sill and on the wall panel, about 1 minute after ignition. The trash bag contents burned within about 2 minutes and high gas temperature close to the burning trash bag was observed only during this period.

The visible damage was confined mostly to the seat above the ignition source. The underside of the seat burned where the foam (seat cushion) carbonized on the surface. Above the arm rest, there was very little damage except for smoke marks. The wall panel did not suffer any fire damage. A substantial volume of the bay in the car on the ignition side was filled with dense smoke.

Test #2: Ignition of Trash Bag on the Seat

In this test there appeared to be more damage than in the case when ignition was under the seat. The flames reached higher levels (2 feet above the top of the seat). The peak temperature recorded was 208 °C (406 °F), just above the seat on the side wall, between the window and the bulkhead. This temperature was recorded about 1.6 minutes into the test when the flames were quite high and still visible. No significant smoke was observed at this time. Highest smoke obscuration was only 38 percent occuring towards the end of the test, 10 minutes from ignition.

No flashover was observed nor did the wall and ceiling materials sustain any damages. What fire damage occurred was confined to the seats. The fabric on the seat back directly opposite the seat on which ignition was effected burned and the foam backing was blackened, presumably caused by radiation.

3.3.3 Conclusions

The tests seem to have been carried out carefully and according to standard practices used for testing the behavior of materials subject to real life fire situations. The test procedure is adequate and the car assemblies tested were well designed to show the relative hazard presented by each case tested. The use of under seat ignition by a bag full of paper has been used extensively in the aviation industry for aircraft materials testing and is considered a reasonable simulation of a possible arson fire.

The above described test results clearly indicate that the materials proposed to be used for the walls, ceiling and the seats are reasonable and will minimize the effect of fires that may be initiated by an arsonist. There was no flashover in either type of ignition nor did the temperature of the ceiling or wall reach very high levels. Most important, there was no fire propagation.

4. UNDERCAR EQUIPMENT

Undercar equipment could be a major source of ignition resulting in a vehicle fire. Ignition may occur in the individual equipment or may result from the placement of a potential ignition source in close proximity to a combustible material. The undercar equipment discussion presented here is drawn from an examination of the prototype "C" Car documentation available as of December 1986, and an inspection of a prototype "C" Car, supplemented by discussions with BART personnel. Each piece of undercar equipment is described and potential ignition sources identified.

The major undercar equipment selected for use in the BART "C" Car prototype is presented in Table 4-1. Each equipment manufacturer is identified and the respective equipment model provided. This table also presents a comparison of the "C" Car equipment and the "A" & "B" Car equipment. Although the "C" car is built by a foreign carbuilder, the undercar equipment, with the exception of the battery and high voltage cable, is provided by U.S. suppliers. The major difference between BART and several other transit systems in this country (including Metropolitan Atlanta Rapid Transit Authority for whom the carbuilder has built vehicles) is that BART operates a 1000 volt dc system at the traction power rail. All other rail transit systems in North America operate between 600 and 750 volts at the power rail. Therefore, a meaningful comparison of performance, reliability and maintenance for certain electrical equipment cannot be made between BART and other transit systems. However, certain BART parts and components are identical to those used by other transit systems and as such permit comparisons.

The following subsections discuss each undercar component and potential ignition sources and review these components in terms of fire safety.

4.1 TRACTION MOTOR

The traction motors for the "C" Car are rated for operation from the 1000 volt dc traction power rail. On each truck, the motors are connected in series (500 volts dc per motor) electrically and are mounted on the truck frame in a parallel configuration with the axles. Each motor is coupled to its respective axle by means of a gear unit with elastomeric mounts. The traction motors respond to

TABLE 4-1. BART "C" CAR EQUIPMENT - COMPARATIVE DATA

EQUIPMENT	MANUFACTURER/MODEL	SAME AS A & B CAR
Traction Motors	WESTINGHOUSE/1463 BA	Yes - but manufactured by GEC
Truck	ALSTHOM ATLANTIQUE	No - is interchangeable
Friction Brakes	KNORR Model STU00524	No
Brake Grids/Resistors	WESTINGHOUSE Design Drawing ID631001601R	No
Pneumatic System Air Compressor	AIR TEK Model 724APG1 Drawing ID631002601L	No
Electric Inverter	GARRET Design Drawing 2019992	No
Current Collector	OHIO BRASS Model #K444-B4	Yes
Battery	SAFT (Model) (French) DE24 SMT-16	No - is interchangeable
HVAC	SAFETY ELECTRIC Model B5525-1	
1) Evaporator	"	No
2) Compressor	"	
High Voltage Cable	PRECICABLE	No
Low Voltage Cable	RAYCHEM	No
Coupler/Draft Gear	WABCO Model 576445-576207	Yes
Line Switch	WESTINGHOUSE Model UPB-55K	No
Motor Control Group	" XCD-398-E	No
Semi-Conductor Group	" TE-430	No

acceleration, deceleration, speed and direction commands from the solid state controller.

In deceleration, the traction motors act as generators and either return the generated energy to the traction power rail, or dissipate this energy through resistors carried on the vehicle.

The traction motors are GEC Limited motors. These motors are the same type as the motors on the present BART "A" & "B" Cars. However, the motors for the "A" & "B" Cars were made by Westinghouse.

4.1.1 Ignition Sources

Flashovers and short circuits could lead to ignition of dirt and grime within the traction motor. These flashovers are caused by poor brush to commutator contact, worn or defective brushes, defective or maladjusted brush holders, or insulation breakdown. Worn or rough commutators are also a means of creating flashovers and shorts. Although it is a rare ocurrence, traction motor bearings can be a source of ignition if they should become worn or defective. This ignition can occur when the heat generated from friction ignites the bearing lubricant.

4.1.2 Evaluation

A review of the "C" Car Contract Book indicates that the traction motor requirements and components are specified in detail. BART has used this type of motor on the "A" & "B" cars and the components that make up this motor have not been a contributor to car fires in the past. The good operating experience by BART with this traction motor (Table 2-2) is reflected in its requirement for the same type of motor for its new fleet of vehicles.

Because of limited amounts of combustible material and thus a low fuel load, traction motor fires are infrequent on the BART system. Also, due to its construction, materials selection, and location under the car, any ignition in a traction motor would usually be contained within the motor shell itself. This was confirmed by a review of the CPUC Fire/Smoke Incident Reports for BART (mechanical causes). These reports indicated only four incidents of fires in traction motors.

Two potential traction motor ignition sources are commutators and brushes/brush holders with bearings as a minor potential ignition source. A motor bearing life requirement of 500,000 miles is specified in the BART Contract Book. It appears that a bearing of such a high rating would have a low failure rate. Therefore, the probability of it generating sufficient heat due to frictional wear and thereby creating an ignition condition is remote. However, should a bearing overheat, oil and grease on the motor frame could result in ignition outside the motor case.

The carbuilder's Preliminary Hazard Analysis addresses shorted field and armature coils and shorted brush holders as sources of ignition. The Operating Hazard Analysis lists, for revenue service, the cause of fire in traction motors as "frayed or cracked insulation or wiring or component short." The FMECA addresses grounded brush holders and broken brushes as sources of ignition. However, no mention is made in any hazard analyses of commutator problems such as rough or worn commutators which also could be sources of ignition. Although, primarily a maintenance issue, commutator problems can result in flashovers within the motor. The resultant fire is, however, generally contained within the motor frame. Historically in the transit industry, commutator problems usually result in electrical flashovers within the motor and any resultant fire would be contained within the motor frame. However, this potential source of ignition is still a concern and should be addressed.

All electrical equipment should be properly grounded. The Contract Book details the ground bus and the method of connecting it from the car body and the axle brushes. During the inspection of the prototype "C" Car, it was pointed out by BART personnel that the ground bus was not utilized and the grounds were connected from a common point under the car to the ground brushes on each axle. This, in itself, should not create any difference in the electrical grounding of the vehicle. However, as a matter of information, proper grounding does not always necessarily mean that there is positive protection against certain electrical faults. Arcing, unless the arc makes positive contact with ground, may not draw sufficient current to activate a protective device (fuse or circuit breaker) but could become intense enough to cause ignition. In addition, arcing caused by creepage, even to ground, may also draw an intense arc, but depending on the protective device, may not activate the device. This would, however, constitute a double point failure and is not addressed by the carbuilder.

During the inspection of the prototype "C" Car, it was observed that the motor leads and high voltage cables mounted on the underside of the car were not positioned sufficiently far apart from one another in the areas where they cross and, in some instances, were chafing. Uncorrected, the chafing would wear through the insulation and create a short circuit condition. Although the leads and cables have circuit protection, ignition could result from this condition before the protective device functions. This condition was recognized by BART personnel and the necessary steps have been taken to correct this problem.

4.2 CURRENT COLLECTOR

The current collector assembly for the BART "C" Car consists of a bracket assembly, collector paddle mounting assembly, collector paddle, and a collector mounting bracket made of an insulating material. There are four assemblies on each vehicle; one mounted on each side of each truck where the paddle of the assembly makes contact with the top of the power rail. Because of the possibility of the current collector making contact with a foreign object along the right-of-way, the paddle is notched to break upon impact. The notch, a BART specified design feature of the Ohio Brass current collectors, is intended to reduce the risk of a partial or total assembly being torn from the mounting upon impact with a foreign object. Power rail current collectors on all transit vehicles in the United States are mounted on the side of the truck and make contact with the power rail to provide the power to the vehicle. That portion of the assembly which makes contact with the power rail is isolated from the truck frame by an insulation material.

4.2.1 Ignition Sources

Arcing at the power rail can ignite foreign matter along the wayside. This arcing could be caused by maladjusted or misaligned current collectors or power rails where positive contact between the current collector paddle and power rail is not made. Should a shoe assembly break off due to contact with a wayside object and make contact between the power rail and the truck, the car body, or the running rail, the resultant arc would create an ignition condition.

Because the power rail has the potential of providing several thousand amperes at 1000 volts dc, the resultant arc could, almost instantly, create a high intensity ignition or burn through the car or truck frame material like a cutting torch, at the point of contact.

The current collector mounting bracket, as indicated in the Ohio Brass drawing, is made of a polymeric material. Should environmental conditions cause material deterioration with resulting cracking, road grime can accumulate in these areas and form a path to ground with resulting ignition.

4.2.2 Evaluation

Due to its location and its contact with the power rail, the current collector has been the cause of many fires on transit systems. These fires are the result of arcing at the current collector itself or creepage across the insulated mounting bracket. For the most part, an arc shield mounted above the current collector assembly will deter arcs from reaching the carbody or truck frame. Occasionally, however, a heavy arc may not be deflected by the arc shield and, if the arc is sustained long enough, various damage to the car will result. Usually, if the arc shield deflects the arc, the only damage is within the current collector assembly itself. Contaminates accumulated on the mounting bracket can create a path to ground. This path usually begins with a minor arc and unless detected will foster and create ignition. In the case of creepage, the fault is usually detected before major damage is done. This was the case of the two incidents relating to current collectors listed on the CPUC Fire/Smoke Incident Report for BART where the fire was limited to the current collector, with minor damage.

There is a fuse at each current collector which will (with the exception of two situations) open the circuit should a ground condition exist. The first situation in which the fuse would offer no protection is if a current collector breaks off from its mounting and becomes wedged between the power rail and the running rail. In this situation, the current collector cable would be free to arc against the vehicle structures, if not restrained. Inspection of the prototype "C" Car showed that the cables leading from each current collector were clamped sufficiently (a problem identified previously by BART) to minimize the potential for problems should a current collector become wedged between the power rail and ground, as a result of a current collector breaking away from its mounting. The Preliminary Hazard Analysis, Operating Hazard Analysis and FMECA all address the hazard of obstructions which could damage the current collector. Although primarily a maintenance issue, the hazards of maladjusted or misaligned power rail should be added to the hazard of obstructions to make the analyses complete.

In the second situation, the fuse would be by-passed if a creepage path were established across the mounting bracket from the current collector paddle to the truck frame. This would result from an accumulation of conductive material (grit, brake shoe dust, etc.) at the mounting bracket, creating a path to ground. Although not prevalent at BART, this situation has been recorded many times within the transit industry. Under either of these circumstances, the only circuit protection available would be the section circuit breaker, either along the line or at the traction power substation. However, if the ground is not positive enough to trip this breaker, the resultant arc at the fault could be sufficiently intense as to cause ignition.

The Preliminary Hazard Analysis classifies arcing/flashovers of the current collector under a Category II classification with contamination as a subheading, but gives no detail. The FMECA identifies the hazard of contamination but classifies it as a Category III hazard. The accumulation of contaminates on the current collector mounting bracket is classified as a Category I hazard in the Operating Hazard Analysis. This contamination may result in subsequent deterioration of the assembly. Therefore, the mounting bracket should be maintained periodically as the carbuilder recommends. Periodic maintanance will serve to minimize the accumulation of conductive matter on the mounting bracket and thereby negate the formation of a creepage path to ground. To fully address this contamination issue, a fault tree should be developed in the SSHA.

A review of the "Fire Loading Summary" submitted by the car builder as part of the contract requirements indicates that the material to be used for the current collector mounting bracket is Cyglas #615, a non-burning material. The total heating value of the four current collectors combined is 163,340 Btu, which is low compared to the heat value of other items in the Fire Loading Summary. Although the fire loading characteristic for the current collector is low, if an arc does occur as a result of a damaged or defective assembly, the arc could be of such intensity that it could burn through the truck frame or carbody.

Although BART right-of-way maintenance keeps foreign matter along the wayside to a minimum, the potential for ignition still exists. It is recognized, however, that unless a vehicle is stopped in an area where there is a fire in progress along the wayside, fires in this area should pose no fire problem to the vehicles.

4.3 DYNAMIC BRAKE RESISTORS

In the dynamic braking mode, the traction motors become generators. During this mode, the generated energy is fed back into the traction power third rail, if the system is receptive to this feedback. When the system is not receptive, the generated energy is dissipated in the form of heat through resistors mounted under the vehicle.

4.3.1 Ignition Sources

Broken cables to the resistors, broken resistor segments and loose or high resistance connections at the resistors can create an overheat or arcing condition which results in ignition. Also, foreign matter that ignites or is conductive could become lodged between the resistor segments shorting out a portion of the resistor, thereby allowing the drawing of more current through the remaining segments. This could create an overheat condition with ignition of foreign matter or other combustibles in the vicinity of the resistor.

4.3.2 Evaluation

The CPUC Fire/Smoke Incident Reports for BART, indicated that there were seven incidents of fire at the dynamic brake resistors during that period. The "C" Car dynamic resistor design is based on the experience of the "A & B" Car fire hardening program. Accordingly, the "C" Car should experience fewer similar incidents.

Recent heavy rail procurements by other transit systems have incorporated overheat protection devices at traction motor acceleration and/or dynamic brake resistors. The Massachusetts Bay Transportation Authority (MBTA) and the New York City Transportation Authority have requirements similar to BART for these devices. The New York vehicles are just going into service, but the MBTA cars, in service since 1981, have some nuisance failures. The BART Contract Book specifies heat detectors for the dynamic brake resistors. However, the Kaiser study estimated that fire detectors on the "C" Car fleet could result in about two failure/false alarms per day.

In the Contract Book, BART specified that heat shields be provided to minimize the possibility of the resistors serving as an ignition source to adjacent components. Inspection of the prototype "C" Car showed that the heat shields installed above the resistors not only protect against rejected heat which can affect the performance of adjacent equipment, but also protect against overheating and arcing to the underside of the car. The overheat protection devices specified by BART are mounted at the heat shield. These devices are designed to open the braking circuit at $450^{o}F \pm 12^{o}F$.

Although the Preliminary Hazard Analyses addresses frayed or cracked wire insulation as a contributor to flame ignition, broken resistor wires are not mentioned in any of the analyses. There are no requirements in the "C" Car Contract Book for the location of wires and cables relative to the dynamic brake resistors. Should wires and cables be mounted over these resistors and an overheat condition occur, the insulation could be damaged and create a creepage, ground, or short circuit condition resulting in ignition. An inspection of the prototype "C" Car indicates that there are no wires or cables mounted over the dynamic brake resistors.

The Carbuilder's Preliminary Hazard Analysis describes only one braking resistor hazard; that of a failed brake resistor which could cause a reduction in electrical braking. The Subsystem Hazard Analysis fault trees mention the potential hazards of overheating and capacitor explosion.

The Safety Critical Items List indicates that the braking resistors are not Category I or II hazards at the major assembly level, since it would not be a single point failure. However, should a heat sensor fail to detect an abnormal heat build-up, the potential for at least a Category II hazard is present when such a large amount of kinetic energy is being dissipated through these resistors.

Inspection of the prototype "C" Car revealed that BART has adopted fire hardening procedures to minimize ignitions on the total underside of the car including the area surrounding the resistor assemblies. This includes the floor which is designed as a fire barrier. The gap between the floor and the side wall which created a penetration area on the A and B cars has also been eliminated.

4.4 STORAGE BATTERY

The storage battery for this vehicle is the source of low voltage dc power for such functions as the propulsion system control logic, emergency lighting and lighting control, door control and operation, train control, and communications. The storage battery is of the nickel-cadmium alkaline type and is made up of 24 cells; the casings of which are made of Grilamid TRE55. This battery is charged by a solid state low voltage power supply. The primary source to the power supply is the three-phase output of the inverter.

4.4.1 Ignition Sources

All nickel cadmium alkaline batteries, even in their normal charging state, generate hydrogen gas. The gas is vented from each cell through vent holes in the filler cap to the top of the battery box where it is directed to the atmosphere through battery box vents.

A potential ignition scenario is the existence of an overcharge condition due to a defective charging circuit. The battery cells can overheat and evaporate the liquid in the cell, generate hydrogen gas at a rapid rate and thereby set up a condition for an explosion. A broken or loose wire in the battery box could stimulate the arc and ignite the hydrogen gas. On the "C" Car, the possibility of this happening is remote due to the protective devices specified in the Contract Book and incorporated in the prototype "C" Car.

4.4.2 Evaluation

The CPUC Fire/Smoke Incident Reports for BART list three battery fire incidents. In one incident the battery box, batteries, adjoining insulation and approximately 15 square feet of floor was damaged.

The BART "C" Car Contract Book specifies placing an overtemperature device in the battery box and an overvoltage device in the charging circuit. These two features should protect against the ignition scenario at the battery. However remote, the combination of more than one failure could set up an explosion in the battery box. With this in mind, no wire or cable, even in conduit, should pass over the battery box. Should an explosion occur and the insulation be penetrated, the circuits could be destroyed. The undercar wiring layout drawing and inspection of the prototype "C" Car indicates cable(s) pass directly over the battery box. Although protected by the battery box cover, this wiring can be damaged by such an explosion.

The PHA does not address potential battery hazards. The Safety Critical Items List Summary states that the battery is not a cause of Category I or II hazards. This assumption is based on the fact that this is not a single point failure.

Inspection of the battery box and the batteries on the prototype "C" Car showed that the battery box is well ventilated and the protection devices are in place over the batteries. Unless there is a failure in the charging circuit and at least one of the protection devices fails (a double point failure), ignition at the batteries is remote.

4.5 FRICTION BRAKE/HANDBRAKE

The "C" Car friction brake system consists of two hydraulic subsystems: one for service braking and one for parking. On each axle, the friction brake system is comprised of a disc and a caliper. A hydraulic pump charges the lines and provides the pressure required to operate the brake calipers.

4.5.1 Ignition Sources

A potential ignition scenario is if the vehicle is in motion and the disc brake caliper is not released properly. This condition can generate enough friction at the disc and caliper to ignite combustibles in the area of the assembly. Leaks in the hydraulic lines or hydraulic apparatus can saturate the area with hydraulic fluid. Such a leak on a hot disc could result in an ignition condition.

4.5.2 Evaluation

The CPUC Fire/Smoke Incident Reports for BART list four incidents of fires generated at the brake discs. These same reports also list two incidents of ruptured hydraulic fluid leaks.

Although the friction brake system is required to have appropriate annunciators to indicate friction brake problems and alert the operating person, defective annunciators or logic errors could negate this safety feature. The Preliminary Hazard Analysis addresses the friction brake relative only to hydraulic brake fluid leaks and mentions a device that would limit brake fluid loss. The FMECA identifies brake pad rubbing as a source of ignition.

There are no heat shields at the brake discs. Although there are hydraulic fluid fuses in the lines from the tank to each brake disc, if a fluid hose leaks or breaks, sufficient fluid could leak onto a hot disc and ignite the fluid, or any accumulated debris or road grit.

4.6 HEATING, VENTILATING, AND COOLING (HVAC)

Air comfort for the "C" Car is provided by unitized air treatment units mounted under the vehicle. These units provide the heating, ventilation and cooling for the vehicle.

4.6.1 Ignition Sources

Potential ignition scenarios could result from reduced airflow to the evaporator heaters, overtemperature at the heaters due to heater defects, or arcing caused by loose or broken heater connections.

4.6.2 Evaluation

The "C" Car Contract Book addresses air flow and temperature at the evaporator heaters. Neither the PHA, the SSHA, nor the FMECA addresses Air Comfort (HVAC) relative to fire hazards. Historically, Air Comfort Systems have had very few problems in this area. Overheated drive motors and compressors account for the few problems that have occurred. The BART "C" Car Contract Book specifies overtemperature sensors for the motors. A review of the drawing and a description of the unit indicates that a device to detect overheating caused by loss of refrigeration or rapid cycling is provided. The motor of this system and the motor bearings are cooled and lubricated by passing a refrigerant oil mixture into the bearing and motor cavities. Therefore, the probability of these motors overheating and causing ignition will be considerably reduced.

The Carbuilder's Safety Critical Items List indicates that the Air Comfort Subsystem is not considered a Category I or II hazard. This is based on their assumption that it is not a single point failure. Although the CPUC Fire/Smoke Incident Reports for BART give no details as to the intensity, it lists eight incidents of fire in the Air Comfort Subsystem. In order to reflect the BART Past Experience, hazard analyses of the "C" Car Air Comfort Subsystem should be performed.

4.7 PROPULSION CONTROLLER

The "C" Car propulsion control system is a solid state system utilizing dc chopper technology. Control system operation and the movement of the vehicle may be through Automatic Train Operation or by means of a P-wire signal when in manual control. The logic for this system is designed to direct the dynamic brake energy, generated during dynamic braking, back into the traction power rail if the system is receptive. If the system is not receptive, the generated energy is dissipated through undercar mounted resistors as heat. Section 4.3 discussed the resistors. The system is protected against voltage surges and has a means of discharging the capacitor banks when the system is de-energized.

4.7.1 Ignition Sources

Potential propulsion control package system scenarios include: failure of electro-mechanical apparatus, mechanical binding of the line breaker, overheated control resistors, defective wire insulation, propulsion blower failure, shorted reactors and coil breakdowns.

4.7.2 Evaluation

Due to the several protective devices built into the propulsion control system of the "A" and "B" Cars, the effect of most component or subsystem failures would result in system shutdown. This was evident in a review of the CPUC Smoke/Fire Incident Reports for BART listing these types of incidents for "A" and "B" Cars. Only two propulsion system incidents were listed other than traction motor or braking resistors and one was a ruptured capacitor. A review of the Contract Book indicated that protective devices have been incorporated into the design of the "C" car.

Although the record of the propulsion subsystem is good relative to smoke/fire incidents, there is a potential for ignition in this subsystem. It is also evident that the protective devices cannot protect against every condition and of the possibility of protection device failure. The Carbuilder's Preliminary Hazard Analysis and the Subsystem Hazard Analysis address only ground faults and short circuits, as well as the problems of semiconductor and reactor failures. The line switch, considered one of the most vulnerable components of a propulsion subsystem by many rail vehicle electrical maintenance personnel, is addressed relative to combustion in the arc chute and contacts not closing properly. However, line switches are designed so that when deenergized, the armature drops by gravity, thereby opening the circuit. If the line switch armature should not drop out completely, the contact may not open sufficiently and arcing may result. This possibility highlights the need for additional analysis regarding proper maintenance of the line switch.

4.8 ALTERNATING CURRENT SOURCE

The BART "C" Car Contract Book states that the on-board ac source shall be either a static inverter or a motor alternator. The equipment approved is a static inverter incorporated into the Auxilary Power Supply Equipment (APSE). The ac power is used on the prototype "C" Car for such subsystems as the hydraulic brakes, air compressor, air conditioning, propulsion system blowers, defrosters, and air conditioning control. The output of the static inverter is 120/208 volts 3 phase. This output also feeds the input to the low voltage dc power supply.

4.8.1 Ignition Source

A potential ignition scenario concerns the input of 1000 volts dc to the static inverter from the traction power rail. The possibility of a broken wire or breakdown of a solid state component may result in a high intensity arc. This arc can result in ignition to components and combustibles within the confines of its housing or spread outside to the undercar area.

4.8.2 Evaluation

The motor alternator as used in the "A" & "B" Cars has a good track record relative to fire incidents. A review of the CPUC Fire/Smoke Incident Reports for BART showed one incident involving a motor alternator. This incident resulted in a smoke report. Because static inverters, which are used in the prototype "C" Car, have not been used in the transit industry to any great extent, their performance cannot be predicted.

In reviewing the analyses relative to the ac source (part of the APSE), ignition within this compartment is addressed in a limited way in the Carbuilder's Preliminary Hazard Analysis. This analysis addresses defects in capacitors, transformers and inductors, only in terms of "possible smoke." The Subsystem Hazard Analysis considers only the presence of unspecified harmonics and energized dead rail while the Operating Hazard Analysis considers only electric shock safety. No consideration is given to the possibility of a high voltage wire breaking within this compartment which also contains ac and low voltage dc circuits. Should a high voltage wire make contact with wires or apparatus of the other voltage, ignition could result. Analysis should be performed to address these potential ignition sources.

4.9 CONCLUSIONS

In order to identify the potential sources of ignition for the "C" Car undercar equipment, the Contract Book and the analyses performed by the carbuilder on the major undercar equipment were reviewed. Also reviewed were fire incident reports and the Fire Hardening Program Plan for the "A" and "B" Cars to determine whether previous fire incidents and known sources of ignition at the undercar areas were taken into consideration during the development of the specifications for the "C" Car.

During the review of the Contract Book, it was noted that BART made considerable effort to address undercar equipment hazards, either through performance requirements or through the System Safety Program as specified in the Contract Book. This program is designed to "identify potential and actual hazards and initiate actions necessary to eliminate them".

A review of the analyses performed by the carbuider on the major undercar equipment indicated that most potential sources of ignition were identified. However, four problem areas were identified that still require resolution: traction motor commutator, current collector, line switch and APSE. Where analyses were not made on these problem areas, a determination was made by the carbuilder that the potential sources of ignition were not single point failures leading to Category I or II hazards.

The Preliminary Hazard Analysis for the traction motor lists it as a Category III hazard, while the Operating Hazard Analysis lists it as a Category II hazard. Although the previously conducted BART Fire Hardening Program Plan lists the traction motor, it does not categorize it. However, the plan states that flashovers are a cause of ignition. The commutator, not mentioned in any analysis, is a known source of traction motor flashovers and therefore should be addressed.

In the analyses, current collector hazards are classified in an inconsistent manner. Depending on the analyses being reviewed, the current collector hazard may be classified as category I, II or III. This situation should be reviewed to clarify the hazard analyses results.

Within the propulsion controller, analyses should be made relative to the line switch. The analyses should address problems such as binding of the armature or binding of the interlock arm. The FMECA lists line switch failures but does not list all potential failures. Although the Fire Hardening Program Plan lists the line switch under fire threat #1 (no potential fire source) and BART has an excellent record for line switch maintenance, line switches are known to bind, draw high wattage arcs and either weld the contact tips or cause ignition and therefore should be considered a single point failure.

Because the input to the APSE is 1000 volts dc, the presence of wires of this voltage within the confines of the compartment creates a serious threat for ignition. Should one of these wires break and come in contact with ground or components that make up the system, a serious fire can result. An analysis of the APSE relative to this possibility should be made.

In summary, experience has shown that the traction motor armature, current collector contamination, line switch armature binding and loose or dangling high voltage wire or cable are potential sources of ignition.

BART and the carbuilder should reevaluate these items relative to their failure and hazard classification. Events should be developed for fault trees under the SSHA to accommodate the conditions for these items to become ignition sources. The

Safety Critical/Catastrophic Items List should be reviewed to determine whether these items should be on the list to be covered by a deviation to the BART specification requirements that "no single point failure shall result in a Category I and II hazard".

5. CONCLUSIONS AND RECOMMENDATIONS

After reviewing the fire safety characteristics of the BART "C" Car, the following conclusions and recommendations are provided for consideration.

5.1 CONCLUSIONS

In reviewing the vehicle documentation, it is apparent that BART has invested considerable care and effort in the development of the "C" Car Contract Book. This process resulted in a detailed performance specification which addressed both the fire safety characteristics of the materials and the vehicle equipment. The documents prepared by the carbuilder in their present state are not as well prepared or presented. As noted in Section 3, several of the carbuilder prepared documents are still undergoing revision. In many instances, the quality, organization and wording of the reports made them difficult to review. The technical content is generally acceptable, but additional areas of analysis may be appropriate and are identified in sections 2 and 4.

Vehicle materials are a critical element in providing a vehicle in which the fire threat has been minimized. For the "C" Car procurement, BART has required the contractor to submit fire and smoke emission data for all flammable materials used in the prototype "C" Car. This has included all materials/components which weigh more than 10 pounds. The scope of the TSC review was directed at those components identified in the UMTA "Recommended Fire Safety Practices for Rail Transit Materials Selection."

The test results provided by BART indicate that the materials selected for the prototype "C" Car meet the BART contract requirements and the UMTA Recommended Fire Safety Practices.

Realizing that the vehicle undercar equipment has the potential of being a major source of ignition, an in-depth review and evaluation of the BART "C" Car drawings and documentation supplied by the carbuilder was made. It can be concluded that a reasonable effort was made by the carbuilder to take into consideration prospective ignition sources that may be present in the undercar equipment. However, several ignition sources do not appear to have been addressed or considered during the analysis phase (these are noted in section 4). Some deviation from the Contract Book or transit vehicle accepted practices were noted. In general, the principles of fire prevention and fire containment have been utilized to minimize the incidence of fires on these cars. An actual inspection of a prototype "C" Car at the BART Hayward Maintenance Facility revealed that the undercar equipment was well laid out and easily accessable. It is apparent from this inspection that BART and the carbuilder have endeavored to minimize the vehicle fire threat through the materials and equipment selection process.

5.2 RECOMMENDATIONS

BART, through the vehicle supporting documentation, materials selection and equipment selection and placement process has attempted to minimize the potential fire threat in the "C" car. It must be understood by all concerned parties that such an endeavor by any organization will not totally eliminate the occurrence of all fire and smoke incidents. These incidents will continue to occur occasionally but their frequency and magnitude should be reduced. It is recommended that BART undertake the following actions to minimize the frequency and severity of the incidents:

1. Work with the carbuilder to resolve the fire safety ignition issues identified in the vehicle documentation and analyses. The resolution of these issues will serve to clarify the vehicle documentation and complete the fire safety analysis effort.

2. BART should formally audit and prepare periodic reports on the implementation of the carbuilders' Quality Assurance Program to ensure that the quality of the materials, equipment, and construction employed in the production "C" Car do not degrade the fire safety characteristics of the car. This monitoring effort should also be carried out for the System Assurance Plan to ensure that the carbuilder adequately addresses, in the production vehicle, all of the identified Category I, II and III hazards.

3. This review of vehicle materials and equipment has been confined to the prototype "C" Car. Realizing that changes may be necessary in the production "C" Car, BART should provide the CPUC with a list of all such changes, the flammability and smoke emission test data for the materials where appropriate and the necessary hazard analysis revisions.

4. Implement the maintenance recommendations provided by the carbuilder and individual suppliers. The BART maintenance record has historically had very few problems with traction motors, wheel bearings, etc.

5. Continue to closely monitor vehicle testing and operating experience to identify prospective hazards. Promptly resolve identified hazards by eliminating or controlling them.

APPENDIX A
CONCERNS OF THE CALIFORNIA PUBLIC UTILITIES COMMISSION (CPUC)

This appendix presents the concerns and needs of the CPUC relative to the fire safety of the BART "C" Car.

A. A review and evaluation is needed of the reports, films, test data, plans, specifications, fire safety analysis, and other information developed by BART and its consultants in connection with the "C" Car fire safety requirements. Included in this review will be the comments provided to BART by the CPUC and the Bay Area Fire Liaison Committee.

B. Using the UMTA Recommended Fire Safety Practices as a point of departure, review the information developed during the BART Fire Hardening Program and other advances in the state-of-the-art to establish appropriate criteria for the liner materials' fire resistive characteristics. A list of materials will be provided from the UMTA Materials Information Bank. Included with this list will be the materials manufacturer and the fire performance characteristics. Where necessary, assistance is needed in assessing the manufacturing difficulties associated with adapting these materials for use in the "C" Car.

C. Utilizing the calculation methodology of the UMTA Recommended Practices, an appropriate time criteria must be established for testing the "C" Car floor. This analysis will take into consideration the UMTA floor testing program presently being conducted by the University of California (UC), Berkeley. The floor test calculation time will use the concept of "nominal time" defined as: twice the time for the train to come to a full stop from maximum speed in normal situations plus the time necessary to evacuate all passengers from a vehicle to a safe area. Evacuation data will be provided by the Bay Area Fire Liaison Committee and the time criteria derived will be reviewed with the committee.

D. As there presently are no viable combustion toxicity criteria that may meaningfully be applied to materials selection, UMTA has initiated a Task Force to address this issue in conjunction with the Office of the Secretary of Transportation. This Task Force, which will be Departmental wide, will develop a plan for establishing guidelines to be employed in addressing the combustion toxicity of materials in conjunction with other government organizations and industry. The CPUC concerns will be put forward in this Task Force and incorporated into the Task Force objectives. Furthermore, where possible, the Task Force results will be incorporated into this technical assistance effort.

E. Evaluate all the materials test results and witness any non-standard tests and the full scale fire test in the Contract Book (Table 19-1 "Fire Resistive Summary").

F. Review the "builders specifications" for the "C" Car to identify compliance with the fire safety requirements outlined in the BART "Contract Book for the Procurement of Transit Vehicles". This review will also insure that both documents address the UMTA Recommended Fire Safety Practices. Included in this review of the specifications will be a review of the Quality Assurance Program proposed by BART and the Contractor.

G. Prepare a final report evaluating BART's "C" Car fire safety in the areas covered by the scope of work herein. Findings, conclusions, and recommendations are to be provided. When necessary these recommendations will identify areas where additional analysis or testing should be conducted.

APPENDIX B
CALCULATION OF FLOOR TEST TIME

The UMTA "Recommended Fire Safety Practices for Rail Vehicles Materials Selection" consider the floor to be a barrier to undercar fires and recommends that flooring be tested using the ASTM E-119, Fire Tests of Building Construction and Materials. The ASTM E-119 test provides a time temperature curve to be employed in the test and a series of pass/fail criteria based on the temperature of the specimen being tested. The time criteria provided in the "Recommended Practices" is specified as a Floor Test Time (F_T) and is calculated as follows:

"The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete safe stop from maximum speed plus the time necessary to evacuate all passengers from a vehicle to a safe area."

$$F_T = 2(T_S) + T_{EV}$$

T_S = Vehicle Stopping Time

T_{EV} = Vehicle Evacuation Time

B.1 STOPPING TIME CALCULATION

The vehicle stopping time (T_S) is calculated from the maximum speed (80 mph) which is limited by the automatic train control system and the service brake rate for a vehicle with a full patron load. This rate is 3.0 mphps.

$$T_S = \frac{80 \text{ mph}}{3.0 \text{ mphps}} = 26.67 \text{ seconds}$$

Assuming a maximum tractive effort deviation of + 10%, the T_S = 26.67 (110%) or 29.34 seconds which is rounded to 30 seconds or 0.5 minutes.

B.2 EVACUATION TIME CALCULATION

The vehicle evacuation time (T_{EV}) is comprised of three elements:

1) time needed to evaluate the situation and make a decision to evacuate (T_D);
2) time to announce evacuation (T_A); and
3) time to evacuate the patrons (T_E).

$$T_{EV} = T_D + T_A + T_E$$

T_D and T_A are assumed to be 10 minutes and 1 minute, respectively. T_E is calculated based on a maximum patron load of 144 patrons. The exit rate may be estimated to be 35 patrons per minute per vehicle. This is based on the report, "Berkeley Hills Tunnel Preferred Evacuation Method", Kaiser Engineers, Report No. 80-6-R, January 1980. This number is used because, although the interest is limited to the evacuation time from the vehicle with the fire under the floor, the evacuation time is constrained by the patron flow rate away from the vehicle, not the number of exits available on the vehicle.

B.3 FLOOR TEST TIME CALCULATION

$$\begin{aligned} F_T &= 2(T_S) + T_{EV} \\ &= 2(0.5) + 15.1 \\ &= 16.1 \text{ minutes.} \end{aligned}$$

REFERENCES

1. BART, Contract Book for the Procurement of Transit Vehicles, Contract No. 42AA-110 October 1982/Revised March 1983. Conformed.

2. BART, Contract Drawings for the Procurement of Transit Vehicles, Contract No. 42AA-110 October 1982/Revised 1983. Conformed.

3. Kaiser, Fire Safety Report BART C Car, March 1981.

4. DESIGN ANALYSIS DOCUMENTS:

   Alsthom Atlantique, System Safety Design Analysis and Critical Items List, Stamped "Tentative and Preliminary for Discussion Purposes only". May 6, 1986. Revision D (Update June 2, 1986).

   Letter from K.V. Hari (BART) to D.M. Boria (Soferval), August 13, 1986. Subject: RMSH Prototype Documentation.

   Reliability Design Analysis and Vehicle System Effectiveness Analysis (FMECA), Volume 2, Revision G, April 21, 1986, Volume 3, Revision F, March 21, 1986.

5. CONTRACT DRAWINGS:

   Undercar Equipment Layout: AA #TRR 340161

   Traction Motor: None

   Current Collector: Ohio Brass #54486

   Dynamic Brake Resistors: None

   Storage Battery: None

   Friction Brake: Knorr (hydraulic unit) #1U10681

   HVAC: Safety Electric (Air Conditioning Package Unit) #B552S

   Propulsion Controller: None

   Electric Inverter: None

   APSE: Garrett #201993

   Undercar Wiring Layout #1 (of 40) Revision A, E

   Undercar Wiring Layout 2-40 (particularly sheet 4) AA:#TRR339782

   Passenger Car Wiring Layout: AA: #TRR339791 (11)

   Cabin Wiring Layout: AA #TRR339786

   X End Wiring Layout: AA: #TRR339794

   Compressor Assembly: Stone Safety #S-11774 Revision G

6. AA/S Fire Loading Report, Revision D , 12-31-85

7. AA/S Structural Description Report, Revision G, 5-28-86

8. TEST PROCEDURES AND RESULTS (Dates are those of submittal by the carbuilder to BART unless otherwise noted.

Seating:

a. Passenger: Cushion - Fire Loading Report, Appendix B, Various tests dated 1984

Upholstery - Component Qualification Data, Woven Upholstery Fabrics, Q.01.23.1.531 June 11, 1985

b. Operator: Cushion - Neoprene Foam, Q.01.11.1.034, Revision A, 08-05-85

Upholstery - Q.01.11.1.531, Revision A, 5-21-85

Panels:

Plastics Flammability Q.01.01.1.062, Revision C, 05-28-86
Plastics Smoke Emission Q.01.01.1.567, Revision C, 06-10-86

Diffusers: Lighting Lenses, Flammability Q.01.18.1.024, Revision A, 09-16-85
Lighting Lens, Smoke Emission Q.01.18.1.025, Revision A, 09-16-85

Ducting (hose) Flammability Q.08.01.1.123 ,Revision A, 08-21-85
Ducts Flammability, Q.08.01.1.121, Revision A, 01-22-86
Rigid and Flexible Ducts Smoke Emission Q.08. 01.1.122, Revision A, 01-22-86

Fire Extinguisher Access Flammability Q.01.1.564 8-19-85
Fire Extinguisher Access Smoke Emission Q.01.01.1.565 8-19-85

Flooring:

Floor Panel Flammability Q.01.16.1.123 4-17-85
Floor Panel Smoke Emission Q.01.16.1.124 4-17-85
Floor Covering NFPA 253 Q.01.17.1.041 Revision B 1-20-86
Floor Fire Resistance Q.01.2.121

Insulation

Insulation Flammability Q.01.01.1.068, Revision A, 01-22-86
Insulation Smoke Emission Q.01.01.1.069, Revision A, 01-22-86

Miscellaneous (Addendum to Plastics report listed above)

Elastomers Flammability and Physical Q.o1.01.1.071 08-01-85

Battery Box Covers Q.01.01 1.562 Flammability (10-85 date of test)
Battery Box Covers Q.01.01 1.567 Smoke Emission 7-03-86

Full Scale:

Final Design Evaluation Tests of The "C" Car Transit Vehicle Interior
Q.01.01.3.062 08-07-86

Corner Tests

Fisher, F.L., and R.B. Williamson, "Screening Tests of Candidate Wall and Ceiling Lining Materials for the BART C Car." University of California at Berkeley, CA. Report date, September 1985

9. AA/S System Assurance Plan, 3-29-83.

10. AA/S Quality Assurance Plan Revision D, 12-02-83.

11. Approved Change Orders:

    CO Status (Undated) 001-076
    Conformed copies of approved C.O. 36, 41, 44, 46, 51, 53, 59, 11-03-83.

12. Williamson, R.B., F.L. Fisher, J.M. Kestler, Study of Fire Endurance of Flooring Configurations of Rail Rapid Transit Vehicles, Report no. DTRS57-82-C-0007, 09-27-85.

250 copies

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