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John A. Volpe National Transportation Systems Center

Kendall Square
Cambridge, Massachusetts 02142

March 1992

Safety of High Speed Magnetic Levitation Transportation Systems: German High-Speed Train Safety Requirements - Potential for Application in the United States

Interim Report   February 1992   DOT/FRA/ORD-92/02

ERATTA

Page 7-14

Revise the first two complete paragraphs as follows:

> The draft MBO requires that the system operator establish measures that will minimize the potential for accidents, minimize the consequences of accidents that do occur, support individual rescue, and facilitate the rescue of others. The operator is also required to summarize these measures (in terms of infrastructure, vehicles, service, and rescue), particularly for tunnels, and to present them to the "competent authority" (undefined) for approval. It also states that the system operator is obligated to manage the maglev operations safely and to maintain the facilities, vehicles, and accessories in "a good, operationally safe condition."
>
> The EBO requires that new vehicles not be placed into service for the first time until they have been demonstrably tested.

Page 9-7

The last sentence of the first paragraph should read as follows:

> In addition, the natural environment is a source of background levels of both steady (dc) and variable (ac) electrical and magnetic fields, and of electromagnetic radiation [46, 47, and 48].

Page 9-15

Third sentence of second complete paragraph should read as follows:

> Magnetic fields are higher in the train operator cabin (about double) than in the passenger area.

Technical Report Documentation Page

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16. Abstract

The safety of various magnetically levitated (maglev) trains under development for possible implementation in the United States is of direct concern to the Federal Railroad Administration (FRA).

This report is the second in a series of reports addressing the safety of high-speed maglev trains and presents the results of the review to determine the suitability of German safety requirements for application to maglev systems as proposed for U.S. operations. The intent of the review was to compare the German and U.S. safety requirements in order to assist the FRA in determining what regulations and guidelines may be necessary to ensure a high level of safety for U.S. passenger service.

The review focuses on the High-Speed Maglev Trains Safety Requirements, Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen (RW MSB), which was developed by a German working group of representatives of the German Federal Railways (DB), the Testing and Planning company for Maglev Systems, (MVP), the Institute for Railway Technology (IFB), and safety experts of TÜV Rheinland and TÜV Hanover, headed by TÜV Rheinland, and sponsored by the Federal Ministry for Research and Technology.

The German safety requirements were reviewed in terms of safety related functional areas of the following areas of the following seven maglev system elements: vehicles; guideway; passenger stations; signal, control, and communications (SCC); plans and procedures; personnel; and operating environment. Potential safety concerns for each of the maglev system functional areas were identified. The German safety requirements and the applicable U.S. safety requirements are described and then compared to determine their applicability to proposed U.S. maglev system operations. Recommendations are also included for FRA consideration.

In general, the German effort appears to ensure the same high level of safety for maglev trains that is expected in the United States for similar ground transportation technologies. The challenge lies in transferring the experience of Germany to the U.S. regulatory environment.

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PREFACE

The use of magnetically levitated (maglev) vehicles for high-speed guided ground transportation could easily become a reality in this decade. The first such system will likely be the Florida Maglev Demonstration Project. A result of this development is that a need exists for the assessment of the safety implications of this new form of guided ground transportation. This is the responsibility of the Federal Railroad Administration (FRA), which is charged with ensuring the safety of maglev systems in the United States under the provisions of the Rail Safety Improvement Act of 1988.

The second in a series of reports addressing high speed maglev transportation safety, this report, German High-Speed Maglev Train Safety Requirements--Potential for Application in the United States, examines the suitability for applying the German requirements to the U.S. environment. This FRA/VNTSC report is based upon a review of the German safety requirements document titled, German High-Speed Maglev Train Safety Requirements [Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen]. This document, known by its abbreviation of RW MSB, was developed by a working group representatives of the German Federal Railways (DB), the Testing and Planning Company for Maglev Systems (MVP), industry, the Institute for Railway Technology (IFB), and safety experts of TÜV Rheinland and TÜV Hanover, headed by TÜV Rheinland, and sponsored by the Federal Ministry of Research and Technology. The working group established the requirements to be fulfilled for an application of the Transrapid technology in revenue service, based on the technology as it currently exists at the Experimental Test facility (TVE), Emsland, Germany.

Examination of these German safety requirements suggests a more detailed specification in certain maglev system functional areas may be required in order to provide an adequate level of safety in the U.S. environment.

In this connection, the report on the results of the German Federal Railways (DB) assessment of Transrapid's Readiness for Application, with a major objective being safety analysis, was recently released. It is anticipated that the opportunity to review this new report and its safety-related supporting material, from the perspective of development of U.S. standards, will help address issues that were outside of the scope of the RW MSB. The expected complementary nature of the "Readiness for Application" process combined with the working-group-established RW MSB will be addressed in a future report. Transrapid Safety Certification testing at TVE, Emsland will also be the subject of a future report.

The FRA plans, in the initial development of U.S. safety rulemaking for maglev systems and, in particular, for the Florida Maglev Demonstration Project, to continue to draw upon the extensive body of knowledge and experience gained by the German parties involved in developing, certifying, testing, and supervising the Transrapid technology.

Frequently, issues raised in the FRA project accompanying safety assessments are already being addressed and resolution of these issues has been met by the time the issues are noted in one of the FRA/VNTSC reports. This occurrence reflects well on the effectiveness of the proactive nature of the project accompanying safety assessment process where working hand-in-hand in a public/private partnership with industry achieves the safest possible guided ground transportation environment.

ACKNOWLEDGEMENT

This report was sponsored by the U.S. Department of Transportation (U.S. DOT), Federal Railroad Administration's (FRA) Office of Research and Development. The authors wish to thank Arne J. Bang, of that Office, for his direction and helpful guidance during the preparation of this document. In addition, Philip Olekszyk, Deputy Associate Administrator and William O'Sullivan, both of the FRA Office of Safety, and Manual Galdo, FRA Office of Research and Development, provided important input and review.

The report was prepared by the staff of the U.S. DOT/Research and Special Programs Administration/Volpe National Transportation Systems Center (RSPA/VNTSC) under the direction of Robert M. Dorer, Project Leader for the VNTSC High Speed Guided Ground Transportation Safety Project. Stephanie H. Markos, VNTSC, served as Report Team Leader. VNTSC organizational units participating included the High Speed Ground Transportation Special Projects Office, the Safety and Environmental Technology Division, the Railway Safety Division, and the Structures and Dynamics Division of the Office of Systems Engineering; the Transportation Strategic Planning and Analysis Office of the Office of Plans and Programs; and the Safety and Security Systems Division of the Office of Transport and Information Resources Management. The authors wish to express their deep appreciation to Robert L. Gaumer, of EG&G Dynatrend, Inc., for his valuable editorial contributions to the clarity of language and overall readability of the report.

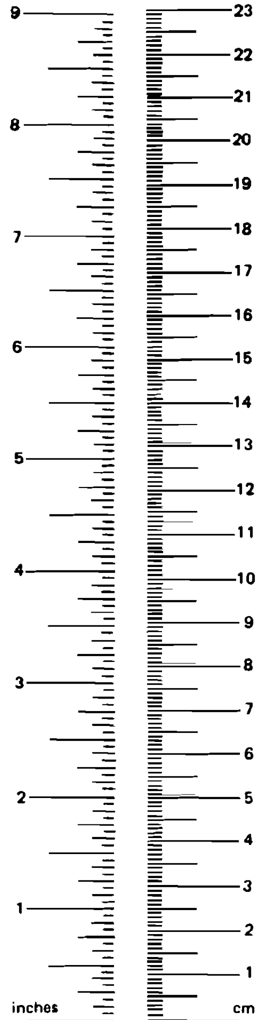
The current level of understanding of the RW MSB maglev system safety requirements and other German safety requirements would not have been possible without the excellent cooperation of the Federal Ministry for Research and Technology, TÜV Rheinland, the Transrapid Consortium, and the Testing and Planning Company for Maglev Systems, GmbH (MVP), all of the Federal Republic of Germany. These organizations provided a wide variety of detailed technical information and the opportunity to observe developmental testing of the Transrapid maglev system in Emsland, Germany.

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		
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	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
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
		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		
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	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
m³	cubic meters	36	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

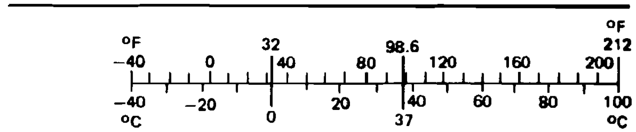


TABLE OF CONTENTS

Section		Page

LIST OF TABLES

LIST OF ABBREVIATIONS

AAR	Association of American Railroads
AC	Advisory Circular
Amtrak	National Railroad Passenger Corporation (U.S.)
APTA	American Public Transit Association
AREA	American Railway Engineering Association
DB	German Federal Railways
DIN	German Standards Institute
DS	Railroad Regulations, Issued by DB
DVS	German Welding Institute
EBO	Railroad Construction and Traffic Regulations (German)
En	European Standard (Issued by European Committee for Standardization)
E VDI	Provisional Standard, Issued by Association of German Engineers
14 CFR	Code of Federal Regulations, Title 14, Aeronautics and Space
49 CFR	Code of Federal Regulations, Title 49, Transportation
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
ICE	Intercity Express (German)
IEC	International Electrotechnical Commission

IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Association
MBO	Maglev Construction and Operating Regulation, Draft (German)
MIL-STD 882B	Military Standard (U.S.): System Safety Program Requirements
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
Pehla RL	Joint Test Laboratory. Owned by German Electrical Industry
RW MSB	Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen (High-Speed Maglev Trains Safety Requirements)
Safety Requirements	Includes regulations, guidelines, standards, specifications, and practices
SNCF	French National Railways
TGV	Train à Grand Vitesse (High-speed train, French)
TÜV Rheinland	Technischer Überwachungs-Verein Rheinland e.V.
VDI	Association of German Engineers
VDE	Association of German Electrical Technicians
VDMA	Institute for Plant and Machinery Construction
UIC	International Union of Railways
UMTA	Urban Mass Transportation Administration (Name changed, in December 1991, to Federal Transit Administration [FTA])

1. INTRODUCTION

This interim report is the second in a series of reports prepared for the Office of Research and Development of the Federal Railroad Administration (FRA). It presents the results of a review by the Volpe National Transportation Systems Center (VNTSC) to determine the suitability of German safety requirements for application to magnetic levitation (maglev) systems as proposed for U.S. passenger operations.

1.1 BACKGROUND

Maglev technology is currently being considered for several passenger ground transportation corridors in the United States. On June 12, 1991, a franchise was awarded to Maglev Transit Inc. (MTI), to build a demonstration project in Florida. A maglev system, linking a station at the Orlando International Airport with a station approximately three miles east of Disney World on International Drive, will be constructed for operation over a 22.5 km (14 mi) route at speeds up to 400 kmph (250 mph).

In addition, maglev technology is being considered for service between Los Angeles (Anaheim), CA and Las Vegas, NV, and between downtown Pittsburgh, PA and the Pittsburgh Airport. Other routes, such as Pittsburgh to Cleveland, OH, and Pittsburgh to Harrisburg, PA, are in the longer-term planning stages.

The Rail Safety Improvement Act of 1988 defined "railroad" to include "all forms of non-highway ground transportation that run on rails or electromagnetic guideways." Accordingly, the FRA is responsible for assessing the safety of maglev systems and has initiated an effort to determine the safety requirements that may be needed for maglev system technologies being considered for U.S. operations. The FRA/VNTSC interim report <u>Preliminary Safety Review of the Transrapid Maglev System</u> [1] identified potential safety issues associated with Transrapid maglev technology and operations.

That report also suggested preliminary findings for the FRA to consider regarding new regulatory efforts; modifications to existing regulations, standards, and guidelines; and the adoption of standards from other industries to address safety issues. As a follow-on effort to the preliminary maglev safety review, VNTSC has completed this more detailed review of the suitability of the German safety requirements for application to maglev systems as proposed for U.S. operations.

1.2 PURPOSE AND SCOPE

This interim report is intended to assist the FRA in determining what new or modified regulations and guidelines may be needed to ensure the safety of maglev passenger trains operating in the United States. It presents the results of a review of the basic content of the German safety requirements pertaining to the functional areas of the electromagnetic maglev system. These requirements are documented in the High-Speed Maglev Trains Safety Requirements, Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen (RW MSB) [2], Railroad Construction and Traffic Regulations (EBO) [3], and the draft Maglev Construction and Operation Regulation (draft MBO) [4].

A process of determining "Readiness for Application" of the Transrapid maglev system technology has been completed in Germany. Many of the safety issues not within the scope of the documents reviewed for this report are covered by this process. A "Readiness for Application" report was released by the German authorities in January of 1992. The safety-relevant information in this report will be considered for its relevance to any U.S. application in a later FRA/VNTSC report.

The initial safety issues as identified in the VNTSC preliminary maglev safety review [1] provided the starting point for the review contained in this report. Additional specific potential safety concerns for selected functional subsystems (i.e., areas), identified as a result of ongoing analysis by VNTSC staff of proposed maglev systems for U.S. operations, were also considered. VNTSC staff also reviewed other selected documents containing safety-related information pertaining to the Transrapid system. Lastly, VNTSC staff obtained clarifying information from conversations and correspondence with the TÜV Rheinland and Transrapid consortium staff specialists.

Section 2 of this report briefly describes the Transrapid maglev system, reviews the U.S. and German approaches to safety, and describes the methodology that VNTSC has used to review the German safety requirements. Sections 3 through 9 contain a detailed review and evaluation of the German safety requirements, in terms of how they address safety concerns associated with each maglev system element and associated functional areas. Alternatives are also provided for FRA consideration in addressing potential maglev safety concerns. Section 10 contains a summary of the findings and recommendations in this report.

1.3 APPROACH

The typical maglev system consists of the same basic system elements (i.e., vehicle; travel surface [guideway]; stations; signal, control, and communications; personnel; plans and procedures; and operating environment) as other guided ground transportation systems. However, a distinguishing characteristic of the electromagnetic maglev system is that electromagnetic forces provide high-speed vehicle propulsion and levitation without any physical contact with the guideway. The maglev system can also carry large numbers of passengers at very high speeds.

The German safety requirements for selected functional areas of the electromagnetic maglev system elements have been reviewed in general and in terms of their U.S. counterpart(s), i.e., compared in terms of the focus, scope, format, and suitability for operations within the U.S. environment. This review identifies safety concerns associated with each maglev system functional element and evaluates the German safety requirements in terms of how effectively they address those concerns.

In addition to reviewing the German safety requirements, VNTSC reviewed FRA, Federal Aviation Administration (FAA), and other U.S. federal agency regulations and guidelines, as well as U.S. industry standards and practices, to determine their potential applicability to the functional areas of electromagnetic maglev technology proposed for U.S. maglev system operations.

1.4 RELATED FRA SPONSORED STUDIES

A more extensive comparison of existing FRA and other federal agency regulations and guidelines, U.S. industry standards, German requirements, and other international codes is being conducted under a separate contract to FRA/VNTSC. The focus of that study is an analysis of German and other foreign requirements cited in each chapter of the RW MSB, with emphasis on those of the German Standards Institute (DIN). Several other studies, under contract to FRA/VNTSC, relevant to maglev safety are also in progress.

Specific reference is made to these studies, as appropriate, within the related functional areas of this report. These studies will provide additional guidance concerning what safety requirements may be appropriate for application to maglev system technology, as proposed for U.S. operations.

2. SAFETY REQUIREMENTS REVIEW PROCESS

The safety goal of any transportation system is to provide passengers and employees with the highest practical level of safety. To determine what FRA regulations and guidelines may be necessary to ensure a high level of safety for U.S. maglev passenger service, VNTSC has reviewed and evaluated German safety requirement documents and selected relevant Transrapid maglev technology safety-related documents. The translated High Speed Maglev Trains Safety Requirements document [2], known by its abbreviation of RW MSB, was the focus of the review. Appendix A contains a brief summary of the contents of each chapter of the RW MSB safety requirements. The intent of the review was to compare the German and U.S. safety requirements to assist the FRA in addressing safety concerns associated with electromagnetic maglev systems, as proposed for U.S. operations.

This section briefly describes the Transrapid maglev system concept, reviews the U.S. and German approaches to safety, and describes the methodology and resources used by VNTSC to review the German maglev safety requirements relating to proposed U.S. maglev operations.

2.1 TRANSRAPID MAGLEV SYSTEM

The distinguishing characteristic of all maglev technologies is the use of magnetic forces for vehicle propulsion without any physical contact with the guideway. Electromagnetic suspension (EMS) and electrodynamic suspension (EDS) are two design approaches which enable a vehicle to "levitate." The Transrapid maglev system uses EMS technology. During all normal operations, vehicle-mounted electromagnets generate attractive forces under the guideway that raise the main vehicle body up off the guideway and maintain a nominal vertical air gap of 8 to 11 mm (0.315 to 0.432 in); other vehicle-mounted electromagnets interact with the side of the guideway to provide a lateral air gap of 8 mm (0.315 in). An important design feature is the uniform distribution of suspension and guidance magnets over the length of the vehicle. This produces an even loading of the guideway and potentially less stress on the guideway girder. Another important design feature is the "safe hover" concept which requires that the vehicle maintain levitation, at least to a designated stop location, under all conceivable failures and emergency conditions. A secondary air-suspension system is used to improve ride quality, and landing skids enable vehicle touchdown in an emergency stop. (A more extensive general system description is contained in Reference 1.) EDS technology, which uses repulsive magnetic forces, is outside the scope of the review contained in this report.

2.2 U.S. APPROACH TO SAFETY

A high level of system safety can be achieved by the continuous evaluation of the potential risk of casualties throughout a particular system's life cycle (acquisition and operation phases) and of the resources required to prevent or minimize potential casualties. By systematically identifying and resolving safety concerns (i.e., hazards) relating to equipment/facilities, people, procedures, and environment before the system is placed into actual operation, the system developer can modify design and operations to eliminate or minimize safety hazards prior to the final development, construction, and operation of the system, thus minimizing the cost of achieving a given level of safety.

Many of the existing FRA regulations and guidelines can be directly applied to maglev systems, and others can be applied in concept to achieve a high level of safety. However, several safety requirements contained in existing FRA regulations are not applicable to maglev systems. The FRA may need to modify these requirements and/or develop new requirements to address maglev-specific safety concerns.

The following subsections review FRA and other federal agency regulations and guidelines, and U.S. industry standards and practices relating to safety that are potentially applicable to proposed U.S. maglev system operations. (The term "safety requirements" is used as a generic term in this report and includes regulations, guidelines, standards, specifications, and practices.)

2.2.1 Federal Railroad Administration Regulations and Guidelines

The FRA promulgates the regulations and guidelines necessary to comply with its Congressional charter. Regulations applicable to passenger train safety are contained in the Code of Federal Regulations, Title 49, Transportation (49 CFR) [5]. In addition, the FRA has published fire safety guidelines which address the flammability and smoke characteristics of materials used in intercity and commuter passenger cars [6].

The FRA regulations reviewed as part of the evaluation conducted for this report (see Table 2-1) relate to safety concerns that are primarily technology-specific and were adopted as the result of years of conventional railroad operating experience. Nevertheless, some of these regulations can either be specifically applied or their intent adapted to other types of guided ground transport technology, such as maglev systems.

2.2.2 U.S. Industry Standards and Practices

The FRA also relies on U.S. industry standards and practices, such as the Association of American Railroads' (AAR) Manual of Standards and Recommended Practices [7] and Field Manual of AAR Interchange Rules [8], the American Railway Engineering Association's (AREA) Manual for Railway Engineering [9], and National Railroad Passenger Corporation (Amtrak) specifications, operating procedures, and other documentation. The majority of these U.S. standards and practices tend to be detailed specifications relating to conventional railroads rather than performance-based criteria; in

Table 2-1 Potentially Applicable FRA Regulations (49 CFR)

209	Railroad Safety Enforcement Procedures
210	Railroad Noise Emission Compliance Regulations
211	Rules of Practice
213	Track Safety Standards
215	Railroad Freight Car Safety Standards
216	Special Notice and Emergency Order Procedures: Railroad, Track, Locomotive, and Equipment
217	Railroad Operating Rules
218	Railroad Operating Practices
219	Control of Alcohol and Drug Use
220	Radio Standards and Procedures
221	Rear End Marking Device - Passenger, Commuter, and Freight Trains
223	Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses
225	Railroad Accidents/Incidents: Reports Classifications and Investigations
228	Hours of Service of Railroad Employees
229	Railroad Locomotive Safety Standards
231	Railroad Safety Appliance Standards
232	Railroad Power Brakes and Drawbars
233	Signal System Reporting Requirements
235	Instructions Governing Applications for Approval of a Discontinuance or Relief from the Requirements of Part 236
236	Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Control Systems, Devices, and Appliances
240	Qualifications for Locomotive Engineers

most cases, this makes it difficult to apply them to other technologies, such as maglev systems.

Non-railroad, industry-specific standards and practices used by railroads include those of the National Fire Protection Association (NFPA), American Concrete Institute, Institute of Electrical and Electronics Engineers (IEEE), and American Society of Mechanical Engineers (ASME).

2.2.3 Other U.S. Federal Agency Safety Requirements

Other federal agency safety requirements may also be suitable for application to maglev systems proposed for U.S. operation. Examples include the Department of Defense (DoD) System Safety Program Requirements (MIL-STD 882B) [10], the FAA Airworthiness Standards, contained in Code of Federal Regulations, Title 14, Aeronautics and Space (14 CFR), Part 25 [11], and the Urban Mass Transportation Administration (UMTA) emergency preparedness guidelines for rail transit vehicles [12 and 13]. Note: It is acknowledged that the name of UMTA was changed in December, 1991 to the Federal Transit Administration (FTA). However, the rail transit-related reports reviewed in this report were prepared for the prior entity prior to December, 1991. As such, they are classified as UMTA sponsored documents for technical reference purposes (i.e., UMTA is included in the report numbers). Accordingly, "UMTA" has been retained in reference to those reports.

2.3 GERMAN APPROACH TO SAFETY

In Germany, each transportation system must be examined, licensed, and certified to operate by an independent organization. The German Federal Railway (DB) is the responsible organization for both conventional railroad and high-speed passenger service, including maglev operations.

TÜV Rheinland, acting for the Federal Ministry of Research and Technology, has applied the process called "Investigation into Safety Features in a Project Accompanying Way" (ISPAW) or "Program Accompanying Safety Certification" (PASC) to the Transrapid maglev system operating at the TVE test facility. This approach is similar to the system safety methodology in that it has been initiated in the maglev system program acquisition phase and is continuing into the operational phase. The ISPAW/PASC approach also recognizes the use of safety analysis to systematically identify and resolve safety issues and concerns.

The RW MSB contains performance-oriented safety requirements goals that must be met by the maglev system developer; TÜV Rheinland is certifying the accomplishment of these requirements through an on-going test program on the TVE test track at Emsland, Germany.

The RW MSB covers specific maglev system properties which are not covered by existing German technical regulations. It establishes safety requirements in 12 topic areas:

- System Properties, Especially Safe Hovering
- Propulsion Including Energy Supply
- On-Board Energy Systems
- On-Board Control System
- Load Assumptions
- Stability Analyses (Guideway/Vehicle)
- Design, Production, and Quality Assurance of Mechanical Structures
- Switch
- Operations Control Equipment
- Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge
- Fire Protection
- Rescue Plan

The requirements apply to maglev vehicles, such as the "Transrapid" type, which use electromagnetic suspension (EMS) technology with long-stator propulsion. The RW MSB describes safety requirements, establishes records/tests to be performed, and lists equally applicable standards for each topic area. In addition, an introductory chapter contains definitions which specifically relate to maglev technology. The RW MSB addresses the safety of maglev technology based on experience with other systems and knowledge gained from evaluation of the Transrapid system under development over the last 12 years.

The RW MSB safety requirements were developed by a working group headed by representatives of the German Federal Railways (DB), the Testing and Planning Company for Maglev Systems (MVP), industry, Institute for Railway Technology (IFB), and safety experts of TÜV Rheinland and TÜV Hanover, headed by TÜV Rheinland and sponsored by the Federal Ministry of Research and Technology. The working group established the requirements to be fulfilled for an application of the Transrapid technology in revenue service, based on the technology as it currently exists at the Experimental Test facility (TVE), Emsland, Germany. The working group also incorporated the results of safety studies and expert inspections of all maglev safety-relevant subsystems and installations in the RW MSB document.

For German operations, the Transrapid system must also meet applicable portions of existing railroad engineering regulations contained in the Railroad Construction and Traffic Regulations (EBO) [3] issued by the DB, in addition to meeting the RW MSB safety requirements. The EBO applies to standard gauge railroads in Germany's public transportation system. Certain portions of this document describe applicable requirements for maglev systems not covered by the RW MSB, i.e., passenger car equipment (including door locks), inspection procedures, and personnel qualifications.

Another German document, <u>Maglev Construction and Operating Regulation</u> (draft MBO) [4], although still in unofficial draft form, contains recommended maglev system technology and non-technology specific safety-related requirements. It specifies protection of the facilities and operation of the maglev system against failure and damage. The draft MBO contains topic areas similar to those in the RW MSB, as well as additional safety-related topics including passenger access/egress (e.g., doors, windows, floor height) and personnel qualifications and training. The draft MBO may be modified before acceptance and formal issuance by the German government. Ultimately, if a final version of the draft MBO is adopted, it is intended to regulate the construction, installation, and operation of German maglev systems.

For this report, the EBO and draft MBO were also reviewed to determine which parts may supplement the RW MSB. The EBO and draft MBO contain safety requirements consistent with those of FRA regulations as contained in several parts of 49 CFR.

The scope of this report is limited to reviewing the RW MSB safety requirements in terms of suitability for potential U.S. application to generic EMS maglev technology systems. Accordingly, information gained from Transrapid-specific references and expert opinions is presented in terms of providing selected examples of how one type of EMS technology has fulfilled the RW MSB requirements.

In addition, a process of determining "Readiness for Application" of the Transrapid technology has been completed in Germany. Many of the safety issues not within the scope of the RW MSB, EBO, or draft MBO are covered by this process. The report contains many references to documents relating to Transrapid-specific technology. The safety-related information in that report will be considered for its relevance to any U.S. maglev system application in a later FRA/VNTSC report.

2.4 PRELIMINARY MAGLEV SAFETY REVIEW

The preliminary maglev safety review [1] has been used as a starting point for the review of the German safety requirements described herein. That report identified ten undesired events which could lead to a potential maglev casualty:

- Fire/Explosion in Vehicle
- Fire in Other Critical System Element
- Vehicle Collision with Object
- Vehicle to Vehicle Collision
- Vehicle Leaves Guideway
- Sudden Stop
- Does not Slow/Stop at Station
- Stranded on Guideway
- Inability to Rescue Occupants
- Passenger Illness/Injury

The undesired events were assessed in terms of severity and probability according to the location of the event in the operating cycle. General countermeasures which could eliminate or minimize the effects of undesired events were described. These countermeasures are in the areas of design, training, operations, maintenance, testing and inspection, configuration management, emergency preparedness, recertification or reinspection, and degraded operations. An initial listing comparing safety requirements potentially suitable for application to maglev system technology as proposed for U.S. operations was also included.

2.5 REVIEW METHODOLOGY

Comparison of the similarities and differences of transportation mode characteristics can help determine the extent to which existing safety requirements for each mode apply to the maglev system. The modes of interest are those which share similar attributes with maglev systems, e.g., conventional railroads, rail transit systems, and aircraft. Therefore, relevant safety-related characteristics of these modes were selected for comparison.

As a starting point for this review, the maglev system elements were divided into functional areas. Table 2-2 indicates which maglev system functional areas are addressed by topic chapters of the RW MSB. Safety concerns associated with each of the maglev system elements and functional areas were identified and analyzed in terms of their contribution to the risk of undesired events which could lead to a "potential maglev casualty" (see Appendix B). This evaluation also addresses the safety issues identified in the preliminary maglev safety report [1]. The German safety requirements were reviewed in general and in terms of their U.S. counterpart(s), i.e., compared in terms of the focus, scope, format, and suitability for operations within the U.S. environment. Existing FRA, FAA, other federal agency, and U.S. industry safety requirements were used for comparison.

The following questions were used in the overall review of the German safety requirements for each functional area of the maglev system:

- What are the safety concerns associated with each maglev system functional area?
- What are the German safety requirements which may be applied to address the safety concerns?
- What FRA or other federal agency regulations and guidelines, U.S. industry standards, as appropriate, may be applied to address the safety concerns?
- What are the key differences between the U.S. and German approaches to safety?
- What are the key differences between the U.S. and German operating environments that might affect the safety of each functional area?

Table 2-2 Relationship of RW MSB Chapters to Maglev System Functional Areas

MAGLEV SYSTEM FUNCTIONAL AREAS

"HIGH SPEED MAGLEV TRAINS SAFETY REQUIREMENTS" (RW MSB) CHAPTERS	VEHICLE									GUIDEWAY			
	Structural Integrity/Crashworthiness	Interior Arrangement	Levitation/Lateral Guidance	Propulsion/Braking	Suspension	Electrical Systems	Access/Egress	Emergency Features & Equip.	Fire Protection	Support Columns & Foundations	Guideway Geometry	Guideway Switches	Guideway Access/Egress
1. System Properties, Especially Safe Hovering			X	X			X		X	X			**
2. Propulsion Including Energy Supply				X		X		X					
3. On-Board Energy Systems				X		X		X	X				
4. On-Board Control Systems		X	X	X			X	X					
5. Load Assumptions	X	*			X					X	X		
6. Stability Analyses (Vehicle/Guideway)	X				X					X	X		
7. Design, Production & Quality Assurance of Mechanical Structures	X	X	X		X					X	X		
8. Switch										X		X	
9. Operations Control Equipment	X			X				X					
10. Lightning Protection, Electromagnetic Compatibility, & Electrostatic Discharge			X						X				
11. Fire Protection							**		X				
12. Rescue Plan				X			X	X	X				X

"HIGH SPEED MAGLEV TRAINS SAFETY REQUIREMENTS" (RW MSB) CHAPTERS	PASSENGER STATIONS	SCC SYSTEMS	PLANS & PROCEDURES					PERSONNEL		OPERATIONAL ENVIRONMENT					
			Normal Operating Rules	Equip. Inspection & Maintenance	Guideway Inspection & Maintenance	System Safety Program, Certification & Quality Assurance	Emergency Plans/Procedures	Qualifications/Staffing	Training	EMC/EMI	EMF Emissions	Shared Right-of-Way /Intrusion	Route Alignment	Lightning	Exterior/Interior Noise
1. System Properties, Especially Safe Hovering	X	X			X					X			X	X	
2. Propulsion Including Energy Supply														X	
3. On-Board Energy Systems		X													
4. On-Board Control Systems		X	X	X											
5. Load Assumptions													X		
6. Stability Analyses (Vehicle/Guideway)					X								X		
7. Design, Production & Quality Assurance of Mechanical Structures	X				X	X			X						
8. Switch		X													
9. Operations Control Equipment		X	X					X	X			X			
10. Lightning Protection, Electromagnetic Compatibility, & Electrostatic Discharge	X	X								X	X			X	
11. Fire Protection									**						
12. Rescue Plan	X	X					X		X			X	X		

* Noted as a Reference to Chapter 7

** Referenced but not discussed

- What further actions should be considered by either the FRA or the maglev system developer/operator to resolve safety concerns?

2.6 TRANSRAPID MAGLEV SYSTEM SAFETY-RELATED DOCUMENTATION REVIEW

Because a maglev-specific safety standard did not exist during the design and construction phase of the Transrapid system operated at the TVE Emsland test facility, the Transrapid developer had to independently identify and address potential safety hazards to ensure that they would not result in casualties. To accomplish this, the developer prepared a series of safety-related documents intended to identify and resolve potential hazards associated with the Transrapid maglev system. The primary safety-related documents reviewed by VNTSC are as follows [14, 15, 16, and 17]:

- Basler and Hofmann. Safety Concept for the Maglev Train, Transrapid, Analysis-Evaluation-Measures, Final Report and Appendices. [Basler and Hofmann Report]

- Institute for Railroad Technology. Technical Readiness, Transrapid Magnetic High-Speed Railway, Safety of Transrapid System. (Including Bibliography) [Technical Readiness Safety Report]

- Thyssen Henschel. Technical Report, Transrapid Revenue Service Vehicles. [Revenue Service Vehicle Report]

- Thyssen Henschel. Revisions for Assessment of Readiness for Application by German Federal Railway (DB). (Revisions for Assessment of Readiness Application to DB)

During the review of the German safety requirements, these documents were used as a baseline to identify potential safety concerns and potential countermeasures which could address those concerns. The contents of these documents are summarized in the following subsections. These documents cite many references and expert opinions relating to specific Transrapid technology. However, the scope of this report is limited to reviewing the RW MSB safety requirements in terms of suitability for potential application to generic EMS maglev technology systems being considered for U. S. operations. Accordingly, information gained from these references and expert opinions is used to provide examples of how one type of EMS technology, i.e., Transrapid, has fulfilled the RW MSB requirements.

As noted previously, the "Readiness for Application" process of the Transrapid technology has been completed in Germany. Many of the safety issues not within the scope of the documents reviewed for this report are covered by this process.

2.6.1 Basler and Hofmann Report

Basler and Hofmann, a Swiss consulting firm, under contract to the German maglev system developer and the German MVP, conducted an in-depth safety analysis and evaluation of the Transrapid system [14]. The effects and probabilities of "resultant" events which could lead to the undesired event "personal injury" were assessed. Fault tree and event tree analyses (with quantification of the number of injuries per event and the probability of injury) are presented for a group of nine resultant events regarded as "particularly risk relevant." Types of accidents (e.g., event), the location of each event, and the persons involved are presented in Table 2-3. These events, while not identical, are consistent with those undesired events identified in the preliminary maglev safety review [1]. Basler and Hofmann determined that the event "collision with an unexpected obstacle" presented the greatest risk of personal injury. A detailed discussion of 21 possible measures which could be used to reduce the risk of fatalities included measures such as earthquake protection, smoking restrictions, and the number of train conductors. An optimal state of seven groups of measures (e.g., guideway earthquake design, smoking ban, and number of train conductors) based on cost versus reduction of fatalities per year was selected. Through application of these measures, Basler and Hofmann determined that the risk level would be reduced by a factor of 10 to 0.02 deaths per 100 million km (62.5 million mi) per person. The probability calculations were based on a previously

Table 2-3 Types of Accidents Identified by Basler and Hofmann

Stopping Place		Description	Persons Affected
Inside the vehicle	1.	Collision with other vehicle, same transportation system	Passengers and crew (= driver in road transportation)
	2.	Leaving the path (railroad = derailing; air = crash, false takeoff, or crash landing)	
	3.	Collision with vehicle, different transportation system (e.g., grade crossings)	
	4.	Collision with unexpected obstructions	
Outside the vehicle	5.	Crossing the transport path in a non-system vehicle (e.g., grade crossing)	Third parties
	6.	Crossing the transport path by foot	
	7.	Maintenance of track and vehicle (only with Transrapid)	Crew
During boarding/ disembarking	8.	Jumping on and off a moving vehicle	Passengers
-	9.	Other	Passengers, crew, third parties

Source: Basler and Hofmann [14], page 3.7.

proposed Essen-Bonn route in Germany. To estimate the level of event effects (in terms of number of injuries) and the probability resultant events for U.S. operation, a conversion would be necessary using data for U.S. railroad operations and the U.S. environment.

The following special points concerning the safety analysis were noted by Basler and Hofmann:

- It included only risk of personal injury (not other damage).
- It did not include vandalism.
- It was based on a conceptual, not actual, system.
- It was subject to estimation error.
- Protection goals differ according to the respective perspectives of the system developer, future system operator, passengers, third parties, etc.

Note: Although the preliminary maglev safety review [1] contains fault tree diagrams illustrating a series of undesired events which could lead to a "potential maglev casualty," this safety requirements review has used the majority of the Basler and Hofmann fault trees, because of their more detailed technical content. However, the original fault tree diagrams in the preliminary maglev safety review relating to maglev passenger slips and falls, fire protection, and emergency evacuation have been retained to provide additional insight into hazards associated with those safety concerns.

2.6.2 Technical Readiness Safety Report

The intent of the Technical Readiness Safety Report, completed in September, 1990 [15], was to provide "clear and understandable documentation on the structural, technological, and organizational measures" relating to the Transrapid system concept. The report was designed to "check whether all relevant measures have been specified and documented to the point that operational safety of the system can be demonstrated before its first public use." Five primary aspects were taken into account: passenger safety, evacuation, operational safety, personnel, and deliberate threat from the outside. For each of these aspects, safety concerns are identified, corrective actions taken are noted and existing unresolved issues indicated, and a bibliography of reports to support the conclusions made for each item is cited. (The preliminary maglev safety review [1] indicated that a Preliminary Hazard Analysis [PHA] would be done. However, a review of the Technical Readiness Safety Report disclosed that although directed at Transrapid technology, its approach utilized the framework of a generic PHA. Although the five aspects reviewed in that report are broader than the maglev system elements and functional areas selected for this evaluation, it was determined that the information contained therein, and in the preliminary maglev safety review, should be substituted for the completion of a new PHA.)

2.6.3 Revenue Service Vehicle Report

The Revenue Service Vehicle Report [16] contains a brief description and several diagrams of the Transrapid "revenue service" vehicle based on the Transrapid concept. Thyssen Henschel takes "into account the developmental potential derived from experience gained from the operation and intensified regular and experimental operation" at the Emsland test facility. A summary of the active and passive safety "qualities" and behavior of the system in case of single or double defects is presented. Reliability values for safety-critical components of vehicle subsystems are estimated. Finally, innovations/improvements made to the regular service vehicle technology are described for each of the following vehicle elements: support, guidance, and braking system; car body; steering and control; balance of weight; aerodynamics; and vehicle guideway dynamics and traveling comfort.

2.6.4 Revisions for Assessment of Readiness Application to DB

Thyssen Henschel prepared a document [17] listing issues related to Transrapid that should be addressed during the "Readiness for Application" process undertaken by DB, as well as a list of those issues that had been settled, as of March, 1991. Worksheets identify in tabular format the problems, task/suggested solutions, responsibility/action, and required time for the folowing maglev safety areas: vehicle, operations control system, guideway, system safety, aerodynamics, and vehicle-guideway interaction.

3. VEHICLE

Maglev vehicles are similar to conventional rail passenger cars and aircraft in several respects. All three types of vehicles have large passenger capacity, can travel at high speeds, and provide a confined environment, with vehicle movement and access/egress not controlled by passengers.

Transrapid vehicles operate as a train of multiple coupled cars (sections). Each section is 25.5 m (84.15 ft) long, weighs 45 tonnes (49.5 tons), has a payload capability of 16 tonnes (17.6 tons), and accommodates 98 passengers. Trains can be configured for bidirectional operation (with an operator's control station at each end) and expanded in length by adding sections (without the operator's console) between the end sections.

The magnetic guidance, levitation, and on-board braking are vital core functions and are located on board the vehicle. Other vital on-board vehicle functions include vehicle location and vehicle protection and control, and both a primary and secondary braking system.

The following safety-related maglev vehicle functional areas are reviewed in this section:

- Structural Integrity/Crashworthiness
- Interior Arrangement/Materials
- Levitation/Lateral Guidance
- Propulsion/Braking
- Suspension
- Electrical Systems
- Access/Egress
- Emergency Features and Equipment
- Fire Protection

3.1 STRUCTURAL INTEGRITY/CRASHWORTHINESS

Structural integrity refers to the ability of the maglev vehicle structural components to function properly and reliably when operating within the specified design limits during normal loading conditions and under abnormal operations (i.e., emergency braking).

Crashworthiness refers to the ability of the vehicle to resist extreme structural deformation and the separation of structural components under extraordinary conditions, such as a collision.

3.1.1 Safety Concerns

Structural integrity concerns include design and location of equipment and attachment points, materials properties, component wear and, in the extreme case, separation of structural components. Structural integrity failures can result from inadequate design strength, inadequate construction procedures, loosening of fasteners and breaks in welds from load and vibration, material degradation from fatigue, and corrosion from environmental exposure or mating of incompatible contact surfaces.

All maglev vehicle components that transmit loads for suspension, levitation, guidance, braking, or propulsion will likely be subjected to high loading and thus are susceptible to loss of structural integrity. These components may include levitation and guidance magnets, eddy current brakes, couplers between maglev vehicle sections and towing point attachments, guiding and support skids, elements of the linear motor, and secondary suspension structures and linkages. The attachment, mounting, and structural strength of these components are critical to safety. Locations where there are connections in the structure to provide relative motion, such as couplers between vehicle sections or suspension elements, can become weak and fail under load, creating potential for structural separation. Components of particular concern are suspension elements, discussed in Section 3.5, Suspension, and vehicle couplers and skids which are discussed in this section.

As in conventional railcars, the couplers between maglev vehicle sections have to withstand the potentially significant loads associated with the tensile and compressive forces in propulsive and braking loads acting on each vehicle section during normal operations. In an emergency which requires towing the maglev train, the towing point attachments and the couplers must be able to withstand the vehicle inertial forces and, if delevitated, the frictional forces of the skids.

During emergency braking, with primary brake (propulsion) failure, at speeds of less than 10 kmph (6.2 mph), the Transrapid vehicle skids support the vehicle and serve as a braking force by means of frictional contact with the guideway surface. Safety concerns related to the integrity of these skids include the thermal effects on braking ability and the wear rate on the skid contact surfaces.

Crashworthiness is a critical determinant of the extent of vehicle damage and personal injury in three types of situations: (1) collisions with solid objects, (2) unintended contact between the maglev vehicle and its guideway, and (3) separation of the vehicle from the guideway.

A moving vehicle has kinetic energy and momentum. The crashworthiness of a vehicle depends on the ability to manage the dissipation of this energy and to control the rate at which the speed is reduced. The factors that affect crashworthiness are the design, material properties, and location of vehicle components, as well as the speed, direction, and mass of the vehicle at the time of impact, all relative to the colliding object.

Vehicle damage could occur as a result of contact (impact) between the maglev vehicle and the guideway, other maglev trains, equipment or parts that fall off a maglev vehicle, construction or maintenance structures, birds and other animals and trees, rocks or other objects that fall, or are blown, dropped, or thrown onto the guideway. In addition, the maglev vehicle or the guideway structure may be struck by out-of-control motor vehicles intruding from an adjacent road or falling from an overpass, by debris (such as that from deteriorated overpasses) falling onto the maglev guideway, and by vandals who shoot at or throw objects from an overpass or along the right-of-way. Finally, snow and ice buildup on the guideway may deflect the vehicle and cause secondary impacts with the guideway. (Sections 9.3, Shared Right-of-Ways/Intrusion, and 9.4, Route Alignment, address these concerns from the environmental perspective.)

One type of vehicle-guideway contact could be scraping of the magnets or skids against the guideway functional components, such as the guide rail, sliding surface, or stator pack. Although the Transrapid skids are designed for low-speed contact with the guide rail and sliding surface, hard impact at high speeds may damage the vehicle and potentially injure passengers. This type of impact could occur if the levitation and guide magnets are unable to maintain the proper gap, i.e., safe hover. Loss of safe hover may result from excessive dynamics of vehicle/guideway interaction, from excessive guideway geometry deviations, or from failures in the magnets and controls (see Section 3.3, Levitation/Lateral Guidance, and Section 4.2, Guideway Geometry).

Gap variations and magnet-to-guideway contact may also result from the dynamic interaction between the vehicle and irregularities in the guideway (see Section 4.2, Guideway Geometry). Guideway irregularities of greatest concern are those that cause guideway components to protrude into the vehicle path. Protrusions can be caused by loose stator packs or guide rails, shifting in the support beams, and by mismatch on switches and functional guideway components (see Section 4.1, Support Columns and Foundations, and Section 4.3, Guideway Switches).

Another source of unintended vehicle-guideway contact may be instability caused by aerodynamic forces, such as wind and air pressure variations caused by passing vehicles, tunnel entry and exit, or other surrounding structures, if the levitation and guidance systems are not able to bear the respective loads. The magnitude and gradient of these aerodynamic forces will determine the extent of the variance in the magnet-to-guideway gap and, accordingly, the amount of instability.

The Transrapid maglev vehicle suspension system wraps around the guideway in a manner that effectively captures the guideway. Thus the vehicle can separate from and leave the guideway only when there is a structural break or an open guideway switch (see Section 4.3, Guideway Switches). Conditions that can cause the vehicle or its compartment to leave the guideway include a structural failure of a critical attachment point that joins the compartment with the wraparound frame, a collision that damages the wraparound frame, or an inertial force so great that it tears the compartment from the wraparound frame.

3.1.2 German Safety Requirements

Magnet impact with the guideway due to insufficient gap clearance is a concern uniquely associated with magnetically levitated suspension. This problem and its causes are addressed in Chapters 5, 6, 7, and 9 of the RW MSB safety requirements.

Chapter 5, Load Assumptions, of the RW MSB discusses the loads to consider in the design by citing the types of loads that the maglev vehicle can expect to encounter, a list of operating states affecting the load, and possible disruptions. Interface loads (i.e., loads at the vehicle/guideway interface) are applied to the vehicle through the levitation magnet suspension, guide magnet suspension, eddy current suspension, bearing skid, and guide skid. These interface loads must be studied under routine operations, braking with the safety braking system, controlled set-down, towing of the vehicle, vehicle- or engine-based breakdown, and disruptions caused by the environment.

Chapter 5 further requires that the external loads acting on the vehicle be considered and that the vehicle be designed so that the magnets do not contact the guideway. The RW MSB does not require that impact of levitation or guide magnets, set-downs at excessive speeds, uncontrolled set-down on both sides, and violation of clearance gauge (i.e., gap) be considered when dimensioning the components as long as there is adequate proof that these disruptions are improbable or will be harmless. The RW MSB does not specify the limits on the magnitudes and characteristics of the interface loads from which the designs are based, but it refers to reports on loads obtained from experimental measurements for Transrapid maglev vehicles.

Chapter 5 cites UIC 651 relating to the structure of operator cabs in locomotives and railcars as an equally applicable standard. A specification for the Transrapid test vehicle and a technical report on wind tunnel studies are also referenced.

Chapter 6, Stability Analyses (Guideway/Vehicle), of the RW MSB defines the various loads and load combinations acting on the vehicle and classifies these loads as primary, secondary, or special. Primary loads influence stability during normal operation, and special loads occur infrequently and outside of scheduled operation. All other loads are secondary.

Chapter 6 requires the vehicle structure to be designed to safely function under various loading conditions. The RW MSB requires proof against structural failure, which is to be provided by a stability analysis that includes a strength analysis, and a determination that permissible failure probability is not exceeded. Four risk classes are described for probability and severity relating failures to the vehicle, guideway, and guideway equipment:

- Class 1, catastrophic risk: failure resulting in significant danger to human life and/or major material damage.
- Class 2, serious risk: failure that endangers human life and/or results in significant material damage.
- Class 3, sustainable risk: failure that results in interruption of service and/or minor material damage, but no threat to persons.

- Class 4, negligible risk: failure that results in no interruption in service and insignificant material damage.

Chapter 6 also specifies requirements for the selection of a factor of safety in the design of the vehicle. This factor depends on the consequence of a failure and the probability that a certain loading will occur. A failure that threatens the integrity of the passenger compartment is assigned to risk class 1, while a detachment of elements outside of the passenger compartment is assigned to risk class 2. All other failures are assigned risk classes 3 or 4. When failure probabilities are not used, the RW MSB considers the factor of safety used for rail vehicles by the German Federal Railway (DB) for speeds greater than 200 kmph (125 mph) to be adequate for maglev operations.

A specific value for crosswind velocities based on the Emsland Transrapid Test Facility (TVE) is provided in Chapter 6. Based on TVE data, vehicle loads from wind velocities up to 10 m/s (22.5 mph) are classified as primary (i.e., loads that influence stability during normal operations), and loads from wind velocities up to 25 m/s (55.9 mph) are classified as secondary (i.e., loads that are neither primary nor special). The RW MSB states that unrestricted operations can occur for wind velocities below 25 m/s (55.9 mph).

Finally, Chapter 6 requires limits on guideway geometry variations that will prevent magnet-to-guideway impact caused by the dynamic interaction between the vehicle and irregularities in the guideway (see Section 4.2, Guideway Geometry). According to Thyssen Henschel, the levitation magnets on the Transrapid vehicle are designed to preclude any contact with the stator pack.

The RW MSB does not cite equally applicable standards for the vehicle in Chapter 6. A technical guideline on reliability, maintenance, and service life is referenced as "other literature."

Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, discusses the safety requirements relating to the structural element of the vehicle. The RW MSB requires that no hazards emanate from the vehicle through mechanical influences. Design requirements include providing access for inspecting structural elements relevant to vehicle stability and inspecting primary connections, using detachable connections for joining installations onto the vehicle and evaluating the compatibility of mating surfaces for the formation of voltaic elements. Production requirements for the vehicle include using materials of known quality that have been tested and documented, producing and testing weld joints according to regulations, testing welding performed by welders according to regulations, documenting suitability and characteristics of bonding agents, providing access to test for looseness of screw connections, and configuring detachable connections to prevent loosening.

Chapter 7 requires that the following technical regulations be observed or applied in the production and quality assurance of the vehicle components: EN 29000, EN 29001, EN 29002, EN 29003, EN 29004, and ISO tolerance field h 9, which applies to semifinished goods. Cited as equally applicable standards are the following welding standards: DIN 29 591, DIN 65 118 (Part 1), DS 952, DVS 1603, DVS 1604, DVS 1608, DVS 1609, and DVS 1610. Also cited are DVS 1611 on evaluation of irradiation in rail vehicle construction, and VDI 2330 on calculation of highly stressed screw connections.

Chapter 9, Operational Control Equipment, of the RW MSB contains requirements intended to specifically protect the vehicle from collisions with obstructions on the guideway (see Section 6, Signal, Control, and Communications, of this report).

The draft MBO specifies that the loading gauge of the vehicle (i.e., the vehicle lateral and vertical positions while stationary and moving) not be exceeded even if all negative factors are present. (The draft MBO specifications are in the process of being developed and will be included as Appendix 3 of the final MBO.)

These factors include support and guidance magnets failures, suspension failure, vehicle set-down, wear (e.g., skids), etc. The draft MBO requires that loads from the vehicle be limited to a level that can be safely absorbed by the guideway, and that the vehicle be able to withstand all loads that arise during proper use. It also specifies that the support and guidance system function under all operational states and environmental conditions and be able to absorb the static and dynamic forces. The draft MBO requires that couplers be designed to avoid unintentional coupling and ensure that the vehicle stops safely if the couplers unintentionally separate. Finally, it requires that glass panes for windows, doors, and walls, as well as mirrors, be made of safety glass.

The EBO specifies limits on wheel-set loads and wheel-set design requirements. It also specifies vehicle gauges and various limiting dimensions and clearances for locomotives and railroad cars. The EBO includes requirements for spring loaded traction and buffing equipment at both car ends and states that screw couplers are to be used (except for special vehicles). "Cowcatchers" must be installed on tractive units and driving vehicles. While no mention is made of mirrors, the EBO specifies the same requirements for new passenger car glazing as contained in the draft MBO (i.e., safety glass must be used).

3.1.3 Applicable U.S. Safety Requirements

The FRA specifies structural design requirements for MU locomotives in 49 CFR, Part 229.141. This part specifies the structural design strength for MU locomotives by requiring the locomotive body to resist a specified minimum static end load without permanent deformation of the body structure. To address the hazard of coupler separation, the FRA requires that the anti-climbing arrangement be designed to resist a specified vertical load, and that the coupler carrier and connections be designed to resist a specified downward vertical load. To protect against end impacts of locomotives, the FRA requires installation of a vertical member at each side of the diaphragm capable of resisting a specified shear force at the underframe attachment point. Finally, the FRA requires that the truck be locked to the MU locomotive body to provide a specified shear strength.

Coupler requirements are contained in 49 CFR, Part 229.61 which specifies various conditions for couplers, including dimensional limits, and provisions for limiting or dissipating excessive slack, providing for anti-creep protection, and guarding against loss of drawbar and connection pins. Part 229.61 also requires that the couplers be free of specified defects.

49 CFR, Part 223 specifies that glazing materials used in locomotive and passenger car end and side windows meet certain impact resistance limits as has been certified by the glazing manufacturer, to meet the following minimum impact requirements:

- FRA Type I Material - for use in windshields and other "end facing" locations - must withstand impacts from a 10.9 kg (24 lb), 20.3 cm (8 in) x 20.3 cm (8 in) x 40.6 cm (16 in) object at a velocity of 48.3 kmph (30 mph) and a 22 caliber, 40 grain (.09 oz) bullet at a velocity of 1,053 kmph (655 mph).
- FRA Type II Material - for side windows - must withstand impacts from a 10.9 kg (24 lb), 20.3 cm (8 in) x 20.3 cm (8 in) x 40.6 cm (16 in) object at a velocity of 13.2 kmph (8.2 mph) and a 22 caliber, 40 grain (.09 oz) bullet at a velocity of 1,053 kmph (655 mph).

49 CFR, Part 229.123 requires that locomotives be equipped with pilots, snowplows, or end plates to clear obstructions off the track.

Section A III, Passenger Car Requirements, of the AAR Manual of Standards and Recommended Practices [7], contains construction requirements for railroad passenger cars. Specifications for the selection of materials and the loading that the car should be designed to meet are included. The design of trucks, bolsters, couplers, draft gears, and various other structural members of the car are also covered.

In 14 CFR, Part 25, the FAA describes the types of loads and load combinations that may act on the aircraft, and requires that the aircraft be safely designed and constructed to withstand these loads. The FAA specifies requirements for selecting a factor of safety, a strength analysis to detect possibility of failure, protection of the structure against weathering and corrosion, and the use of fasteners and locking devices. The FAA also requires that materials be of known quality and strength, that they be suitable for use, and that the aircraft be accessible for inspection, replacement, adjustment, and lubrication.

Part 25.571 describes specific procedures for evaluating structures against failure arising from fatigue, corrosion, and accidental damage. The FAA also requires a damage-tolerance evaluation of structures to include probable locations and modes of damage as determined from analysis, test, and service experience.

The FAA requires that the structure be designed to safely meet the load environment acting on the aircraft. To ensure adequate structural strength, the FAA requires a factor of safety of 1.5, but specifies higher factors of safety in the form of special factors for castings, bearings, and fittings to account for uncertainties in strength, variability in manufacturing, and likelihood of deterioration in service. Part 25.305 requires that the structure be able to support a limit load (maximum load expected) without detrimental permanent deformation. The structure must also be able to support ultimate loads (limit load multiplied by the factor of safety) for 3 seconds without failure, or a test must be performed to provide proof of strength.

To address aircraft gust loads, the FAA, in 14 CFR, Part 25.341, requires that gusts of 20 m/s (45 mph) be considered at sea level. Based on statistical data, the strongest gust that is likely to be encountered in normal operations is equivalent to a 9 m/s (20.5 mph) sharp-edged gust (i.e., a gust without gradient) [18].

The FAA specifies requirements for aircraft windshields and windows in Part 25.775. Interior panes must be of non-splintering material. The panes in front of the pilot must withstand, without penetration, the impact of a 1.8 kg (4 lb) bird when the velocity of the airplane relative to the bird is at the design cruising speed; protection must be provided against fragments from birds striking the vehicle. The design of the windshield and windows must consider the effects of cycle loading, inherent characteristics of materials used, and effects of temperatures and temperature differentials. The panes must be arranged such that, if vision through any one panel is impeded, the pilot will be able to use another panel to permit continued safe flight and landing.

3.1.4 Discussion/Recommendations

The RW MSB addresses structural integrity and crashworthiness by identifying the loads that the maglev vehicle is expected to experience and by specifying vehicle design and construction which will enable vehicles to safely respond to these loads. The systematic and comprehensive load identification described in the RW MSB provides a necessary process for the safe design of the maglev system. This approach is similar to the FAA aircraft design and construction requirements.

One unique feature of the maglev vehicle is that the structural design is similar to that of an aircraft and thus would not be able to withstand the buff forces that are required of locomotives or passenger cars. Consideration should be given to revising the design requirements for body structures of MU locomotives contained in 49 CFR, Part 229.141, so that they apply to the lightweight design of maglev vehicles and the operational characteristics distinctive to maglev systems.

The FRA requirements for couplers apply to the standard railroad swinging-knuckle design, but address certain concerns that would be common to any couplers. For example, the requirement that couplers be free from defects and that the couplers be securely mounted, would also apply to maglev vehicles. Since maglev couplers may not be of the swinging-knuckle design, the specific elements of the coupler that are specified by the FRA requirements will be different. The requirement for energy absorption will depend on whether the maglev vehicle is expected to undergo the degree of impacts seen in couplings and operations of a railroad train, which is unlikely.

Extensive operational data exist for the Transrapid maglev vehicles as a result of tests conducted at TVE, in Emsland, Germany. Further analysis of these data could help finalize the maglev structural integrity requirements necessary to maintain operational revenue service. Certain FAA requirements contained in 49 CFR, Part 25, could also be applicable to maglev vehicle structural integrity.

The RW MSB requirement that the levitation and guidance magnets not contact the guideway during normal operations provides the basis for safe maglev design and operation. However, it is not clear what the effects would be if any of the following disruptions occur: impact with levitation or guide magnets, set-downs at excessive speeds, uncontrolled set-down on both sides, and violation of clearance gauge. Also, physical limits on magnet size and configuration may be needed to prevent magnet-to-guideway contact.

To ensure safe operation, the RW MSB requires that objects not be permitted to land on the guideway (see Sections 6, Signal, Control, and Communications, and 9.3, Shared Right of Ways/Intrusion, of this report for further discussion of this issue). The FRA requirements in Part 223 are intended to specifically protect the locomotives and passenger cars from impact with airborne objects or with objects on the track. As noted in the preliminary maglev safety review [1], while existing FRA regulations are oriented toward impacts with relatively large objects, the maglev vehicle windshield could be vulnerable to damage from small objects, such as birds, because of its high operating speeds. Accordingly, consideration should be given to the use of FAA glazing requirements in modifying the FRA regulations for maglev application. Also, the FRA requirement that locomotives be equipped with pilots, snowplows, or end plates may not be appropriate for maglev vehicles, because those devices may produce adverse aerodynamic effects.

The RW MSB's two wind velocity limits defining permissible maglev operations correspond to the gust severity that would be expected, as specified by the FAA and other sources. It would be appropriate for the FRA to use the RW MSB wind velocity limits for defining the unrestricted operating zone, provided that the vehicle, particularly the levitation and guide magnets, have been designed to maintain non-contact operation under these wind loads.

The draft MBO describes in a general manner the basic safety requirements which the maglev vehicles must meet. Some of the requirements are similar to those specified in the RW MSB; in addition, the draft MBO will include limiting values for vehicle loading gauge, once the specifications to be contained in Appendix 3 are completed. These quantitative specifications will be useful for establishing clearances, such as for wayside structures and station platforms.

Although the EBO requirements apply to conventional railcars, the glazing provisions could also be applied to maglev vehicles.

For U.S. application, consideration should be given to:

- Determining the structural loading that maglev vehicles must resist in a crash (e.g., the severity and probability) taking into consideration the "equivalent systems safety" concept. Modifying the current FRA rules on design requirements for body structures of MU locomotives in 49 CFR, Part 229.141, if a lower structural strength requirement for maglev vehicles can still maintain an "equivalent systems safety."
- Modifying the FRA requirements in 49 CFR, Part 229.123, to allow for alternative front-end configurations, if the FRA requirements for locomotives to be equipped with pilots, snowplows, or end plates adversely affect the aerodynamic characteristics of a maglev vehicle. Alternative configurations should provide the same level of safety as the current FRA requirements.
- Modifying existing FRA regulations for window glazing to consider the high speed operation of the maglev system in the U.S. operating environment. The FAA aircraft glazing requirements may be appropriate for maglev operations.

Two studies that have relevance to maglev vehicle structural design are currently underway. One study is a comprehensive in-depth analysis of foreign industry safety requirements (e.g., DINs, UIC), as cited in the RW MSB. The purpose of the second study is the development of a collision avoidance and accident survivability performance specification for high-speed guided ground transportation vehicles. The results of these two studies will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle structural strength/crashworthiness.

3.2 INTERIOR ARRANGEMENT

The maglev train proposed for U.S. service will have an operator cab at each end and passenger sections between the end sections. The operator cab compartment has a seat, an operating console, and lights. Each passenger compartment has passenger seats, overhead luggage racks, a center aisle, and lighting. One designated unit of the maglev train will provide an area for wheelchair securement.

This section reviews the maglev train interior arrangement in terms of the maglev on-board operator's cab compartment and the passenger compartment.

3.2.1 Safety Concerns

The design of the occupant interior compartment has important safety implications relating to seating, aisle width, interior fittings, and lighting.

The fault trees contained in Appendix C of the preliminary maglev safety review [1] identified passenger slips and falls as a safety concern. The seating arrangement, width of aisles, lighting, and flooring material can all affect the severity of passenger slips and falls. Moreover, seats which break away could block the aisle; the lack of emergency lighting at access/egress points could hamper rescue/evacuation efforts in an emergency. (Sections 3.7, Access/Egress, and 3.8, Emergency Features and Equipment, discuss interior arrangement in relation to emergency response crew access and passenger evacuation.)

In many collisions or sudden stops, injuries are more likely to result from secondary impacts between passengers and hard surfaces, sharp edges, loose luggage, and detached components than from gross vehicle crushing. This fact is particularly important even at low speeds when sudden deceleration forces can cause passengers to be thrown from their seats or cause them to hit other seats or structural components of the vehicle. Most fully automated systems are designed so that sudden deceleration cannot occur. However, unintended deceleration could occur if manual operation becomes necessary.

Because of significantly higher operating speeds, the maglev train operator will have less time to react, and the margin for human error is smaller. Therefore, in addition to the collision concerns described above, the working environment (ergonomics) of the cab, in terms of lighting, control, and display arrangement, as well as the demands and potential stresses placed on the operator must also be considered.

The fire performance of interior materials is also an important safety concern. Section 3.9, Fire Protection, contains an extensive discussion of fire safety, including the fire and smoke characteristics of vehicle interior materials such as seating, wall and ceiling materials, and floors.

3.2.2 German Safety Requirements

Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, of the RW MSB safety requirements states that no restrictions are applicable to the vehicle structural design beyond the generally recognized rules of technology as long as the maglev vehicle is designed in such a way that persons within the passenger compartment are not endangered by objects that have become detached or are loosely mounted. Chapter 7 also permits alternative designs to the rules of technology if their suitability is demonstrated to the [German] approval authority; proof must apply to all modes of operation listed in Chapter 5, Load Assumptions.

Chapter 4, On-Board Control System, requires that the operating console meet ergonomic requirements (i.e, dimensions, climate, display equipment, and seating) specified in DINs 33 400, 33 402, 33 413, and 33 414; compliance with records and tests for those DINs is required to be documented.

The draft MBO does not contain any interior arrangement requirements other than use of safety glass in windows, doors, and walls. (Windows are discussed in Section 3.1, Structural Integrity/ Crashworthiness, of this report.) The EBO requires that passenger cars have lighting.

3.2.3 Applicable U.S. Safety Requirements

The FRA regulations do not address passenger car interior arrangement. Amtrak requires that interior passenger car fittings (e.g., seating, partitions, baggage rack) must withstand 6 g_n longitudinal, 3 g_n vertical, and 3 g_n lateral accelerations.

The Americans with Disabilities Act (ADA) requires accessibility of transportation vehicles to mobility-impaired persons. Accordingly, 49 CFR, Part 38 [19] contains requirements for intercity railcar interior arrangement which implement ADA provisions. (These requirements are consistent with the guidelines issued by the Architectural and Transportation Barriers Compliance Board [ATBCB] in 36 CFR, Part 1191.) Part 38.175 requires that high-speed railcars (including maglev cars) comply with applicable sections which apply to intercity rail cars. These requirements include the provision of at least two mobility aid (e.g., wheelchair) seating locations. One of these locations provides sufficient space for the person to remain in the wheelchair; the other permits the person to transfer to a regular coach seat and provides space to hold and store the passenger's wheelchair. An aisle width of 813 mm (32 in) is required, as well as non-slip floor surfaces and lighting at doorways of cars which do not operate at lighted station platforms. These latter requirements have passenger safety implications for the general public (e.g., passenger slip and fall prevention).

The FRA requirements for operator cab interior arrangements are contained in 49 CFR, Part 229. Part 229.41 requires that fan openings, exposed gears and pinions, exposed moving parts and mechanisms, pipes carrying hot gases and high-voltage equipment, switches, circuit breakers, contactors, and fuses shall be in non-hazardous locations or equipped with guards to prevent personal injury. Part 229.43 includes the requirement that exhaust products of combustion be released entirely outside the cab; in addition, batteries must be kept from gassing excessively and be vented. Part 229.117 requires that controlling locomotives used at speeds more than 32 kmph (20 mph) be accurate to within ± 5 kmph (3 mph) and be equipped with a speed indicator clearly readable under all light conditions. Part 229.119 requires that cab seats be securely mounted and braced and that floors must be treated to provide secure footing. In addition, the cab shall have adequate ventilation and a heating system which maintains a temperature of at least 10° C (50° F) 152.4 mm (6 in) above the center of the cab seat. Part 229.127 specifies that each locomotive shall have cab lights illuminating control instruments, meters, and gauges, as well as a reading light.

Section F, Locomotive and Electrical Equipment, of the AAR Manual of Standards and Recommended Practices [7] contains extensive requirements for locomotive cab seats, including cushion and armrest specifications, as well as seat adjustment, tilt, and swivel. The AAR Manual also requires that the seat assembly undergo a test of a 113.6 kg (250 lb) horizontal impact force of 1 1/2 g_n and 3 g_n and a rotational stability test. In addition, the AAR Manual requires padding of locomotive sunvisors and certain control handles, recessed or flush-mounted location for other controls, as well as rounded edges for all possible exposed convex edges and corners.

Section A III, Passenger Car Requirements, of the AAR Manual of Standards and Recommended Practices [7], contains extensive provisions for interior lighting. Requirements for lighting at passenger entry doorways are also included.

The FAA requirements relating to aircraft interior arrangement are contained in 49 CFR, Part 25. Part 25.785 requires seats to be designed such that passengers are not injured as a result of specified inertia forces, and that protruding objects which might injure seated persons be padded. In addition, if seat backs do not provide a firm handhold, handgrips or handrails must be located along each aisle. Part 25.787 requires that stowage compartments (e.g., overhead luggage storage bins) be designed for the placarded maximum weight of contents and for the critical load distribution at the maximum load factors corresponding to flight, ground load, and emergency landing conditions.

Part 25.777 includes requirements for cockpit control location and arrangement, and knob shape. Part 25.1321 contains requirements for arrangement and visibility of instruments.

3.2.4 Discussion/Recommendations

The RW MSB requirements in Chapter 7 recognize the necessity to protect passengers from impact with detached or loosely mounted objects through structural design. However, it is not clear what the term "generally recognized rules of technology" actually means. It is also not clear which authority may approve suitable alternative designs: a government entity, the system developer, or the system operator. The DIN requirements listed in Chapter 4, as reflected by their titles, appear to cover operator cab controls and instrumentation in a manner consistent with the FRA and AAR requirements for locomotive cabs; however, further review of these DINs is necessary to provide a more direct comparison.

In contrast to locomotive safety requirements, neither the FRA nor AAR address the safety of passenger car interior arrangements. Moreover, European trains such as the ICE, TGV, and X2000, as well the Transrapid, have cab and passenger compartment layouts which are designed with extensive ergonomic considerations, versus the more limited U.S. practice. In part, this is due to the more interactive relationship of European designers and regulatory experts, as well the more recent expanded understanding of ergonomics. Ergonomic considerations are an important area which should be investigated further.

In addition to requiring accessibility for mobility-impaired persons, the ADA requirements in 49 CFR, Part 38, regarding aisle width, non-slip floors, etc., provide requirements which are related to general passenger safety, e.g., slip and fall prevention.

The total force or acceleration/deceleration environment must be clearly defined under all allowed operating conditions, including manual operation. Some form of requirements, similar to the FAA provisions for seats and luggage stowage, should be considered for application to maglev vehicles.

For U.S. application, consideration should be given to:

- Reviewing FAA requirements to determine potential for applicability to maglev vehicle interior arrangement.
- Developing specific FRA requirements for passenger car interior arrangement, including, but not be limited to, provisions for seating attachments, interior fittings, elimination of sharp edges, and lighting.
- Investigating ergonomic considerations for passenger car interiors and operating compartments.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, and the analysis of collision survivability, as related to design of interior fittings, will provide additional information for FRA consideration in determining the U.S. regulations and guidelines that may be appropriate for maglev vehicle passenger and operator cab interior arrangement.

3.3 LEVITATION/LATERAL GUIDANCE

The EMS maglev system requires a continuous power source to keep the magnets energized and to maintain levitation. Vehicle-mounted electromagnets generate attractive forces which pull the magnets (and vehicle) toward the guideway for both levitation and lateral guidance; the Transrapid system maintains a nominal vertical air gap of 8 to 11 mm (0.315 to 0.432 in) and lateral air gap of 8 mm (0.315 in) during normal operations. The levitation and lateral guidance electromagnets are the principal elements of the primary suspension. Levitation (vertical) and guidance (lateral) are controlled by varying the strength of the magnetic forces acting between the vehicle and guideway to maintain the proper gap.

The mechanical connections between the magnets and the levitation bogies are also part of the primary suspension. This section discusses the unique aspects of the electromagnet suspension elements. Section 3.5, Suspension, discusses the mechanical suspension elements connecting the magnets to the levitation bogie and the bogie to the car body.

3.3.1 Safety Concerns

While the maglev vehicle is moving (particularly at high speed), the unplanned loss of levitation or guidance could lead to uncontrolled contact between the vehicle and the guideway; this could cause a sudden stop that could damage equipment and injure passengers. If either air gap control or guideway integrity is lost, the vehicle guide magnets can touch the guideway. Thus, it is essential to avoid any vehicle-guideway contact except when such contact is controlled or otherwise known to be harmless.

Should the vehicle come to an unplanned stop at a location that is not configured to allow passenger egress/rescue crew access, passengers may not be able to evacuate the vehicle during an emergency.

Levitation or lateral guidance loss may result from the failure of vehicle magnets and controls. In addition, guideway and associated component failure (e.g., power loss), obstructions on the guideway and external factors, such as electromagnetic interference (EMI), lightning, and electrostatic discharges (ESD), may result in loss of levitation or lateral guidance.

3.3.2 German Safety Requirements

Levitation and lateral guidance requirements are included in Chapters 1 and 7 of the RW MSB safety requirements. Chapter 1, System Properties, Especially Safe Hovering, extensively describes the "safe hover" concept required for the Transrapid vehicle. The safe hover concept requires that the vehicle maintain levitation, at least to a designated stop location, under all conceivable failures and emergency conditions. Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, describes design considerations and quality assurance procedures relating to maintaining safe hover and preventing vehicle-guideway contact.

Since failures cannot be completely eliminated, Chapter 1 requires that the maglev system be designed to be fault tolerant, i.e., fail-operational (safe life). The RW MSB places design constraints on the system to ensure that the safe hover is fault tolerant; operating rules prohibit dispatching a vehicle unless its likelihood of satisfactorily completing its mission has been verified. The vehicle is also required to be stopped at a designated stopping point should any situation jeopardizing safe hover develop.

Chapter 1 identifies the following failures which must be prevented to ensure safe hover: loss of levitation or guidance, magnet-to-guideway contact, failure of the programmed brake function, violation of clearance limits, and other external factors.

The RW MSB has identified the following failures which can result in loss of levitation or guidance: loss of power supply, faulty drive control, software defect, loss of synchronism followed by set-down, and entry into stator short-circuit loop before the neutral point. The RW MSB does not consider individual levitation or guidance magnet failures to be a concern because of its requirement for enough autonomous, redundant units to prevent loss of function during the maximum number of conceivable failures.

Power loss refers only to loss of on-board power. It does not refer to wayside power because the RW MSB requirements prohibit the vehicle from leaving an acceleration zone unless it has enough kinetic energy and battery capacity (considering possible system failures) to reach a designated stopping zone, thus eliminating dependence on wayside power. Enough independently redundant on-board power systems must be provided to ensure that safe hover is maintained despite loss of some of the power systems. (See Section 3.6, Electrical Systems of this report.) Because vehicle power must be shut off at times, a power down command is provided. The RW MSB requires that this command be interlocked so that it cannot be actuated unless the vehicle is stopped and set down on its skids.

Levitation power must be disabled to set the vehicle down on skids, but a set-down command at the wrong time could prevent the vehicle from reaching an otherwise attainable safe stopping point. Accordingly, the RW MSB includes a requirement that this command be interlocked so that a set-down command cannot be given unless vehicle speed is below a pre-set threshold velocity.

The RW MSB requires that software used to control levitation be error free. In particular, single channel software must be valid and correct. The RW MSB requirements for software validation are included in Chapter 4, On-Board Control System, and are discussed in Section 6, Signal, Control, and Communications, of this report.

Loss of synchronism between the long-stator traveling wave field and the levitation field moving along the guideway at vehicle velocity may result in loss of control and subsequent vehicle-guideway contact. The RW MSB addresses this concern by requiring that loss of synchronism be demonstrated to be harmless, or that it is recognized in time for the control system to take corrective action. The Transrapid long stator is a three-phase Y-connected ac synchronous motor. Each phase of the long stator is connected to the propulsion power source at a power connection switch station and routed along the guideway to a termination point. The three phases are joined at the termination point to complete the Y circuit. Two phases shorting together within 150 m (495 ft) of the termination point will set up a low-impedance shorted loop that disrupts the gap control system. The RW MSB requires that the system be configured to detect short circuits between long-stator windings, and that appropriate protective action be taken to prevent loss of levitation unless the vehicle to guideway contact can be shown to be harmless. (See Section 6, Signal, Control and Communications, of this report.)

Levitation magnets will "race" and contact the guideway if the magnetic gap control does not de-energize the magnets as the gap approaches zero. The RW MSB requires that the response of gap control and monitoring system, and the fail-safe design of the magnetic circuit choppers reliably prevent racing and subsequent contact. The gap control system must allow for gap variations within the tolerance of guideway irregularities, but must be designed and verified in tests to interrupt magnetization current if the gap decreases to a minimum value.

The programmed brake function can fail if one of the following functions is lost: position location, vehicle operational control equipment, and safety braking system. Section 6, Signal Control, and Communications, of this report extensively reviews the first two functions, and Section 3.4, Propulsion/Braking, reviews the third function.

It is critical that the vehicle equipment clearance limits be maintained to ensure the necessary air gap under all conditions. The RW MSB has identified guideway tolerances, obstructions, and guideway component mounting as potential concerns which must be addressed to maintain minimum clearance limits. These safety requirements are described in Chapter 7 of the RW MSB and discussed in detail in other sections of this report.

For the Transrapid system, skid-to-guideway contact is possible if there are dual failures at a hinge point. However, in this case, the air bag suspension over the hinge point is automatically disabled.

Loss of levitation may also be caused by factors external to the vehicle, power supply, or control system. The RW MSB identifies three factors: electromagnetic compatibility, lightning, and fire.

Chapter 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge, addresses electromagnetic interference and compatibility (EMI/EMC). The RW MSB specifies that the system components must not generate interference which would cause problems in the control system or jeopardize safe hovering. EMI/EMC for functions other than for safe hover is addressed in Sections 9.1, Electromagnetic Interference and Electromagnetic Compatibility (EMI/EMC), and 9.2, Electromagnetic Field (EMF) Emissions, of this report.

In addition, Chapter 1 of the RW MSB requires that the threat to safe hovering from lightning be prevented by potential equalization, shielded conductors, shielded equipment, cabling layout, and overvoltage limiters. Lightning is discussed in more detail in Section 9.5, Lightning/Electrostatic Discharge, of this report.

Chapter 1 also includes the requirement that safe hover be maintained in the event of a fire to allow the vehicle to reach a safe passenger evacuation area. This requirement is discussed more extensively in Sections 3.4, Propulsion/Braking, and 3.9, Fire Protection, of this report.

Chapter 7 of the RW MSB describes extensive production and quality assurance requirements for vehicles and mechanical structures to ensure that construction and inspection will allow conditions that may jeopardize safe hover to be detected and corrected. It also includes requirements to prevent deterioration of vehicle and guideway component alignments to prevent vehicle to guideway contact.

The draft MBO requires that the failure of any or all components in the levitation, guidance, and suspension systems cannot cause the vehicle to exceed the static and/or kinematic gauges (envelopes) in Appendix 3 of the draft MBO. (Appendix 3 of the draft MBO has not yet been completed.) Although in less detail, the draft MBO includes the principal RW MSB requirements for levitation, guidance, braking systems, and operation.

3.3.3 Applicable U.S. Safety Requirements

Existing FRA and other U.S. requirements were developed for conventional steel-wheel-on-steel-rail systems and are thus not directly applicable to the unique maglev levitation and guidance functions.

3.3.4 Discussion/Recommendations

Chapter 1 of the RW MSB contains extensive requirements for maintaining safe hover, which are based on the concept of fault tolerant operation. These requirements specify that safe hover can be ensured by preventing: loss of levitation or guidance, magnet-to magnet-contact, failure of programmed braking function, violation of clearance limits, and other external factors. To prevent these failures from causing the loss of safe hover, the RW MSB requirements specify a variety of means to preserve safe hover and ensure system reliability. These means include system design, redundancy, wiring practices, circuit protection, and immunity to interference (e.g., electromagnetic and lightning), and fire resistance.

The preliminary maglev safety review [1] identified the potential hazard of continued operation even though some part of the redundant system has failed. Operating procedures which prohibit the maglev system operator from disregarding such failures to prevent continued operations with a system that is no longer fault tolerant may be advisable.

As a function of maintaining safe hover, the RW MSB identifies a number of DINs (e.g., electrical standards), as well as other standards and codes in other chapters, in addition to the requirements in Chapters 1 and 7. These other requirements are discussed as appropriate in Sections 3.6, Electrical Systems, 3.9, Fire Protection, and 9.5, Lightning/Electrostatic Discharge of this report.

The RW MSB requires that the maglev vehicle not delevitate above a safe set-down speed. However, the safe set-down speed is not specified and delevitation at high speeds is not considered. Currently, the Transrapid system normal set-down speed is 50 kmph (31 mph). Although, in the case of Transrapid, Thyssen Henschel (the vehicle developer) has calculated that the probability of losing safe hover at high operating speeds is remote, such an occurrence, if it is not adequately planned for, may result in vehicle damage and passenger injury. [The Transrapid vehicle is designed to be capable of setting down on its skids from any speed without excessive deceleration forces or vehicle damage.] Thus, for U.S. application, if loss of safe hover cannot be completely excluded, it may be reasonable to require that (1) maglev vehicles be capable of safely coming to rest on their skids or other support system from any speed up to the maximum revenue speed allowed and (2) the lateral guidance system also be able to withstand guideway contact under all conditions, e.g., wind gusts and guidance system failure.

In summary, the RW MSB safety requirements represent a comprehensive approach for reliably maintaining maglev system levitation and guidance functions. For U. S. application, consideration should also be given to:

- Requiring operating procedures which forbid operations beyond the point where failure tolerance is jeopardized.
- Requiring that failures be tracked in a nondestructible storage medium (e.g., a black box recorder).
- Requiring that maglev vehicles be equipped with a support system which permits them to safely come to rest without levitation from any speed up to the maximum revenue speed.
- Requiring that the maglev vehicle lateral guidance system be capable of withstanding guideway contact under all conditions.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining what U.S. regulations and guidelines may be appropriate for maglev system levitation and guidance functions.

3.4 PROPULSION/BRAKING

Transrapid vehicle propulsion and primary braking are both provided by the levitation support magnetic field reacting with the long-stator synchronous motor. Secondary braking is provided by an eddy current brake which acts on the solid steel lateral guidance rail. Because the eddy current brake loses effectiveness at low speeds, it is integrated with a skid brake system.

3.4.1 Safety Concerns

A propulsion failure could strand the maglev vehicle along the guideway. Depending on the location (i.e., if the train stops in an inaccessible area), the consequences could be critical or even catastrophic, e.g., in case of fire.

A braking system failure could result in a collision if a vehicle fails to stop, or in the stranding of passengers if the vehicle does not stop at a designated safe stopping area. Therefore, the maglev vehicle braking system must be able to achieve a minimum predetermined braking rate (1) to stop the vehicle in an emergency to avoid another vehicle or obstruction and (2) to stop the vehicle at a safe stopping area which permits passenger evacuation/rescue crew access. Thus, operational separation between vehicles and unsecured portions of the guideway must be predicated on a braking rate no higher than the minimum rate. Moreover, a "fail-safe" or a backup braking system is needed to ensure that the vehicles can always be stopped.

The interface between the braking system and the signal, control, and communications systems (SCC) (see Section 6, Signal, Control, and Communications) is an important information link. It ensures that the operating characteristics, in particular the available deceleration rates, are always known and available to any system that monitors the safe stopping distances and allows route allocations. Whether the braking system is controlled centrally, on board the vehicle, or manually, the "fail-safe" portion of it must always be available under any condition that could possibly occur during the life cycle of the maglev operation.

The software that controls the braking system must be sufficiently reliable to safely control the vehicle at all times. Safety concerns, requirements, and recommendations relative to software, firmware, and hardware elements of the brake system are discussed in Section 6, Signal, Control, and Communications.

3.4.2 German Safety Requirements

Chapter 2, Propulsion Including Energy Supply, of the RW MSB safety requirements states that propulsion is not considered to be a safety-critical function since the vehicle (taking into account the speed range and topography) must continue to levitate and maintain sufficient momentum to coast to the next available stopping point, even if the propulsion system fails.

Chapter 2 requires that the propulsion system present no danger to persons in the event of a breakdown. The failure of the power supply must not cause or facilitate a safety engineering failure that cannot be overcome by the operational control equipment.

Moreover, Chapter 2 addresses propulsion failure by requiring redundancy in the distribution and power conditioning systems. Each substation must be functionally redundant, beginning at the input utility service feeders and terminating at the long-stator motor segments. If a failure of one substation section reduces power availability with a corresponding reduction in performance, the vehicle must be able to complete its mission. Similarly, each side of the guideway must be connected to separate feeds from the substations. If a failure of one substation section causes a loss of power on one side of the guideway, the long-stator on the other side must provide propulsion power.

Chapter 1, System Properties, Especially Safe Hovering, requires that the vehicle, even without active propulsion, be able to maintain safe hovering until it reaches a safe stopping area, and requires a secondary braking system which acts independently of wayside power. Moreover, the RW MSB requires that braking systems be sufficiently redundant to preclude a reduction in braking capability.

In addition, Chapter 1 requires that the programmed braking function (including position location, vehicle operational control equipment, and the safety braking system) be sufficiently reliable to virtually eliminate the probability of failure. This chapter specifies that environmental influences must not lead to impairment of the braking capacity. The possibility of mobile guideway elements impeding proper operation must be factored into stopping point location and safe route control such that a vehicle can always stop safely at an evacuation point if the switch does not line up properly.

Chapter 1 also refers to the draft MBO requirement for two independent brakes. In addition, this chapter requires safe programmed braking capacity in the event of a breakdown and requires a controllable braking function under all circumstances. Braking forces must be compatible with guideway and vehicle design and the minimum force available must agree with the accepted margin of safety. The requirements specify how the two independent braking systems should function to attain a fail-safe design. Location information, which is key to the programmed braking and safe hover concept is discussed in more detail in Section 6, Signal, Control, and Communications, of this report.

Chapter 2, Propulsion Including Energy Supply, contains requirements for disengagement of propulsion during braking (see also Chapter 12, Rescue Plan).

Chapter 3, On-Board Energy Systems, specifies requirements for the on-board energy system, including those systems that ensure availability of the braking function.

Chapter 4 specifies requirements for the on-board control system and subsystems; the key safety subsystem for the braking function is the auxiliary brake control. The on-board control system must be able to determine when an impermissible operating state has occurred and initiate safe emergency braking.

Impermissible operating situations described in Chapter 4 include (1) loss of data communication, (2) loss of redundancy such that any fault, when combined with an existing fault, would create an unsafe state, and (3) loss of ventilation for the computer (which must be able to function without ventilation long enough for the train to be safely stopped).

Requirements for the safety braking system (emergency braking) are also described in Chapter 4. This braking system must be located on the vehicle and must be able to operate independently of wayside communication and operator input. Several independent braking circuits are required and the system must be capable of meeting braking requirements after the failure of one circuit. During operation, initiation of emergency braking is required after the failure of two circuits. If failure detection during operation is not possible, the braking system must be tested at startup and at every stop. A highly reliable signal transmission is required between the safety computer and the safety braking system, but no detailed requirements are given.

A passenger emergency signal is mentioned in Chapters 4 and 12. The on-board computer system must send a report of the signal to the train guard or conductor, the diagnostic installations, and the control center. However, a direct link to the brakes is not required.

Chapter 9, Operations Control Equipment, describes requirements for safe operations. Safe braking operations include not exceeding maximum permissible speeds, achieving and maintaining minimum speeds, and not proceeding beyond the terminal point of the safe guideway. They also include emergency braking requirements and highly reliable shutdown of propulsion in certain situations. Allowance for intervention by competent authorized personnel during operation is required but not defined. Chapter 9 also requires safety-relevant technical installations (e.g., safety braking system) to function properly before any passenger revenue trip begins.

The draft MBO requires two independent braking systems, with one system independent of the drive system. A mechanical braking system is required as a backup in case the energy supply for a stationary train fails. The draft MBO also requires a check of the braking system before each trip.

The EBO describes the braking system requirements for steel-wheel-on-steel-rail trains in general terms. Brake tests are required at the originating station. However, it appears that trains whose consist remains unchanged can be exempted from the originating station brake test. Air brake systems, as constituted in either Germany or North America, fulfill the EBO requirements, even though the requirements are not air-brake specific. However, electro-pneumatic or non-air-brake systems are feasible alternatives within the framework of the EBO requirements.

3.4.3 Applicable U.S. Safety Requirements

The intent of the FRA regulations contained in 49 CFR, Part 229 and Part 232, is to ensure adequate braking capability and to ensure that a departing train can complete its trip safely.

Part 229 outlines the inspection levels and requirements for locomotives and the restrictions for moving locomotives that do not pass inspection. Inspections of increasing detail are required daily, every 92 days, every year, and every 2 years. Also cited is the need for an emergency brake valve that is accessible to at least one crew member other than the train operator. Part 229.46 requires that before each trip the operating authority know that the locomotive brakes and devices for regulating all pressures, including but not limited to automatic and independent brake valves, operate as intended. Part 229.47 requires that MU and control cab locomotives have a clearly marked emergency brake control valve accessible to another crew member in the passenger compartment or vestibule. Part 232.1 includes requirements for braking system availability before departure.

Part 232 outlines the percentages of working brakes required for train operation and the various detailed inspections required that relate directly to the condition of the train air brake system. Initial terminal and running brake tests are detailed. This part also details the testing and repair requirements while trains are in the shop, and it refers to the Field Manual of AAR Interchange Rules [8] and the AAR Code of Tests for details.

FAA safety requirements for aircraft brake systems are contained in 14 CFR, Part 25.125 and Part 25.735. An approval requirement and a series of conditions which the system must meet are detailed. Although the wording tends to be aircraft specific in describing scenarios that must be handled by the braking system, the scope is more performance oriented than the FRA brake-related regulations. For example, Subsection (b)(3) of Part 25.125, which details the landing scenario brake requirements, states "Means other than wheel brakes may be used if that means: is safe and reliable, is used so that consistent results can be expected in service, and is such that exceptional skill is not required to control the airplane."

The intent of the FRA and FAA requirements is to ensure that braking necessary for safe operations is provided. The difference is that the FAA allows active braking systems that have demonstrated adequate redundancy to contribute to the minimum braking effort. The FAA requires conservative estimates of braking capabilities by dictating the use of the most adverse parameters for brake operation including landing loads, vehicle speed, tire-to-runway friction, forward thrust and aerodynamic drag, and "the most adverse single engine or propeller malfunction."

3.4.4 Discussion/Recommendations

The scope and content of the RW MSB requirements vary from that of the FRA safety requirements. This variance may result from the respective environments within which the German and the FRA safety assurance programs operate, including regulation development and enforcement practices.

The RW MSB presents a series of braking system requirements that, if complied with, will ensure a safe maglev braking system. However, the approach used is more general than that traditionally used by the FRA. Compliance is determined by the use of expert opinions of independent test and certification organizations, such as TÜV Rheinland, within the authority given them by the German government. The criteria used to determine compliance with these requirements is documented in the findings of the expert for a specific system or subsystem. Such findings determine whether requirements such as not allowing revenue operation on unsafe sections of the guideway or requiring a highly reliable shutdown of the propulsion system, when necessary, are met.

The RW MSB does not require an operator controlled emergency brake mode wherein the maglev train can be braked at a higher than normal rate to quickly stop the train. In an emergency, the Transrapid operator's emergency brake request is processed by the automated control system and the train is programmed to stop at the next available stopping place. This braking is achieved either by braking with the linear synchronous motor or by use of eddy current brakes, with skids being used to supplant the eddy current brakes at low speeds where the eddy current brakes lose effectiveness. This operational practice is contrary to the accepted U. S. practice which allows the operator of the vehicle to immediately override automated systems when necessary and to initiate maximum braking effort at any time, speed, or location.

The intent of the FRA safety requirements in Parts 229 and 232 is to ensure that a safe braking system is always available on any operating train through regular inspection of the braking systems of locomotives, cars, and complete train consists. While these regulations cannot be directly transferred to a maglev system, in most cases, the intent and scope are considered transferable to a maglev perspective. Although most details and references to air gauges, compressors, pistons, etc., in existing FRA regulations may not be appropriate, drafting of new regulations that cover FRA intent should be straightforward. New regulations could be drafted with a broader perspective to cover traditional rail operations, maglev (electromagnetic and electrodynamic), and high-speed rail, or narrower regulations could be drafted to fit specific technologies, such as EMS (Transrapid) maglev. The broader perspective would seem to be the preferred approach.

The FAA specifies, in Part 25.735, that "each brake must be approved." However, because the FRA does not approve equipment as such, this approach may not be appropriate; however, the remainder of this requirement is a good example of a more performance-oriented regulation that may be applicable to a maglev system.

The EBO is also a good source for the type of content necessary to avoid technology-specific limitations in regulations. However, its scope appears too limited when compared to the coverage of the FRA regulations.

For U.S. application, if RW MSB propulsion and braking requirements are used as a basis for regulating maglev system technology, consideration should be given to:

- Clarifying the environmental aspects that must not affect brake operation.

- Clarifying breakdowns or failures for which backups must be available.
- Analyzing whether the operator should be able to initiate an immediate maximum deceleration stop of the vehicle at any time. (The RW MSB requirements do not consider this option necessary. For a situation which requires an emergency stop, TÜV considers programmed braking to the next designated stopping place to be a superior approach, in terms of safety.)

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle braking systems.

3.5 SUSPENSION

Suspension systems function to isolate the maglev vehicle from guideway irregularities in order to provide a comfortable ride and proper dynamic control so that the levitation and guide magnets maintain the proper gap from the guideway. The typical maglev vehicle has two levels of suspension, primary and secondary.

The primary suspension system connects the levitation and guidance magnets to the levitation bogies, and includes the electromagnetic forces acting between the magnets and the guideway. In the Transrapid vehicle, the mechanical part of the primary suspension attaches the magnets to the levitation frame by means of linear guides and rubber springs. Section 3.3, Levitation/Lateral Guidance, discusses the levitation and lateral guide magnets.

This section focuses on the secondary suspension system, which connects the car body to the levitation bogies. The Transrapid secondary suspension is an intricate arrangement of components that function as springs and shock absorbers and use structural, mechanical, fluid, and electrical technologies. This system consists of pneumatic springs, dampers, rods, and hydraulic cylinders that control the vertical, lateral, and roll motions of the vehicle.

3.5.1 Safety Concerns

The car body in each maglev vehicle section is supported by a number of suspension devices at various points. While a total failure in all suspension support is an extreme situation that is quite unlikely, failure of some of the suspension components is possible and may significantly affect the vehicle dynamics. Suspension failures can result from a structural break in the links and hinges, a leak in either of the fluid devices (pneumatic spring or hydraulic cylinder), or a malfunction in the controller.

If a suspension failure occurs (such as collapsed pneumatic springs from air leaks or leaks in the fluid dampers) and if the levitation bogies support an excessive unsprung weight or if insufficient damping exists, the ability of the magnets to maintain the proper gap could be reduced, thereby increasing the likelihood of the magnets striking the guideway. Moreover, the changes in stiffness or damping could adversely alter the dynamic response of the vehicle, producing a rough ride; passenger falls could occur.

A second suspension failure concern is that if the pneumatic springs on only one side of the vehicle lose pressure, the car body could lean to one side. This could cause a collision if the overhang of the car body tilt exceeds the clearance of any wayside structures such as station platforms.

Another concern is the potential inability to redistribute the load between the car body and levitation bogies due to failures in the system that controls the air pressures in the pneumatic springs. One instance where there is a need for load redistribution is when there is a magnet failure. In this instance, each Transrapid pneumatic spring is designed to have the pressure released when it is located over a levitation bogie that contains an inoperative magnet. Failure of a pneumatic spring to have its pressure released and loads redistributed could put an excessive, uneven load on the remaining functioning magnets, reducing their ability to maintain the proper gap.

Finally, the attachment between the car body and the levitation bogies is a concern. This attachment must provide freedom of movement and a path where the lateral and longitudinal forces can be transmitted between the car body and levitation bogies. If a structural break occurs at a load path, the car body could separate from the levitation bogies.

3.5.2 German Safety Requirements

While the RW MSB does not have specific safety requirements for suspension systems, Chapter 6, Stability Analysis (Guideway/Vehicle), does assign failures that threaten the integrity of the passenger compartment to risk class 1, and failures that result in a detachment of elements installed outside of the passenger compartment to risk class 2. (See Section 3.1, Structural Integrity/Crashworthiness, of this report for risk class definitions.) Failures in the suspension system that can lead to a separation of the car body from the levitation bogies or that can cause suspension parts to fall off onto the guideway would be assigned to either risk class 1 or 2. In addition, the loading specifications and analyses and the requirements for design, production, and quality assurance in Chapters 5, 6, and 7 may be applicable to suspension systems.

The draft MBO discusses suspension related components in terms of functional requirements and specifies that the installations for levitation and guidance functions be able to absorb the highest conceivable static and dynamic forces. The draft MBO also requires that the suspension system be designed to maintain the loading gauge of the vehicle. (See Section 3.1, Structural Integrity/Crashworthiness, of this report.)

The EBO requires that wheel sets which are not gauge changing do not slide laterally on the wheel shaft. Also specified are dimensions and wheel flange requirements of wheel sets.

3.5.3 Applicable U.S. Safety Requirements

The FRA, in 49 CFR, Parts 229.63 through 229.73, specifies safety requirements for locomotive truck suspensions with wheel sets running on railroad tracks of 1,435 mm (56.5 in) gauge. Permissible limits for clearance, gauge, and play between truck components are included. Also specified are requirements that the suspension components not be cracked or broken, that there are no leaking lubricants or leaking fluids in shock absorbers, and that there are no defects in the wheel and tire. Finally, the FRA requires that the truck frame be structurally sound, that the truck is securely attached to the car body, and that suspension parts be prevented from dropping onto the track.

3.5.4 Discussion/Recommendations

The load identification and classification, and design and production requirements specified in Chapters 5, 6, and 7 of the RW MSB apply to any mechanical and structural elements of the vehicle (see Section 3.1, Structural Integrity/Crashworthiness, of this report). Therefore, the requirements specified in these chapters could apply to the suspension system as well.

According to Thyssen Henschel, any failures in the pneumatic springs of the Transrapid maglev vehicle affect only the ride quality, not the levitation system for safe hover.

The draft MBO indirectly specifies general functional requirements for a suspension system which the design must be able to meet and, as such, should be considered in suspension design. In addition, the limits indicated by the vehicle loading gauge will set limits on the vehicle motion, thereby influencing suspension design.

The FRA suspension requirements apply to locomotive trucks with wheels. While the suspension system of the truck and wheel assembly for locomotives differs from that of maglev vehicles using magnetically levitating bogie assembly, both systems have similar components, such as springs and dampers. Because of the differences in design and configuration of the suspensions between locomotives and maglev vehicles, the FRA requirements that reference design-related specifications, if used, would have to be modified. For example, tolerance and permissible play for suspension components would have to be determined for the specific maglev suspension involved. Where the failure of a suspension component (e.g., excessive dynamic response that could cause magnet-guideway contact), could affect the safe operation of the vehicle, specific requirements such as permissible tolerances and structural soundness would have to be established. Although the FRA requirements that are concerned with the suspension component's condition and structural soundness may also apply to maglev systems, the specific conditions and the structure whose soundness is critical would have to be established for maglev suspension components.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle suspension systems.

3.6 ELECTRICAL SYSTEMS

In addition to power for propulsion, levitation, guidance, and control, electrical power must be supplied for auxiliary, or hotel, power. Auxiliary power includes heating, ventilation, air conditioning, lighting, and other electrical loads.

3.6.1 Safety Concerns

On-board maglev vehicle electrical equipment hazards can have critical or even catastrophic consequences for passengers, personnel, and equipment. Hazards include passenger/personnel exposure to high voltage; disruption of safety-critical subsystems, e.g., computer power supplies, levitation, guidance and control, caused by interference from short circuits, arcing, ground currents, etc.; lack of lighting and air conditioning resulting from loss of power; and fires caused by high currents in failed circuit wiring.

3.6.2 German Safety Requirements

The RW MSB safety requirements address maglev electrical system safety concerns in Chapters 2, Propulsion Including Energy Supply, and 3, On-Board Energy Systems. Although emphasis is on the propulsion system and safety-critical circuits, safety requirements for grounding, circuit protection, and fire prevention also apply to non-safety-critical components, such as air conditioning, heating, and lighting. To comply with safe hover and operational requirements that a vehicle stop only at designated safe stopping locations, system faults must be isolated, and the vehicle must continue to operate with failed systems.

Chapter 2 presents general design criteria for propulsion unit design. Recognizing that the propulsion system cannot be designed fail-safe, the RW MSB has established requirements to minimize the likelihood of a total system failure caused by a propulsion system failure. Therefore, a redundant system is required to supply propulsion power even if there is a partial system failure. Both the propulsion supply and long-stator windings must be separate and redundant. Thus, if either one half of the supply or the long-stator winding on either side of the guideway fail, reduced propulsion power will still be available. The RW MSB requires that short circuits and/or ground faults be "reliably" prevented and detected. The control system must be able to overcome any propulsion power supply failure so that the vehicle can continue to the next safe stopping point, thereby avoiding a safety-critical failure.

The RW MSB lists DIN VDE standards which require personnel protection from high voltages or currents in the power system, fast acting ground fault interrupters, and selection of wiring insulation ratings based on worst-case voltage levels. Resonance effects must be considered, and overvoltage suppressors incorporated. The maximum voltage generated as a result of circuit failure must be calculated and the duration of the high voltage presence coordinated with ground fault interrupter circuit response time. Electromagnetic interference (EMI) with signal circuits must also be considered (see Section 9.1, Electromagnetic Interference and Compatibility (EMC/EMI), of this report). Chapter 2 requires that feeder cables be routed away from lower voltage and communication cables. It also requires that cables, including the long stator windings, be shielded and that the shields have conductivity required to conduct worst case fault currents without high-voltage buildup until circuit protection takes effect.

Chapter 3 states that electronic equipment must be designed to withstand ground faults on input and output lines, and must be capable of normal operation when the fault is cleared. Power cables must be sized for the maximum voltages and currents that can be applied by the system, and high current effects on cable displacement must be considered. Long-stator cables may, however, be sized for intermittent service, provided the cable thermal limits are not exceeded.

The RW MSB recognizes that de-energized lines may become energized by magnetic coupling, as when energized levitation magnets pass over de-energized long-stator windings, and that test equipment may impress hazardous voltages on otherwise de-energized circuits. Therefore, Chapter 3 includes requirements for operating practices that will prevent hazards to personnel working on these systems. It addresses on-board electrical system safety requirements which parallel the protection requirements specified for wayside circuitry, but also includes additional requirements for vehicle-specific systems. Chapter 3 also describes requirements for battery charging, ventilation, and temperature control. Energy conversion requirements for the dc-ac converters, levitation and guidance choppers, and the brake chopper must meet DIN standards, as well as requirements for heat-proof structural elements for equipment, overheat temperature prevention, electric arcs, and fire-spread limitation. Safe de-energizing of the levitation, guidance, and brake choppers is required. Grounding of all circuits to the vehicle frame is allowed, but the frame cannot be used as a current conductor. Automatic discharge of capacitors is required for fire safety, electric arcs must be prevented, and contactors must not be relied on as the sole circuit disconnection mechanism.

Chapter 2 cites 28 DIN standards, as well as IEC 502, Pehla RL, and VDI 4005 for power systems, equipment and personnel safety, etc., as "equally applicable standards." Other literature referred to includes three specifications and one test report (each published by Thyssen Henschel, Kabelmetal, and TÜV Rheinland). Twenty-one DIN standards, VDI 2244, and VDMA standard 24169, all of which relate to electrical safety, are cited as equally applicable standards in Chapter 3.

Requirements for electrical circuit design and protection are not included in either the draft MBO or the EBO.

3.6.3 Applicable U.S. Safety Requirements

FRA requirements for electrical system safety are contained in CFR 49, Part 229. Part 229.41 addresses protection against personal injury; it requires that personnel not be exposed to electrical system hazards, i.e., high-voltage equipment, contactors, switches, etc. The requirement also specifies that personnel not be exposed to rotating or moving parts in mechanical systems. Although this rule is not as detailed as the RW MSB requirements, its intent is clear and it appears that the RW MSB meets the intent of this rule.

Part 229.43(b) specifies that the battery be vented and kept from excessive gassing. This also parallels the RW MSB in less detail, but its intent is clear.

Part 229.45 refers to the general condition of a locomotive and prevention of hazards to the crew caused by poorly mounted or maintained components.

Part 229.83 refers to insulation and grounding of metal parts to prevent injury to crew members and requires that all metal components be grounded or thoroughly insulated.

Part 229.87 refers to switch operation, specifically to switches with voltages over 150 V applied. Part 229.89 refers to jumper and cable connections between locomotives, and could be applied to cable connections between sections of maglev trains.

The FAA addresses aircraft electrical system and equipment safety in 14 CFR, Parts 25.1351 through 25.1363. Part 25.1351 addresses power generation and external power connection to aircraft. This part also applies to battery systems and requires functional independence of sources, fire immunity of sources, and transient suppression. Part 25.1353 is concerned with electrical equipment and installations and addresses electromagnetic compatibility by requiring that all systems function without adversely affecting other systems. This part also contains requirements for cable routing and effects of fault currents on adjacent cables and for battery design and installation. Part 25.1355 addresses the power distribution system, but is mainly concerned with connecting an alternate power supply in the event a primary supply fails. Part 25.1363 addresses the procedures for conducting electrical system tests.

NFPA Fixed Guideway Transit Systems (NFPA 130) [20] contains requirements for wire sizes and wiring methods, overload protection, battery installation, insulation, gap and creepage distances, motors and motor controls. NFPA 130 references IEEE No. 11-80, "Standard for Rotating Electrical Machinery for Rail and Road Vehicles," and calls for similar levels of ratings for non-rotary (linear) motors.

Other U.S. safety requirements, e.g., the NFPA National Electrical Code (NEC 70) [21] and National Electrical Manufacturers Association, address electrical safety.

3.6.4 Discussion/Recommendations

The RW MSB contains safety requirements for maglev on-board electrical equipment and combines these requirements with those of German and other European industry. Design, circuit protection coordination, and fabrication practices are similar to those of U.S. industry, as noted previously.

Although the intent of the FRA regulations included in Part 229 is clear, maglev electrical systems are not specifically addressed. Accordingly, these regulations could be modified, as required, to expand their scope and clarify their application to maglev systems. For example, Part 229.45, which addresses equipment mountings, could be expanded to include prevention of injury to passengers and crew, and Part 229.89, which addresses MU cabling of locomotives, could be modified to cover interconnecting cables between maglev vehicles.

Many of the RW MSB requirements either meet or exceed U.S. electrical safety requirements. The FAA requirements in 14 CFR, Parts 25.1351 through 25.1363, as well as other requirements, e.g., those listed in NFPA 130 and IEEE 11-80, could also be modified as necessary to cover maglev systems. It is advisable that requirements for electrical systems be developed for safe maglev system operation in the United States.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle electrical systems.

3.7 ACCESS/EGRESS

The maglev vehicle has side doors for passengers to enter and exit the vehicle at stations. It is intended that passengers will step directly from the vehicle onto the maglev station platform without the need to step up or down. The typical terminal station will configured so that the doors will open on to one platform to allow passengers to exit from the train; then the doors on the other side of the train will open to allow passengers to board. The on-board train attendant will control the opening and closing of the train side doors.

Each vehicle section has end doors, where coupled to another vehicle section. Passengers will have free passage between sections of the Transrapid train, except from passenger sections into the control cab at either end of the train.

3.7.1 Safety Concerns

Prevention of injuries to passengers as they enter and exit the maglev vehicle is an important safety concern. The fault trees contained in Appendix C of the preliminary maglev safety review [1] illustrate that passengers could trip or fall or could become trapped between side or end doors.

The preliminary maglev safety review [1] identified emergency evacuation as a safety issue, particularly because of the wraparound design of the Transrapid vehicle. Passengers must be able to exit the maglev vehicle quickly during a fire or other life-threatening emergency. If the train is stopped on an elevated guideway, swift passenger evacuation from the vehicle can be difficult, and rescue personnel may have difficulty reaching the emergency site. (Emergency access/egress is also discussed in Sections 3.8, Emergency Features and Equipment, 4.4 Guideway Access/Egress, and 7.5, Emergency Plans and Procedures.)

Another key safety concern is the ability of elderly and disabled passengers to enter and exit the vehicle, under normal conditions and in an emergency.

3.7.2 German Safety Requirements

Chapter 4, On-Board Control System, of the RW MSB describes the communication system between the on-board computer and on-board door sensors and controls, including requirements for vehicle door commands. It requires that safe and reliable transmission of all commands to open and close doors on either side of the train, between the on-board safety computer and operating console, be guaranteed. Failure indications for these signals are required in the vehicle and must be relayed to central control. In addition, the computer system is required to give a "proceed" signal only when all "doors closed" signals are indicated. Finally, Chapter 4 cites Part 3, Principles for dimensioning corridors, passages, and entry ways, contained in DIN 33 402, which applies to human physical dimensions.

The RW MSB addresses emergency access and egress in Chapter 1, System Properties, Especially Safe Hovering, Chapter 11, Fire Protection, and Chapter 12, Rescue Plan. Because optimal evacuation of a maglev train is possible only at specified stopping places, the maglev train is compared to an airplane in Chapter 1, and aviation engineering regulations are used as the basis for the evacuation requirements in Chapter 12. The fire protection requirements described in Chapter 11 are considered an integral part of the rescue strategy for the maglev vehicle, as interior materials must used which meet the highest fire safety level according to DIN 5510, Part 1 [22]. Moreover, fire walls which have a 30-minute fire resistance are required between vehicle sections.

Chapter 12 requires that in an emergency passengers be able to use connecting passageways to exit from one vehicle section to another. In addition, Chapter 12 states that in a fire the escape route is through connecting passages to an adjacent vehicle section. It indicates that when exiting from a burning section, passengers and crew should use the shortest route from each position in the vehicle. Chapter 12 requires that the escape route must not be "too narrow." In addition, it requires that "self-rescue" disembarkation equipment (one safety rope per vehicle exit or slides) and adequate space for its use be provided in each vehicle. Chapter 12 also requires that danger-free disembarkation through vehicle exit doors be ensured at stations and designated stopping places. Finally, it requires that escape routes and exit doors have emergency lighting and signs.

The draft MBO requires that the vehicle floors be dimensioned such that passengers can enter and exit the vehicle without danger, and requires that, if possible, the floors be level with the loading area platform. In addition, it requires that boarding doors be designed to prevent danger to persons during closing and to prevent passengers from opening doors while the train is moving. The draft MBO requires that vehicles may not move until all external doors are locked in the closed position. Although it requires that it be possible to open the maglev vehicle doors at a speed of less than 5 kmph (3.1 mph), the draft MBO also requires that the doors be monitored while the train is moving to ensure that the doors remain closed (the implication is that the doors should only be opened at a station or designated stopping place). Opening of external vehicle doors, disconnection of blocking devices, and entering and exiting the train while it is moving are prohibited. The draft MBO also requires installations on the vehicle that provide for train safety to be reliable and fail-safe [door operation would probably be included in this category]. Finally, the draft MBO requires that vehicle emergency exits be provided.

The EBO requires that passenger car boarding doors have secure, in some cases double, locking devices. However, the design must be such that doors can be opened by passengers when the vehicle is moving at a speed of less than 5 kmph (3.1 mph). Boarding doors must also have pinch protection, and remotely controlled or automatically closing doors must be constructed so that, when activated, they are not a danger to people.

3.7.3 Applicable U.S. Safety Requirements

The FRA requirements for access and egress are contained in 49 CFR, Part 223.15. This part does not address passenger door design or operation, but does require that each passenger car have at least four emergency windows.

The ADA of 1990 requires that transportation systems provide access to mobility-impaired persons. Provisions for the implementation of the ADA regulations that are applicable to maglev vehicles are contained 49 CFR, Part 38 [19], which describes extensive requirements for access to intercity railroad passenger trains and high-speed railcars. Part 38.175 requires that maglev cars be designed for high-level platform boarding and comply with certain sections that apply to intercity railcars. The applicable intercity railcar requirements include those related to wheelchair access, platform gap, vertical alignment of cars, boarding handrails and stanchions, and floor-slip resistance. These requirements have implications for general passenger safety, in terms of slip and fall prevention.

Section A III of the AAR Manual of Standards and Practices, Passenger Car Requirements [7] requires that four emergency exits be provided for each 26 m (85 ft) long passenger car.

The Amtrak booklet Emergency Evacuation from Amtrak Trains [23] contains diagrams which illustrate the type, location, and operation of emergency windows, as well as the manual operation of doors, locks, and latches in a malfunction or emergency.

The UMTA emergency preparedness guidelines [12 and 13] contain several recommendations regarding vehicle door safety. These include door controls to ensure that doors are closed when the train is moving, manual operation of doors in an emergency both inside and outside of the vehicle, and signs indicating the location and instructions for the emergency door release.

NFPA 130, Fixed Guideway Transit Systems [20] requires that each transit vehicle have emergency exits on the sides or the ends. Alternate emergency exit facilities, as necessary for the type of vehicle, may be approved by the authority having jurisdiction. In addition, NFPA requires that a means be provided to evacuate the vehicle to a walk surface or other suitable area under the supervision of authorized employees in case of an emergency. (Section 4.4, Guideway Access/Egress, further discusses the NFPA emergency evacuation requirements.)

The FAA requirements relating to emergency exits are contained in 14 CFR, Part 25. For airplanes with a capacity of more than 44 passengers, Part 25.803 requires that evacuation of the maximum seating capacity (including crew) be accomplished within 90 seconds from the airplane to the ground under simulated emergency conditions. Parts 25.807, 25.809, 25.811, and 25.813 prescribe the type, arrangement, marking, and accessibility of emergency exits. Part 25.812 requires an emergency lighting system independent of the main power supply that includes illumination of emergency exit marking and locating signs, interior lighting in exit areas, floor proximity escape path, and exterior lighting; more specific requirements are included for planes that are configured for more than ten passengers.

3.7.4 Discussion/Recommendations

The draft MBO requires vehicle floors to be level with platforms, thereby minimizing the likelihood of passengers tripping and falling when entering and exiting the vehicle. However, neither the RW MSB, draft MBO, nor EBO addresses safety concerns such as slipperiness of floor surfaces, handrails, or platform gap. Although the requirements contained in 49 CFR, Part 38, apply to transportation vehicle access by mobility-impaired persons, many of the provisions, i.e., floor slip resistance, have safety implications for the general public.

The RW MSB, draft MBO, and EBO requirements for door operation provide a baseline for passenger safety in terms of opening and closing vehicle doors at the proper time, including preventing doors from opening while the train is moving. However, the German requirements do not include provisions for manual operation of doors, which would be necessary to open a malfunctioning door or to open a door if electro-pneumatic power is shut down.

In addition, the RW MSB requires emergency lighting and signs indicating the location of emergency exits, but does not specify how many or what type of emergency exits are required.

In an emergency (defined by the RW MSB as a fire), the safe hover concept is intended to enable the maglev train to reach a designated stopping place, which is equipped with facilities for passenger evacuation. The fire protection requirements described in Chapter 11, which require a 30-minute fire wall, provide a means to protect passengers from injury until the next station or designated stopping place can be reached.

The RW MSB does account for unplanned stopping outside of designated stopping places, in the worst case. If the maglev train is stopped on an elevated guideway segment, self-rescue devices could be used for passenger evacuation, as a last resort. However, in certain areas, the local terrain and height of the guideway may not allow use of self-rescue devices. Moreover, the devices and procedures for their use do not address the special evacuation needs of elderly and disabled passengers.

If the maglev vehicle is unable to reach a station or authorized stopping place, the RW MSB options for evacuating the maglev vehicle from an at-grade or tunnel guideway segment (using ladders and footbridges) are consistent with U.S. practice. Despite the estimated remote likelihood of stopping outside of a designated stopping place as calculated by Thyssen Henschel (the vehicle developer), other means of evacuating the train on an elevated guideway segment may be necessary, in an emergency. One RW MSB option for passenger evacuation from a maglev vehicle stopped on an elevated segment includes widened bridge supports for guideway segments over water, to provide egress capability. In addition, the RW MSB demonstrates an awareness that, as a last resort, other means of evacuating the vehicle in an emergency may be advisable, as it states that alternative "outside" means of rescue can be used depending on the infrastructure. Moreover, the RW MSB notes the rescue plan requirements that access roads be constructed and landing sites for helicopters be provided, if necessary. Other acceptable options for maglev vehicle evacuation which could be considered for U. S. application include rescue trains, lifting platforms, and rescue boats (for guideway segments located over water). See Sections 4.4, Guideway Access/Egress, and 7.5, Emergency Plans and Procedures, of this report for additional discussion concerning emergency evacuation of passengers.

The ADA, AAR, Amtrak, UMTA, NFPA, and FAA requirements provide useful resources for considering what information is necessary to supplement the German requirements for safety-critical access and egress.

For U.S. application, consideration should be given to:

- Requiring that the maglev vehicle contain an external and internal means to manually operate the doors, in the event of power failure affecting door operation.
- Reviewing further the FAA aircraft emergency egress requirements (e.g., location, marking, operation) in 14 CFR, Part 25, to determine their applicability to maglev vehicles.

- Reviewing further the Amtrak, UMTA, NFPA, and AAR safety requirements relating to vehicle access and egress, and developing additional vehicle safety requirements that are appropriate for maglev systems during normal operations and emergencies.
- Requiring that the maglev system developer and system operator provide rescue crews with the capability to access the vehicle at locations other than stopping places.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle access and egress.

3.8 EMERGENCY FEATURES AND EQUIPMENT

To minimize the consequences of an emergency, in terms of personal injury and vehicle damage, maglev vehicles should be equipped with appropriate emergency features and equipment. Accordingly, this section discusses vehicle emergency features and equipment which can shorten emergency response time, improve effectiveness of passenger evacuation, and minimize the effects of the emergency.

3.8.1 Safety Concerns

Potential maglev system emergencies include vehicle fire, collision, sudden stop, passenger illness, loss of communication between the vehicle or guideway equipment or the vehicle operator and central control, high winds, an earthquake, guideway intrusion, and power failure.

The type and location of an emergency can affect the safety of maglev system passengers and crew. A fire could cause burns or result in smoke and toxic gas inhalation. Extreme heat or cold in the event of a vehicle breakdown could aggravate physical or medical conditions. In addition, absence of vehicle emergency exits, lighting, communications, and tools could delay passenger evacuation and result in passenger injury. Sections 3.7, Access/Egress, and 4.4, Guideway Access/Egress, focus on passenger evacuation from the maglev system during emergencies.

3.8.2 German Safety Requirements

Chapter 2, Propulsion Including Energy Supply, of the RW MSB safety requirements addresses emergency braking capability. Chapter 3, On-Board Energy Systems, addresses fault and failure detection. Chapter 4, On-Board Control System, addresses faulty component shutdown. Chapter 9, Operations Control Equipment, addresses redundancy of equipment to provide backup capabilities for safety-critical items, such as propulsion and power supply systems and computer systems. These requirements focus on maintaining safe hover long enough in an emergency for the vehicle to reach a safe stopping point. Vehicle features and equipment relating to passenger and crew safety in an emergency, e.g., rescue and evacuation, are presented in Chapter 12. Extensive discussion of how the RW MSB requirements address these topics within the context of operational safety is contained in earlier subsections of Section 3, as well as in Section 4.4, Guideway Access/Egress, and Section 6, Signal, Control, and Communications, of this report.

Chapter 12, Rescue Plan, requires that the vehicle be equipped with two independent communication installations for voice contact between the vehicle and operational control center (and vice versa). A passenger emergency signal (visual or acoustic) by which passengers can inform the train crew of a breakdown or emergency situation is required. (This signal is also mentioned in Chapter 4.)

In addition, Chapter 12 requires that emergency lighting be provided for all vehicle escape routes and that "self-rescue" disembarkation equipment (one safety rope per vehicle exit or rescue slides) and adequate space for its use must be provided in each vehicle. (For further discussion relating to self-rescue devices, see Sections 3.7, Access/Egress, 4.4, Guideway

Access/Egress, and 7.5, Emergency Plans and Procedures, of this report.)

Chapter 12 requires at least one first aid kit for each maglev vehicle. In addition, it requires that two portable fire extinguishers be provided in each section; the location depends on whether the section has an operator cab. (For further discussion of fire safety, see Section 3.9, Fire Protection, of this report and Chapter 11, Fire Protection, of the RW MSB.)

In addition to requiring signs for escape routes and exit doors, Chapter 12 requires that permanent, legible, easily discernable signs be provided on firefighting and rescue equipment and first aid kits. The passenger emergency signal must be clearly marked and accessible and contain a warning of the consequences of misuse. Chapter 4 requires that the passenger emergency signal be transmitted reliably to the on-board safety computer and that a report be sent to the train crew, diagnosis installations, and control center. Chapter 12 also states that, depending on the situation, an emergency stop can be triggered by the operator; however, no details are given.

The draft MBO requires that vehicles be equipped with communications systems which permit voice communication with personnel in the central control facility or vice versa. In addition, the draft MBO requires that vehicles be equipped with fire extinguishers and first aid kits, an acoustic warning system, and front and rear signaling lights.

The EBO requires that one step and one handhold for each train crew member be proved on each side of the car. First aid kits are also required on passenger trains. It requires that emergency brake handles be located in passenger cars such that they are easily seen and reached by passengers and attendants.

The draft MBO and EBO requirements for emergency braking are discussed in Section 3.4, Propulsion/Braking, of this report.

3.8.3 Applicable U.S. Safety Requirements

The FRA safety requirements relating to emergency equipment are contained in 49 CFR, Parts 213, 221, 229, and Part 231. Part 213.23 requires that each passenger car have a minimum of four emergency windows. Part 221 addresses rear-end marking devices; unless equipped with a photoelectric cell, each device must continuously flash 1 hour before and after sunset and during other conditions restricting visibility. Part 229.47 requires that MU and control cab locomotives have a clearly marked emergency brake control valve accessible to another crew member in the passenger compartment or vestibule. (See Section 3.4, Propulsion/Braking, for a discussion of emergency braking.) Part 231.4 contains passenger car requirements including a hand brake compatible with the power brake uncoupling levers, and the type, number, and location of sill steps, side and end handholds and handrails, and side doors steps.

Section A III, Passenger Car Requirements, of the AAR Manual of Standards and Practices [7] requires that each passenger car have emergency lighting independent of the power supply, wrecking tools (including ax and sledge hammer), and a conductor's brake valve to initiate an emergency stop. Amtrak passenger cars have fire extinguishers and emergency tools, certain other cars (multilevel and viewliner) also have first aid kits, and locomotives have fire extinguishers and first aid kits. In addition, Amtrak passenger cars have a public address system, as well as emergency lighting independent of the locomotive.

The UMTA rail transit emergency preparedness guidelines [12 and 13] include recommendations for emergency lighting and access/egress, graphics (signs), ventilation, communications, and fire extinguishers.

The NFPA Fixed Guideway Transit Systems (NFPA 130) [20] contains requirements relating to vehicle emergency features. These include ventilation deactivation, an emergency battery cut-off switch, emergency lighting, emergency egress, communications, and fire extinguishers.

The FAA requirements relating to emergency features and equipment are contained in 14 CFR, Part 25. Part 25.831 requires that crew and passenger compartment air be free of harmful or hazardous gases or vapors, and that smoke evacuation be accomplished starting with full pressurization and without depressurizing beyond safe limits. Part 25.851 requires that hand-held fire extinguishers be conveniently located in passenger compartments (see Section 3.9, Fire Protection). Part 25.1411 contains provisions for safety equipment accessibility and stowage (including public address microphones). Part 25.1307 requires two systems for two-way radio communications; the failure of one system shall not preclude the operation of the other system. Part 25.1423 requires that the public address system be powerable after the shutdown of all engines or auxiliary power or after the failure or disconnection of power sources dependent on their continued operation for at least 10 minutes. Part 25.1561 requires that safety equipment and controls and their locations be clearly and conspicuously marked.

3.8.4 Discussion/Recommendations

Although the RW MSB discusses emergency features and equipment (e.g., emergency lighting, fire extinguishers, etc.), the focus is maglev technology; thus the RW MSB is not intended to present a detailed, comprehensive review of this subject. In addition to safety requirements similar to those described in the RW MSB, the draft MBO and the EBO cover additional necessary emergency-related items such as voice and acoustic warning devices.

The FRA safety requirements provide limited guidance for the provision of passenger train emergency features and equipment. In addition to meeting the FRA safety requirements, Amtrak has equipped its passengers cars with tools, first aid kits, public address systems, and emergency lighting. Sections 3.7, Access/Egress, 4.4, Guideway Access/Egress, and 7.5, Emergency

Plans and Procedures, of this report present more information concerning passenger evacuation and rescue during an emergency.

It is critically important that the maglev system developer and system operator work jointly to ensure that the vehicle is equipped with emergency features and equipment that are appropriate for the environment of the local operation.

For U.S. application, consideration should be given to:

- Requiring the maglev system developer and system operator to use the NFPA 130, UMTA emergency preparedness guidelines, FAA regulations, and AAR and Amtrak specifications as a baseline to develop comprehensive requirements for maglev vehicle emergency features and equipment that are appropriate for the local operating environment.
- Requiring that emergency features and equipment include but, not be limited to, emergency lighting, communications facilities (e.g., a public address system and a passenger emergency signal), ventilation, graphics, and on-board support equipment (i.e., access keys and tools, fire extinguishers, and first aid kits).

The results of the analysis of foreign safety requirements (e.g., DINs, UIC, etc.), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev vehicle emergency features and equipment.

3.9 FIRE PROTECTION

Protection against fires is critical to the safety of passengers and crew on the maglev system. Fire-resistant materials, the proper arrangement of maglev vehicle equipment, and barriers can prevent ignition from occurring, as well as contain fire spread and smoke generation to a limited area of the vehicle; time to evacuate the vehicle would also be provided. Detection systems provide the means to alert train and central control personnel to the fire location so that the proper suppression methods can be used in a timely manner. Accordingly, this section discusses maglev vehicle fire protection in terms of measures to prevent fires, minimize the effects of fires which occur, and provide sufficient time to allow passengers and crew to evacuate the maglev vehicle, if necessary.

3.9.1 Safety Concerns

Prevention and containment, detection, and suppression of a potential fire must all be considered when designing adequate levels of fire protection for maglev vehicles. Maglev system fires could be caused by electrical shorts, equipment overheating, arcing of components, mechanical friction, arson or human error, carry on hazards (e.g., flammable gases and liquids), explosions from gases (e.g., battery), or acts of God (e.g., lightning). Materials which do not resist ignition or contain flame spread and smoke emission could enable a fire to spread and involve other components.

Moreover, fires which are not detected and swiftly suppressed may generate smoke and toxic gases. Fire detection is especially important for unmanned areas or confined spaces containing equipment where there is no means of visually detecting ignition. The fault trees contained in Appendix C of the preliminary maglev safety review [1] and the Basler and Hofmann report [14] illustrate the various types of fire situations which could occur and the importance of timely and effective fire containment and suppression.

A system fire may cause passengers to be injured as a result of burns and smoke/toxic gas inhalation. A fire may also cause panic, confusion, decreased visibility, or reduced oxygen, any of which can complicate passenger evacuation. (See Sections 3.7, Access/Egress, 4.4, Guideway Access/Egress, and 7.5, Emergency Plans and Procedures, for additional discussion of passenger evacuation.)

3.9.2 German Safety Requirements

The RW MSB safety requirements address fire protection in Chapter 1, System Properties, Especially Safe Hovering; Chapter 3, On-Board Energy Systems; Chapter 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge; and Chapter 11, Fire Protection. Chapter 12, Rescue Plan, refers to fire safety in relation to passenger evacuation.

Chapter 1 discusses fire protection in terms of maintaining safe hover long enough for the vehicle to reach a safe evacuation point. The RW MSB requires that the maglev vehicle be categorized in fire protection Class 4 as defined in DIN 5510 [22], which is a source of preventive fire protection requirements for rail vehicles. DIN 5510 assumes that for Class 4 the vehicle is operated on lines which do not have safety areas available for evacuation.

Chapter 3 addresses fire protection in relation to overload and short-circuit protection of on-board electrical/electronic systems. The RW MSB describes two special conditions resulting in the need to maintain a safe energy supply. First, after a network affected by a short-circuit is shut off, there must be no further uncontrolled shutoff of the unaffected networks. Second, a power feed by an electronic component that is current limited during a fault, especially a short circuit over an extended period of time, must not lead to a fire that would threaten safe hovering. Part 5 of DIN 5510 [22] is cited as a source of fire protection safety requirements for rail vehicle electrical operating equipment.

Chapter 3 requires that lines and cables be provided with overcurrent protection devices or equivalent protection devices against effects of excessive heating. It describes additional requirements for line and cable positioning, power rating, stress, corrosion, etc. Cable and line insulation must be halogen free and flame resistant, and not emit toxic gases. Chapter 3 also requires that safety-relevant wiring be preserved after a 1-hour flame exposure. It describes many battery requirements, including prevention of battery overcharging and overheating, and supply of adequate ventilation. Finally, Chapter 3 cites several DINs which pertain to electrical system fire protection.

The RW MSB states that compliance with the lightning protection requirements described in Chapter 10 offers adequate fire protection, if it is assumed that vehicles are not susceptible to fire to explosion or do not contain explosive materials according to the definitions contained in DIN VDE 0185, Part 2.

Chapter 11 requires that the supporting structures, fittings, and linings of maglev vehicles be selected and arranged to prevent or delay danger to passengers, crew, and rescue personnel caused by the development, propagation, and transmission of fire. That is, breakdown in stability, burn damage, and fire transmission during a fire must be prevented or delayed. In addition, the materials and their design and arrangement used in fire walls must be able to prevent a breakdown of stability, heat conduction, or heat radiation long enough to evacuate passengers and crew.

Chapter 11 requires that materials (including composites) used in fittings and linings for components other than the supporting vehicle structure supports comply with the burning behavior requirements for either non-combustible materials which meet the Building Material Class A in DIN 4102, Part 1, or combustible materials which meet the testing requirements of DS 899/35, Section VI. Moreover, combustible materials that drain off or fall while burning, emit dense smoke, or form significant amounts of corrosive or toxic decomposition products are not permitted. For design of the vehicle structure, the RW MSB cites requirements contained in DIN 5510, Part 4 [22].

Chapter 11 states that batteries and cables should be positioned outside the passenger areas; if located inside passenger compartments, the requirements for structural supports, fittings, and linings must be met. These requirements also apply to battery case and container materials, cable insulation, and cable conduit and bushing materials that are located in passenger areas and control cabs. The RW MSB states that the requirements in DIN 5510, Part 5, [22] and that Chapter 3 of the RW MSB are applicable to electrical operating equipment located in passenger areas and control cabs, especially lighting, heating, and air conditioning systems.

Furthermore, Chapter 11 requires that compliance with these fire protection requirements be proven by the results of several qualification and monitoring tests, which must be documented. These tests include the following: fire transmission, DIN 4102, Part 2, 4, or 5; fire propagation, UIC 564-2, Appendix 4, Method A or Method B; burning behavior (including combustibility, smoke development, and capacity for forming drops), DS 899/35; decomposition products (toxicity and corrosion), ATA 10000.001, Section 7.3; heat transfer, 49 CFR, Part 25.853, Appendix F, Part III; and heat release, 49 CFR, Part 25.853, Appendix F, Part IV.

Chapter 11 also requires that each maglev vehicle be equipped with an automatic fire alarm which meets DIN 5510, Part 6, Section 4 [22]. Each passenger area and control cab must also contain at least two fire extinguishers that meet the requirements in DIN 5510, Part 6, Section 5. If automatically activating fire suppression systems are installed, the minimum requirements contained in DIN 5510, Part 6, Table 1, are applicable. Compliance must be proven by results of tests cited in DIN 5510, Part 6, Section 6.

Prior to initial acceptance, compliance with the requirements in Chapter 11 must be proven by the results of qualification tests which are confirmed by an expert. Results of monitoring tests based on DIN 18 200 are required, to prove compliance with Chapter 11 during production. These results must be consistent with the qualification tests and must be confirmed by an expert. Prior to release or delivery of vehicles to the operator, correspondence and final reports based on the qualification reports must be checked and certified by a person responsible for monitoring the materials used, design and arrangement, production and assembly methods, and installing a fire protection system.

Finally, Chapter 11 requires that no-smoking zones located in the front and rear areas of each vehicle section, luggage areas, and toilets be marked by permanent, legible, and easily recognizable signs.

In addition to the previously cited DINS, the RW MSB cites DIN 18 200, which relates to quality monitoring of building materials, components, and designs, and DIN 50 060, which includes terms for the burning behavior of materials and products.

Chapter 12 of the RW MSB states that if a vehicle fire cannot be brought under control with on-board resources, passenger evacuation must be initiated. If a fire occurs, passengers must be able to move from one vehicle section to another using connecting passageways which are configured as fire walls. Chapter 12 states that each vehicle section is considered a fire segment which must confine a fire for at least 30 minutes. (Chapter 12 makes further references to fire wall requirements contained in Chapter 11.)

The draft MBO requires that the passenger vehicle design and building materials provide state-of-the-art fire protection. Specifically, the building materials and structural components in the passenger compartment must adequately resist the development and spread of fire. In addition, the draft MBO requires that the development and spread of heat and harmful substances (i.e., smoke and toxic gases) be prevented long enough to evacuate the train. Moreover, it states that if vehicles are operated on track segments without safety areas (designated stopping places), they must be designed so that system-specific fires cannot occur in the passenger compartment (This language is similar to that of DIN 5510, Part 1). In the case of a system-specific fire originating outside the passenger compartment, passengers are to be protected from injury to the extent possible until rescue. Lastly, the draft MBO requires that vehicles be equipped with hand-held fire extinguishers.

3.9.3 Applicable U.S. Safety Requirements

The FRA has guidelines for selecting materials for intercity and commuter-rail passenger cars which address flame spread and smoke generation [6]. These guidelines provide (American Society of Testing Materials (ASTM) and FAA (for upholstery) test procedures and performance criteria for vehicle components including passenger seats, wall and ceiling linings, partitions and wind screens, windows, ducting, light diffusers, structural flooring, floor covering, thermal and acoustical insulation, elastomers, exterior plastic components, and component box covers. In addition, the guidelines indicate that penetrations (e.g., ducts) should be designed against acting as a passageway for fire and smoke.

Amtrak has used these FRA guidelines for recent vehicle procurements and has expanded on the guidelines in several ways [24]; certain components must meet additional criteria. For example, if exterior plastic and exterior/interior boxes are supplied as laminate construction or composites, they shall be tested as complete assemblies. In addition, each material must be evaluated in its base form, and in a compound form as it is intended to be supplied as a finished product. High-performance electrical wire insulation must be tested according to Amtrak Specification Number 323 [25]. All materials tested for fire spread and smoke generation shall also be tested to determine the acute inhalation toxicity, using NBSIR 82-2532. Finally, Amtrak requires that several other factors, e.g., quantity of material present, configuration, and proximity to other combustibles, be considered in combination with the material test data to develop a fire-hazard assessment which will be used to select materials on the basis of function, safety, and cost.

Amtrak also provides a fire extinguisher in each passenger car and restricts smoking to designated cars.

The NFPA Fixed Guideway Transit Systems (NFPA 130) [20] contains extensive fire protection requirements for vehicles. The portions of the vehicle body that separate major ignition, energy, or fuel loading sources from the passenger compartment are required to resist fire penetration to the interior of the vehicle by an external fire for a period consistent with the safe evacuation from the vehicle of a full load of passengers in the worst case situation. In particular, the vehicle floor is required to demonstrate fire resistivity by meeting certain criteria when subjected to a fire exposure test for 15 minutes.

NFPA 130 requires that materials and finishes also have sufficient resistance to fire propagation in the interior of the vehicle by an interior fire to allow for the safe evacuation of a full load of passengers from the vehicle. A fire risk assessment must be used to evaluate smoke emission, ease of ignition, and rate of heat and smoke release, in addition to fire propagation resistance. NFPA 130 indicates that a hazard load analysis and the use of materials with appropriate properties are two means which can be used to perform the fire risk assessment. Tests and performance criteria for flame spread and smoke emission are presented for vehicle interior materials. Although applicable for rail transit car materials, the majority of these tests and criteria are, in most cases, identical to the FRA fire safety guidelines for rail passenger cars. NFPA 130 also describes requirements for electrical insulation and other electrical system fire safety requirements. In addition, it encourages the use of tests which evaluate materials in certain subassemblies and the use of full scale tests.

NFPA 130 requires that all floor, wall, and roof opening penetrations be adequately sealed/protected to maintain the fire and smoke integrity of the vehicle structure. To isolate potential ignition sources from combustible materials and to control fire and smoke propagation, NFPA 130 requires that equipment be located external to the passenger compartment, whenever practical. Suitable shields and enclosures must be used to isolate equipment if it is necessary that it be installed within the passenger compartment.

Requirements for electrical system fire safety are also described in NFPA 130. Provisions are included for the following components: air gap and creepage voltage potentials, propulsion motors, motor control, and propulsion and braking system resistors, wiring, and overload protection. In addition, the design of battery installation and circuitry is specified, e.g., minimal use of organic material, use of smoke and heat detectors, and use of an emergency cut-off switch.

Finally, NFPA 130 requires that vehicles have provisions to deactivate all ventilation systems remotely or automatically.

FAA fire protection requirements for aircraft are contained in 49 CFR, Part 25. Part 25.853 requires that for each compartment occupied by passengers or crew: materials (including finishes) meet certain test criteria described in Appendix F, Part I, or equivalent; seat cushions meet test criteria in Appendix F, Part II; and interior ceiling and wall panels (excluding light diffusers, partitions, and outer surfaces of large cabinets, stowage compartments, and galleys) meet test requirements contained in Appendix F, Parts III and IV, or equivalent methods.

Part 25.855 describes requirements for cargo or baggage compartments. These include provisions that ceilings and wall liners meet Appendix F, Part III, or equivalent; all other materials meet Appendix F, Parts I or equivalent; controls, wiring, lines, etc., be protected so that breakage or failure does not present a fire hazard; cargo or baggage cannot interfere with fire protective features; heat shield and insulation be used; and tests be conducted to ensure compliance with Part 25.857.

Part 25.857 classifies cargo compartments according to their size, their accessibility to crew members for fire detection, whether or not approved fire or smoke detection systems and fire extinguishing system are provided, whether or not ventilation and draft control are provided, whether or not hazardous quantities of smoke, flames, and extinguishing agent can be excluded from any compartment occupied by passengers or crew, and whether or not a fire can occur and can be completely confined without endangering safety of the aircraft or occupants. Part 25.858 describes fire detection system requirements for cargo compartments. Part 25.859 requires that essential flight controls, engine mounts and other flight structures be constructed of fireproof materials or shielded so that they are capable of withstanding the effects of a fire. Part 25.869 requires that electrical system components meet the applicable fire and smoke protection requirements in Parts 25.831 (c) and 25.863, be fire resistant, be shrouded by electrically insulated flexible conduit, and have self-extinguishing insulation.

Finally, Part 25.851 describes requirements for hand fire extinguishers and built-in fire extinguishers. The number and placement of extinguishers in the pilot, passenger compartments, and cargo compartments are specified; toxic gas concentration hazards must also be minimized.

3.9.4 Discussion/Recommendations

The RW MSB requires the highest level of fire protection for the maglev vehicle, as defined in DIN 5510, Part 1. The intent of this DIN is to require that ignition be prevented by the use of materials which resist ignition and fire spread. In addition, Chapters 1 and 12 of the RW MSB, as well as the draft MBO, consider maglev vehicle fire protection within the context of limiting potential fire growth in order to allow the train to reach the next station or designated stopping place, as well as to permit adequate (30 minutes) time for passenger emergency evacuation.

Requirements for maglev vehicle material fire characteristics, equipment arrangement, detection and suppression systems, electrical systems, and lightning protection have all been addressed by the RW MSB and the draft MBO in a manner similar to FRA, Amtrak, NFPA, and FAA requirements for fire protection.

In particular, the RW MSB requirements contained in Chapter 3 for electrical circuit and battery protection, and wiring insulation and integrity (based on DIN 5510, Part 5) are noteworthy for their comprehensive approach. Moreover, provisions contained in other parts of DIN 5510, as cited in Chapter 11 of the RW MSB, address many other fire protection concerns in a manner consistent with NFPA 130. For example, DIN 5510, Part 4 requires that it be possible to shut down the vehicle passenger ventilation system in case of fire; such a requirement would limit smoke generation. Part 4 also requires that ducting arrangements not impair the function of space sealing systems to form fire sections (e.g., barriers).

However, clarification is necessary for several of the RW MSB requirements in Chapter 11, in relation to the U.S. safety requirements. For example, the FRA fire safety guidelines for selecting rail passenger car materials provide a baseline which Amtrak and commuter railroads have successfully used to evaluate fire and smoke characteristics of passenger car interior materials. Further information is necessary for the specific components and types of interior and exterior materials which RW MSB requires to be tested. In addition, the RW MSB does not indicate what materials are to be tested or what specific performance criteria are required for the burning behavior, decomposition products, and heat transfer and release tests. Certain terms are not defined in the RW MSB, e.g., "fire resistant."

The 30-minute fire barrier specified by the RW MSB appears consistent with U.S. requirements that resistance to fire penetration provide a period of time sufficient to evacuate a fully loaded vehicle in a worst case. However, while the RW MSB specifies the positive requirement that vehicle section ends be provided with 30-minute fire walls, no such requirements appear to be specified for structural flooring. To meet the RW MSB requirement that batteries and other electrical equipment be located outside the maglev passenger compartment, most of the electrical equipment and wiring will be located under the vehicle floor. If an undercar vehicle fire occurs, it is important that the maglev structural flooring resist heat penetration. For structural flooring, the RW MSB cites only the FAA test requirement contained in 14 CFR, Appendix F (Part I) of Part 25. However, that requirement is for a vertical test which relates to burn length and flaming dripping, not fire penetration and heat release, in contrast to the ASTM-E119 test cited in the FRA fire safety guidelines. Although the requirements of DIN 5510, Part 4, as cited in the RW MSB, indicate that adequate spacing, non-combustible installation, and radiation protection plates are measures to be used for heating and ventilation systems, neither the DIN nor the RW MSB indicate requirements to reduce potential ignition sources from other undercar equipment or to provide barriers for other high-voltage undercar equipment. As required by the FRA fire safety guidelines for passenger cars, the test requirements of ASTM E-119 would provide a means to determine whether fire resistance of the maglev vehicle structural flooring is acceptable for the U.S. environment.

The FAA requirements cited in the RW MSB do not specify tests and performance criteria for certain components (i.e., elastomers and component box covers) which are addressed in the FRA fire safety guidelines for intercity rail passenger cars.

In addition to the FRA fire safety guidelines, the Amtrak and NFPA requirements provide additional information which could be used to evaluate maglev vehicle fire protection. For example, the concept of testing materials as part of an assembly provides important information about the actual behavior of materials in a "real world" vehicle fire.

The RW MSB and draft MBO describe extensive requirements for maglev vehicle fire protection. However, some of those requirements differ from the U.S. safety requirements. A more detailed analysis is needed to evaluate the compatibility of the German and U.S. approaches to fire protection. In addition, as noted in the RW MSB, certification of test results for the materials actually used in the maglev revenue vehicle is necessary.

For U.S. application, consideration should be given to:

- Requiring that the maglev system developer provide proof of compliance with the fire and smoke tests, performance criteria, and other safety requirements contained in the FRA fire safety guidelines. As an alternative, the developer should provide an analysis that demonstrates equivalent or better flame spread and smoke emission values.

- Requiring that the maglev system developer certify that the maglev vehicle comply with (or demonstrate equivalence to) other Amtrak and NFPA fire safety requirements, including, but not limited to, the following:

  - Use of fire-hazard assessment methodology which considers quantity, configuration of materials, etc., in addition to individual materials test data

  - Testing of subassemblies (Use of full scale testing is encouraged to determine behavior of materials in a "real world" vehicle fire)

  - Testing for toxicity (NBSIR 82-2532)

  - Design and placement of high voltage undercar equipment and wires and cable in a manner that minimizes the potential for vehicle fires

  - Provision of ventilation shut-off controls.

- Analyzing further the FAA requirements for fire protection contained in 49 CFR, Part 25, particularly the test methods contained in Appendix F, to determine their potential usefulness in evaluating maglev vehicle materials.

- Requiring that the system developer analyze the fire and smoke detection systems (including heat sensors) and suppression systems, to demonstrate that they limit fire propagation and will not cause false alarms. (This analysis should specify the type and location of detection systems to be installed in the maglev vehicle.)

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations and guidelines that may be appropriate for maglev vehicle fire protection.

4. GUIDEWAY

The principal function of the guideway is to bear the supporting and guiding loads of the vehicle. The Transrapid guideway is typically elevated or at grade. For elevated portions, column support substructures are either A-shaped or slim-line ("H") concrete pillars. The main supporting structure of the Transrapid guideway is a concrete or steel girder with a T-shaped cross section where the vehicle wraps around the top of the guideway.

While the guideway girder provides the load support for the vehicle, functional components are required on the guideway for the vehicle to operate. Three types of functional components are mounted on the Transrapid guideway girder: (1) the long stators which produce the traveling magnetic field for the linear motor, provide power through induction for the linear generators, and serve as an attractive-reaction rail for the levitation magnets; (2) the guide rails that interact with the guide magnets to provide the lateral attractive force to guide the vehicle, and the reaction rail for the eddy current brakes; and (3) the two parallel sliding surfaces which the support skids of the vehicle contact when the vehicle is lowered onto the guideway.

To direct a vehicle to one of the two paths of the guideway, the Transrapid system uses a flexible switch to move a special section (a long, continuous girder) of the guideway. To ensure safe passage of a vehicle, the guideway has locking devices that properly align and lock the switch.

The Transrapid system provides guideway emergency access and egress by installing designated stopping places at specified intervals along the guideway.

The following safety-related maglev guideway components are reviewed in this section: support columns and foundations, guideway geometry, guideway switch, and guideway access/egress.

4.1 SUPPORT COLUMNS AND FOUNDATIONS

The elevated structures used in the Transrapid system are typically concrete pillars on pad or pile foundations. This is a common structural practice and is used extensively in highway and conventional railway construction. Unique to the maglev application is the requirement for high precision in the location of the support points for the guideway beams. These support points are adjustable, allowing for normal construction tolerances and post-installation settlement. These columns must transmit all guideway induced loadings to the foundation without allowing gross displacement of the beam attachment points.

4.1.1 Safety Concerns

The primary safety concern is that a supporting column or foundation might fail and cause an uncontrolled touchdown of the vehicle to the guideway or allow the vehicle to leave the guideway by dropping a span. The column or foundation can fail either gradually or suddenly.

Gradual failures could result from slow settlement due to varying water tables, fatigue, or higher than expected vehicle or guideway induced loadings. These failures would normally be detected prior to complete failure through periodic inspections of both the support structure and the actual guideway geometry. (See Section 4.2, Guideway Geometry.)

Of far greater concern are sudden failures of the support structure. These could be caused by collisions with vehicles sharing the right-of-way, washouts due to flooding, undetected fatigue cracks resulting in a column or attachment point failure, or an earthquake. Again, the failure could result in an uncontrolled touchdown or, even worse, dislocation of a span, allowing the vehicle to leave the guideway.

The two levels of failure must be considered differently. While a failure causing an elevated span to drop must not be allowed under even fairly extreme loading conditions, a failure, due to the guideway geometry being out of tolerance, causing a vehicle touchdown may be tolerated under extreme conditions, such as an earthquake.

4.1.2 German Safety Requirements

Siting and load requirements for the elevated guideway support structure, including columns and foundations, are specified in Chapters 1, System Properties, Especially Safe Hovering; 5, Load Assumptions; 6, Stability Analyses (Guideway/Vehicle); and 7, Design, Production, and Quality Assurance of Mechanical Structures, of the RW MSB safety requirements. Some additional special requirements for the columns supporting the bending beam switch are noted in Chapter 8, Switch; however, most of these are covered in the earlier chapters in greater detail.

Chapter 1 of the RW MSB discusses earthquakes and settling, in the context of maintaining safe hover. For foundation siting, the RW MSB requires that areas subject to earthquakes be bypassed whenever possible; otherwise, foundation stability should be ensured by using geological, hydrological maps, mining plans, and miscellaneous soil studies to determine route alignment. Also required are separate guideways for double track sections located far enough apart that interference cannot occur to both simultaneously. The RW MSB also requires ground motion detectors, primarily in the vertical plane. Permanent, hydrostatic monitoring could be achieved by installing liquid containers in the ends of guideway supports.

The RW MSB separates the process for assessing the safety of elevated guideways from a structural point of view into three steps: Chapter 5 defines vehicle and guideway loads, Chapter 6 contains requirements for combining loading conditions including factors of safety and permissible failure probabilities, and Chapter 7 covers design and quality assurance requirements.

In terms of the columns and foundation, the RW MSB requirements contained in Chapter 6 are simple and straightforward: under probable loading combinations the support structure may not displace in such a way that the guideway surface becomes dimensionally dangerous for normal operations. Even under the most severe combination of difficulties for the support structure, i.e., an earthquake with high winds and other loading conditions, the vehicle must be able to stop safely and remain on the guideway. This requirement essentially states that the guideway must be designed to remain intact and must be capable of sustaining severe vehicle-induced loading, even during an uncontrolled vehicle touchdown at maximum speed on one side. If structural impact occurs, special unscheduled inspection of the guideway is required prior to release for operations.

Chapter 6 requires three levels of proof in studying structures, strength analysis, positional safety analysis, and deformation analysis. The first calls for normal stress analysis of the appropriate structural elements. The next requires that guideway components not change position, including soil movement near the foundation. The third requires that the geometry of the functional surfaces remain acceptable under the loadings and movements allowed. (See Section 4.2, Guideway Geometry, of this report for additional discussion relating to guideway geometry.)

The primary German requirements for load definition are DS 804, DS 899/59, and DIN 1072. The RW MSB notes that the requirements are only appropriate for Germany and that some modifications may be required for application in other locations.

Chapter 7 references many DIN, DS, VDI, and DVS standards which cover areas such as welding requirements and screw connection requirements.

Applicable DINs for dimensioning tall or elevated structures in earthquake zones include 1045, which covers concrete structures; 4227, which covers prestressed concrete; and 18 800, which covers steel structures. The requirements for the structures depend on the likely severity and frequency of earthquakes in the area. DIN 4149 specifies the earthquake zones for Germany.

4.1.3 Applicable U.S. Safety Requirements

In general, the FRA depends on industry guidelines and accepted practices in defining structural requirements for conventional rail. The FRA does require special inspections of track structures after events which might have damaged the structure (49 CFR, Part 213.239). Other requirements concerning drainage, vegetation control, and ballast would be applicable in varying degrees to the guideway structure. (See Section 9.4, Route Alignment, for further discussion of drainage and vegetation.)

The U.S. railroad industry depends on numerous construction codes and guidelines to specify the requirements for elevated structures and bridges. Many of these guidelines have been developed by the American Railway Engineering Association (AREA) [9] and the Federal Highway Administration and cover design requirements and inspection procedures. The inspection procedures appropriate for railway bridges are routinely reviewed by industry to ensure current guidelines for advanced bridge designs and changes in the operating environment. (See Section 7.3, Guideway Maintenance, which extensively discusses guideway inspection.)

4.1.4 Discussion/Recommendations

The RW MSB requirements define a process for assessing the safety of elevated guideways from a structural point of view. This process entails a considerable amount of work by the system developer in defining loading conditions, some of which can only be determined experimentally. As a checklist of loads to consider and as a process for combining the severe loading conditions, the RW

MSB requirements are an excellent resource. However, further review of the load combination likelihoods which will be used by the maglev developer for the specific operating environment is advisable.

Traditional signal circuits on U.S. railroads contain, at a minimum, a rail integrity feature (protection against broken rails) and, in some cases, additional integrity monitoring, such as washout or landslide protection. As part of the maglev structural design requirements, a route-integrity sensing strategy reflecting the requirements in Chapter 1 of the RW MSB could provide warnings of gross deformations to the guideway resulting from washouts, impacts from vehicles sharing the right-of-way, or even earthquakes.

Routine guideway surface geometry measurements are not reliable enough for warning of impending structural failures. The inspection procedures for the guideway structure and foundation should be formalized so that safety critical components are inspected frequently enough to prevent catastrophic failures. A more detailed discussion of guideway inspection is contained in Section 7.3 of this report.

For U.S. application, consideration should be given to:

- Reviewing the appropriate load combinations, as defined by the maglev system developer, to be used in the design of maglev guideway columns and foundations for the specific operating environment.
- Requiring the maglev system developer to submit a guideway integrity assurance strategy as part of the structural design requirements.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, as well as several other studies relating to guideway design in progress under contract to the FRA, should provide additional information for FRA consideration in determining the modifications to U.S. regulations or guidelines that may be appropriate for maglev guideway support columns and foundations.

4.2 GUIDEWAY GEOMETRY

"Guideway geometry" refers to positional characteristics of the guideway, including grade, curvature, superelevation, and rates of change of these characteristics with respect to distance along the guideway. There are two factors that influence the geometry of a guideway: (1) the routing design variations in alignment (configuration in the horizontal plane) and profile (configuration in the vertical plane), which consist of sections of tangents and curves, and (2) deviations from the design path arising from manufacturing and installation imperfections, structural flexion as the guideway is subjected to load application, structural expansion and contraction from thermal effects, and degradation of the various structural and mechanical components.

The vehicle and guideway interact as an integral dynamic system, as forces are transmitted at the interface between the vehicle and guideway for levitating, guiding, propelling, and braking the vehicle. Therefore, any variation in the geometry of the guideway or any gauge in the guideway that is outside the design limit can affect the response of the vehicle. The dynamics of the vehicle response can reduce ride quality, cause the vehicle to contact the guideway, or create excessive stress if the vehicle is set down on the skids while it is moving.

4.2.1 Safety Concerns

A major safety concern of guideway geometry is the effect of two conditions on vehicle response: improper guideway gauge and variations in guideway lateral and vertical alignments. A gauge that is outside the specified tolerance limit will result in a magnet-to-guideway gap that is either too wide or too narrow. Either situation can reduce the vehicle's ability to control the guide magnet, thereby increasing the likelihood of the magnet contacting the guideway. Another concern is the vehicle dynamic response from the interaction of the vehicle with the variations in guideway geometry. Depending on vehicle speed and the amplitude and periodicity of the guideway deviations, the vehicle can respond with large displacements causing magnet-to-guideway contact, can produce high stress levels if it comes down on the skids while in motion, or can respond with an amplitude and frequency producing unacceptable ride quality.

Two gauges in the Transrapid maglev guideway must be kept to the specified dimensions to provide the proper gap clearance between the vehicle and the guideway. The first gauge is the lateral distance between the outside surfaces of guide rails which affects the guide magnet gap size. The second is the vertical distance between stator pack bottom surface and the top of the sliding surface. This latter gauge may affect the clearance between the support skids and the sliding surface.

Deviations in guideway geometry include the lateral and vertical alignment variations in the guideway structure. The sources of these deviations are subsidence in the girder supports (see Section 4.1, Support Columns and Foundations), girder flexing under load, and variability in production and assembly of the functional components. As the maglev train traverses the guideway, the girder bends in response to the loading; the vehicle-guideway dynamic response will depend on the train's length, weight, speed, and location on the span. Operational loads and thermal effects can exert extreme forces on the functional components; these can produce surface irregularities, which include vertical deviations on the sliding surface and stator packs and lateral deviations on the guide rail. Moreover, mismatches can result from gaps in functional components where the spans of two girders meet or where the individual stator packs come together.

Operational loads exerted on the functional components can place high stresses on hardware connecting the stator pack and guide rail to the guideway girder. The vehicle magnetic forces attracting both the stator pack and guide rail apply a strong pull to the guideway equipment that must be resisted by the connecting hardware. With continual cyclic guideway loading from maglev operation, there is a concern that these connections may weaken and break.

4.2.2 German Safety Requirements

Chapters 5, Load Assumptions, 6, Stability Analyses (Guideway/ Vehicle), and 7, Design, Production, and Quality Assurance of Mechanical Structures, of the RW MSB specify safety requirements for the types of loads and load combinations acting on the guide-way, and the design and production requirements for the guideway. Many of the requirements included in these chapters are the same for both the guideway and the vehicle (see Section 3.1, Structural Integrity/Crashworthiness, of this report).

Chapter 5 specifies the loads to consider in the guideway design, a list of operating states affecting the load, and possible disruptions. Interface loads (i.e., loads at the vehicle/guideway interface) are applied to the guideway through the stator pack mounting, guide rail mounting, and slide rail mount. These interface loads must be studied under routine operations, braking with the safety braking system, controlled set-down, towing of the vehicle, vehicle- or engine-based breakdown, and disruptions due to the environment.

Chapter 5 further requires that the external loads acting on the guideway be considered, and that the effects of temperature differences on the guideway girder and between the guideway girder and the guideway equipment be established. The RW MSB refers to temperature measurements made on the TVE guideway for data concerning the thermal effects on the guideway. The RW MSB does not require that impact of levitation or guide magnets, safe set-downs above threshold speeds, uncontrolled set-down at any speed on both sides, and violation of clearance gauge be considered when dimensioning the components as long as there is adequate proof that these disruptions are improbable or will be harmless. The RW MSB does not specify limits on the magnitudes and characteristics of the interface loads from which the designs are based, but it refers to load measurement reports obtained from the TVE guideway.

Equally applicable standards cited in Chapter 5 are DS 804, DS 899/59, and DIN 1072, all of which apply to bridges. References to literature include two technical reports on temperature and load measurements on the TVE guideway.

Chapter 6, Stability Analyses (Guideway/Vehicle), of the RW MSB defines the various loads and load combinations that the guideway can expect to encounter and classifies these loads as primary, secondary, or special. For example, loads that are encountered from guideway discontinuities and deviations are considered primary loads. (For definition of the load classifications, see Section 3.1, Structural Integrity/Crashworthiness, of this report.)

Chapter 6 requires that the guideway be designed to safely withstand the loads that it is expected to encounter. This chapter specifies requirements for selecting a factor of safety and a strength evaluation of the guideway structure to provide proof against failure. These requirements, as well as four risk classes, are described in Section 3.1, Structural Integrity/Crashworthiness, of this report. Also required is a positional safety analysis, to prove that the guideway will not shift, and a deformation analysis, to prove that the geometry of the functional surfaces will not change beyond permissible levels.

The requirements for a safely dimensioned guideway vary according to the particular components involved. The guideway components in risk classes 1 and 2 may be considered safely dimensioned if they meet the safety level of DS 804, DIN 1045, DIN 4227, and DIN 18 800 (Part 1). Studies of the consequences of failure have not been performed for some of the guideway components and their connections that are in the load path. The RW MSB assigns risk class 1 to these components and considers them safely dimensioned when safetythreatening failures are not anticipated and when they have been qualified by a design certification test. These additional safety requirements can be met by using "cold redundancy with fault detection" (this technique is discussed later in this section).

Chapter 6 also requires that permissible deformations be established as a function of impermissible tolerances of functional surfaces, nominal gaps and the gap requirements of the levitation/guidance system, and the properties (lining, cushioning, etc.) of the bearing/guide skids according to certain specifications. During normal operations, there must be no contact between the leviation/guidance magnets and the corresponding surface. During a breakdown, the resulting deformation of the functional surfaces must guarantee at least danger-free emergency braking and, in the event of an earthquake, a dead stop by the vehicle without personal injury.

Chapter 6 cites several DINs, including DIN 1045 and DIN 4227 which relate to concrete and reinforced concrete, and DIN 18 800 (Part 1) which contains standards for steel structures. DIN 4149 (Part 1) is referenced, in DS 804, for designing structures in Germany's earthquake zones. A technical guideline on reliability, maintenance, and service life, and a technical report on the permissible deformations of the TVE guideway are also referenced.

Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, discusses the safety requirements relating to the structural element of the guideway. The RW MSB requires that no hazards emanate from the guideway through mechanical influences. Design requirements include providing access for inspecting structural elements relevant to guideway stability, inspecting primary connections, and evaluating the compatibility of mating surfaces for the formation of voltaic elements.

Chapter 7 also specifies the types and sources of guideway deviations. The RW MSB requires that guideway geometry be designed such that the magnets do not contact the guideway in normal operations, and that any contact of the magnets and skids with the functional surfaces during a breakdown will not exceed the permissible stresses. To ensure that the guideway girder and the components of the guideway equipment do not exceed the permissible lateral and vertical tolerances at the points of impact, the RW MSB requires safe attachment of stator packs and guide rails to the guideway, and a suitable bearing of the guideway girder. The RW MSB also requires that a measuring system be available to detect and locate impermissible changes in guideway geometry but does not specify details for this system.

Chapter 7 cites DIN 1075 for concrete bridge dimensioning, DIN 1079 on steel road bridge design, DIN 1084 for supervision of concrete and reinforced concrete construction, in addition to DIN 1045, DIN 4227, DIN 18 800 (Part 1), DS 804, and DS 899/59. Six technical reports relating to the Transrapid guideway and the stator pack are also referenced.

Chapters 6 and 7 specify mounting requirements for guideway components with particular emphasis on a design that would not threaten overall operation in the event of failure of one component. To achieve this, the RW MSB requires diverse mounting design by use of "cold redundancy" where the load is supported by one of two branches. If the first branch fails, the load is supported by the second branch for continuous safe operation. Also required is fault disclosure capability to detect any first branch failures during regular inspections.

The draft MBO requires that the maglev guideway geometry meet specified dimensions (which are being developed and will be included as Appendix 1 of the officially issued MBO) and that the operator establish the tolerances. The draft MBO also includes specific limiting guideway geometry requirements involving curvature, superelevation, side acceleration, and gradients, with additional limiting values to be established by the operator. It requires that the guideway be designed to withstand all loads from the system.

The EBO specifications are for railroad tracks, and include requirements on track gauge and limits on curvature, superelevation, and track slope. The EBO also specifies the loading conditions that the track must withstand.

4.2.3 Applicable U.S. Safety Requirements

FRA guideway geometry standards are specified for tracks with two rails having a gauge of 1,435 mm (56.5 in) for railroad car operations. The FRA requirements for track geometry are specified in 49 CFR, Part 213. (This section reviews only those FRA requirements with potential applicability to maglev guideways.) Part 213.9 restricts passenger train operating speed limit for Class 6 track to 176 kmph (110 mph). Amtrak operates the Metroliner at speeds up to 200 kmph (125 mph) in the Northeast Corridor under an FRA waiver. Parts 213.53, 213.55, 213.57, 213.59, and 213.63 specify safe limits for track gauge, alignment, curve (outside rail) elevation and speed, curve elevation runoff, and track surface. Parts 213.103, 213.123, and 213.201 include requirements for ballast, rail fastenings, and track appliances and track-related devices.

4.2.4 Discussion/Recommendations

The RW MSB approach to guideway design and permissible guideway geometry variations is similar to the approach taken in vehicle design and construction (see Section 3.1, Structural Integrity/ Crashworthiness, of this report). The RW MSB systematically and comprehensively identifies the loads that act on the guideway, and requires that the guideway be able to safely support these loads. In addition, the draft MBO specifies safety requirements for maglev guideways, including quantitative values for guideway geometry. The calculation of dimensional values and gap distances between vehicle and guideway has not been completed; these values are necessary specifications for guideway routing design and for establishing tolerances for guideway geometry to avoid magnet-to-guideway contact.

For U.S. application, it may be advisable to require further specification of guideway tolerances and guideway geometry deviations. Although the FRA requirements in 49 CFR, Part 213, address geometry requirements which are conceptually similar for maglev guideway, the specific FRA track geometry limits must be modified for U.S. application because of the structural and configurational differences between railroad tracks and maglev guideways.

As indicated in the preliminary maglev safety review [1], additional information is required on controls to be applied to guideway geometry variations and operational procedures to detect and correct guideway irregularities. The RW MSB does require that measuring systems be available for detecting changes in guideway geometry but does not specify details for this measuring system.

As also noted in the preliminary maglev safety review, more information is also required on fail-safe and safe-life philosophies and their applications. The RW MSB requirements of "cold redundancy" with fault disclosure provides a backup that reduces the threat to safety in the event of failure of the first support branch. For guideway components whose safety is critical, consideration should be given to adoption of the "cold redundancy" concept. How to prevent possible abuse of failure-tolerant design, such as continual operation disregarding the presence of the partial failure, should be included as an operating procedure (see Section 3.3, Levitation/Guidance, of this report).

For U.S. application, consideration should be given to:

- Establishing guideway tolerances and permissible geometry deviation limits, and modifying 49 CFR, Part 213, to reflect appropriate guideway requirements for maglev systems.
- Adopting the "cold redundancy" concept for safety-critical guideway components. The effectiveness of this concept depends on reliable fault detection and timely action taken to repair the failure once the fault has been disclosed.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, as well as the results of several other studies relating to guideway geometry, should provide additional information for FRA consideration in determining the modifications to U.S. regulations that may be appropriate for maglev guideway geometry.

4.3 GUIDEWAY SWITCH

The bending beam switch design used by Transrapid presents a unique case for guideway structural requirements because the guideway must be able to move between two precisely defined positions on demand and remain in these positions under severe vehicle and environmental loading conditions. While the requirements for the switch are both operational and structural, only the structural requirements are discussed here.

4.3.1 Safety Concerns

All of the safety concerns applicable to normal guideway sections also apply to the bending beam switch. In addition, there are concerns associated with the unique characteristics of the switch beam and the unique requirement that the guideway be able to move between and precisely assume two positions.

One unique characteristic of the switch beam is that it is generally much longer than the normal elevated guideway beams and, accordingly, responds much more to thermal variations than normal beam sections. This presents a special case for guideway geometry especially on the sliding surfaces on the top of the guideway. A large thermal expansion gap between the switch beam and the beam must be properly bridged so that a sliding vehicle will pass over the joint smoothly.

The principal structural safety concern is that during the movement of the beam, a component could fail, allowing the beam to adopt a dangerous configuration. Operationally, a number of sensors and tests, which rely on structural elements, are used to determine the position of the switch. From a structural point of view, beam and switch components must withstand potentially high loads from the actuators if synchronicity fails. Finally, with the switch in position, the structure must hold the beam in place without further deformation when subjected to various loading conditions, including earthquakes, emergency stops, power failures, and collisions with support columns from vehicles sharing the right-of-way.

Another unique aspect of the switch is the concentration of mechanical and electrical components which must be inspected and maintained. In addition, during bending, the beam may be subjected to high local stresses capable of initiating fatigue cracks which could result in a complete failure of the guideway under load.

4.3.2 German Safety Requirements

Chapter 8, Switch, of the RW MSB safety requirements discusses the bending beam switch in some detail, highlighting the special requirements for maintaining two precise positions. A primary requirement is that the switch reach closure at all actuators. That is, at each actuator (normally eight per switch), a precise position must be achieved and maintained.

An important aspect of Chapter 8 is that it allows use of non-mechanical or non-positive closures, as well as mechanical closures, to hold the switch in position. This is important in determining whether the switch is securely in position. If non-mechanical closures are used, the switch must convert to a positive closure in the event of a fault. Hydraulic actuators are examples of non-positive closures unless they have stop valves, in which case they are considered short-term positive closures.

Another important consideration noted in Chapter 8 is the synchronous operation of the actuators and the timely completion of the switching operation. Synchronous operation of the actuators requires the beam to bend uniformly. If the actuators do not act together, the beam could become overstressed, possibly leading to a component failure. Timeliness is important: a slow operation is an indicator of improper function.

The RW MSB considers the switch to be out of service if a safe position is not reached, but it does not specify the inspection or maintenance activity required to restore the switch to service.

The RW MSB does require that only "type-tested" components or components which have been tested and documented for application at a similar safety level be used. This is related to material specifications, operational stability, and quality assurance.

The EBO and draft MBO specify construction standards which would apply specifically to switches, as well as to general structures. DS 804 and DS 899/59 discuss design requirements for elevated structures and railroad bridges. DIN 24 343 and DIN 24 346 specify standards for hydraulic actuator systems. TRB and TRGL discuss high-pressure gas conduits and pressurized containers that are primarily pressure vessel type codes. ZH1/153 specifies special force-opening position switches.

4.3.3 Applicable U.S. Safety Requirements

Parts 213.133 through 212.143 of 49 CFR specify requirements for conventional railroad switches. While the specifics of the regulations would not apply to maglev, the intent is the same as in the RW MSB: to require that the switch be reliable enough to assume two positions and, when in a position, be capable of supporting the loads required by normal operations.

4.3.4 Discussion/Recommendations

The RW MSB presents a process for determining the adequacy of components for use in a switch. Special analysis and/or tests must be conducted to determine the loading conditions appropriate for the specification of the support foundation. Of particular concern is the loading condition of an uncontrolled touchdown at operational speed while traversing the switch in the diverging bent configuration.

Many special structural, as well as operational, issues should be addressed: What constitutes positive closure? How many sensors are required? What are the limits of actuator synchronicity? What is the appropriate inspection frequency and procedure for the switch? What must be done when a switch fails prior to resuming operation?

For U.S. application, consideration should be given to:

- Revising the switch requirements in 49 CFR, Parts 213.133 through 213.143 to reflect the requirements described in the RW MSB.
- Defining tolerance limits for switch operations.
- Modifying the intent of the switch maintenance and inspection portions of the FRA regulations as appropriate for maglev system operations.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, should provide additional information for FRA consideration in determining the modifications to U.S. regulations that may be appropriate for maglev guideway switches.

4.4 GUIDEWAY ACCESS/EGRESS

As proposed for U.S. application, the majority of maglev guideway segments will be elevated. However, certain segments may be located at grade or in tunnels. This section reviews guideway access and egress from the perspective of emergency access and egress. Intrusion onto the guideway is reviewed in Section 9.3, Shared Right-of-Ways/Intrusion.

In the event of a breakdown or emergency between stations, the Transrapid vehicle is required to maintain safe hover long enough to reach a station or designated stopping place. Accordingly, designated stopping places are required at specified intervals along the maglev guideway.

4.4.1 Safety Concerns

The location of the maglev vehicle and guideway, i.e., on an elevated structure, at grade or in a tunnel, affects the safety of passengers during an emergency evacuation. For example, during a fire, an at-grade or elevated guideway, because of the less confined environment and access to open air, may be less dangerous than a tunnel with poor ventilation. Evacuating a train located on an elevated structure is more difficult than a train located at-grade.

A specific safety concern is that designated stopping places may be too short or too narrow to allow immediate egress of all passengers from a crowded train. Moreover, stairways leading to an area of safe refuge could be too narrow or too steep, preventing passengers (especially those who are elderly or disabled) from swiftly evacuating from elevated guideways or from tunnels.

The absence of a safe means of leaving the vehicle and the inability of emergency response personnel to reach or evacuate passengers, under certain circumstances (e.g., fire, extreme heat, passenger illness), may cause injury or aggravate existing injuries or medical, physical, or mental conditions.

An emergency (unplanned) stop may occur between designated stopping places. Depending on guideway accessibility, a stop at a location over a lake or swamp or on an elevated segment could prevent or delay evacuation of passengers and crew from the vehicle (see also Section 9.4, Route Alignment, for additional discussion).

4.4.2 German Safety Requirements

Chapter 1, System Properties, Especially Safe Hovering, Chapter 11, Fire Protection, and Chapter 12, Rescue Plan, of the RW MSB safety requirements describe provisions relating to passenger evacuation in a maglev emergency.

Chapter 1 indicates that it must be determined for each individual application whether a rescue plan utilizing programmed braking to a designated stopping place) can be realized or whether other supplemental strategies are to be pursued, especially in terms of the planned rescue measures described in Chapter 12, Rescue Plan.

The RW MSB considers the fire protection requirements contained in Chapter 11 to be an integral part of the rescue strategy for the maglev vehicle, as interior materials must be used which meet the highest fire safety level according to DIN 5510, Part 1 [22].

Chapter 12 contains designated stopping place requirements and states that disembarking onto the elevated guideway is impermissible. The RW MSB states that unless the entire guideway route alignment allows evacuation without designated stopping places (i.e., at grade), the guideway cannot be considered a "safe" stopping place.

Designated stopping places are to be located before danger points (e.g., open guideway at a bending switch) and between stations if the vehicle has insufficient kinetic energy to reach the next station in the event of an breakdown. The designated stopping places are required to allow danger-free egress options for persons in an emergency and are to be provided with communication and access points for rescue services. Chapter 12 also recommends that, depending on local circumstances, stationary energy supplies be located at the designated stopping places.

The RW MSB requires that the egress areas at the designated stopping places be long enough to allow passengers to exit by way of all external train doors on one side. Variability of the programmed stop must be considered when determining the length of the stopping area necessary.

Chapter 12 describes five egress options depending on the height of the guideway gradient. Ladders transported on the vehicle can be used for at-grade, i.e, less than 1.5 m (5 ft), passenger evacuation. For elevated guideways up to 20 m (66 ft), passenger evacuation will be onto parallel platforms with at least one stairway at each end. For elevated segments which are 1.5 m (5 ft) to 9 m (30 ft) high, rescue slides are an alternative, if the terrain allows. For elevated guideway segments greater than 20 m (66 ft) or from special structures such as bridges, passengers will disembark onto widened bridge supports. Evacuation from tunnels will be by means of a parallel walkway and escape path. Finally, designated stopping places and the parallel platforms and walkways must be protected and monitored to prevent unauthorized access.

In addition to the designated stopping places located at intervals between stations, Chapter 12 requires that the length of the acceleration areas adjacent to the stations also be capable of being used for egress.

Although the RW MSB considers planned stopping between designated stopping places to be impermissible (see Chapter 1, System Properties, Especially Safe Hovering), Chapter 12 describes two situations which could result in an unplanned stop, in the worst case. Vehicle emergency braking could occur outside the egress area of a station or after restart from a designated stopping place. Egress areas are not required in the acceleration stretches of stopping points. Depending on the location of the unplanned stop, i.e., at grade, in a tunnel, on a bridge, or on an elevated guideway segment, one of the five evacuation options described previously is to be used for passenger egress. Chapter 12 also states that adequate time for evacuation is available since a fire must be isolated for 30 minutes after the fire walls are sealed between train sections (Chapter 11, Fire Protection is referenced).

Chapter 12 requires that if the entire guideway or individual line segments are to be used as a stopping place, evacuation options be provided for the entire segment in accordance with the requirements for designated stopping places. Moreover, in this instance, it requires that a line telephone linked to central control be provided at 500 m (1,650 ft) intervals, and that, depending on local conditions, a third rail be provided on the guideway for connection to the vehicle to maintain auxiliary power after the train stops.

Chapter 12 states that alternative, outside means of rescue can be used for designated stopping places and station acceleration areas, depending on the existing infrastructure. Although designated stopping place alternatives are not detailed, the alternative means of rescue for acceleration areas must be kept in or near stations. If they are kept outside the station, Chapter 12 requires that a permanent parallel road be built along the egress area.

The draft MBO includes requirements that "authorized stopping places" (in this context, the term seems to mean "stations") be safe and comfortable, be accessible without steps for sections located at grade, and protect persons from moving trains. Specifically, it requires that operating installations and vehicles feature devices (undefined) that work together to ensure that, in all cases, vehicles can reach "auxiliary stopping points" (i.e., designated stopping places) if stations cannot be reached. The guideway is also required to have an adequate (undefined) number of these auxiliary stopping points and to facilitate safe egress from the train and access for the rescue team. The auxiliary stopping points must also be safeguarded against unauthorized boarding.

4.4.3 Applicable U.S. Safety Requirements

The FRA regulations do not contain safety requirements for conventional trainway access and egress. However, Amtrak, in its Emergency Evacuation from Trains [23] booklet, reviews the location of emergency ramps and exits, as well as telephones and ventilation where provided, for tunnels in New York City, Washington D.C., and Baltimore. Amtrak also lists the name, location, and length of tunnels over 300 m (1,000 ft) long for all routes in the system; these tunnels do not contain emergency exits.

The UMTA emergency preparedness guidelines [12 and 13] address transit passenger evacuation from the trainway in terms of access and egress, walkways, and lighting.

NFPA Fixed Guideway Transit Systems (NFPA 130) [20] contains detailed requirements for tunnel trainway emergency exits. Tunnel exits must provide access to a point of safety (i.e., enclosed fire exit at grade "point", or other passage offering equal protection). Exit stairways to the surface are to be located at intervals not greater than 381 m (1,250 ft). Cross passageways that meet ventilation and fire barrier criteria may be used to provide passengers with alternative protection if the trainways are divided by a 2-hour-rated fire wall or are located in twin bores. These passageways cannot be more than 244 m (800 ft) apart. Additional requirements are described for exit doors and hatches, emergency lighting, fire extinguishers, standpipes, etc.

NFPA 130 also requires that hinged or sliding access gates for surface trainways be provided in security fences as deemed necessary by the local authority. These gates are to be two exit units wide, and the route and location of each gate must be clearly identified on or adjacent to the gate. A means of passenger egress must be incorporated that allows passengers to evacuate the train at any point along the trainway and reach a safe area.

In addition, NFPA 130 requires that access to elevated trainways be from stations or mobile ladder equipment from roadways adjacent to the trainway. If no adjacent or crossing roadways exist, access roads must be provided at a maximum of 762 m (2,500 ft) intervals. If security fences are used, they must meet the same requirements as those for surface trainways, and graphics must be legible from the ground level outside the trainway. NFPA 130 requires that a walk surface or other suitable means of egress be provided so that passengers can evacuate from a train at any point along a guideway and reach a station or wait for an evacuation train to arrive.

Finally, NFPA 130 requires that system egress points for tunnels and surface and elevated sections of the trainway be illuminated and meet detailed requirements, including NFPA 101, Life Safety Code [26], and the NFPA National Electrical Code [21].

4.4.4 Discussion/Recommendations

The RW MSB addresses the issue of guideway access and egress by emphasizing the maglev developer's (Transrapid) technological approach and dependence on maintaining safe hover long enough for the vehicle to reach stations or designated stopping places. However, the RW MSB does recognize that it must determined for each individual application whether such a rescue plan can be realized or whether other supplemental strategies must be pursued, especially in terms of the planned rescue measures described in Chapter 12, Rescue Plan.

The RW MSB does account for unplanned stopping (in the worst case) outside of designated stopping places. Depending on the location of the stopped train (at-grade or tunnel), the RW MSB requires that passenger evacuation from vehicles be accomplished off the guideway by ladders and platforms. As a last resort, self-rescuing devices are to be used if the maglev train is stopped on an elevated guideway segment. However, the terrain and height of the guideway may not allow the use of self-rescue devices. (The RW MSB mentions that the ejection of rescue slides must be possible in terms of the guideway height and surrounding terrain.) In addition, the use of these devices do not address the special evacuation needs of elderly and disabled passengers.

Despite the estimated remote probability of unplanned stopping as calculated by Thyssen Henschel (the vehicle developer), other means of evacuating a train stopped on an elevated guideway segment may be necessary. One RW MSB option for passenger evacuation from a maglev vehicle stopped on an elevated segment includes widened bridge supports for egress capability for guideway segments over water. Other options which could be considered acceptable for maglev vehicle evacuation include rescue trains, lifting platforms, and rescue boats (for guideway segments located over water). The RW MSB requirements demonstrate an awareness that, as a last resort, other means of evacuating the vehicle in an emergency may be necessary by stating that alternative "outside" means of rescue can be used depending on the infrastructure. Moreover, the RW MSB requires that access roads be constructed and landing sites for helicopters be provided, if necessary. In addition, the RW MSB requires access roads for the alternative means of rescue if the equipment is stored away from the designated stopping place.

It is necessary that the maglev system developer and system operator work together with local emergency response organizations to ensure that passenger evacuation can be accomplished, considering the entire local operating environment. The RW MSB states that firefighting and rescue organizations, hospitals, and police should be included in rescue planning. See Section 7.5, Emergency Plans and Procedures, of this report for additional discussion of emergency plans.

The Amtrak, UMTA, and NFPA 130 safety requirements describe specific requirements for trainway emergency access/egress which are comparable to and in some cases exceed the more general RW MSB requirements.

For U.S. application, in addition to the RW MSB requirements, consideration should be given to:

- Using UMTA, FAA, and NFPA safety requirements, in addition to current Amtrak provisions, to develop comprehensive requirements containing criteria for the maglev guideway designated stopping places. These requirements should include, but not be limited to, access for emergency response organizations, egress for passengers, emergency lighting, ventilation, communications, graphics, and support equipment (i.e., access tools, fire extinguishers, etc.).

- Requiring that the maglev system developer and operator provide access for emergency response crews to the guideway at locations other than designated stopping places.

- Requiring that the maglev system developer and system operator address the special evacuation needs of elderly and disabled passengers.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, should provide additional information for FRA consideration in determining the U.S. regulations or guidelines that may be appropriate to ensure maglev guideway access and egress in an emergency.

5. PASSENGER STATIONS

Passenger stations will provide the normal means for passengers to board and exit the maglev train. Tickets will be sold and luggage checked in stations. The stations will be enclosed and air conditioned. At a typical station, the platforms will be designed so that passengers do not have to use steps to enter the maglev vehicle. Passengers will have about 2 minutes to exit the vehicle, while boarding passengers will have approximately 8 minutes to enter.

The design, layout, and construction materials used in the stations affect passenger safety. Station design is also important to ensure access for mobility-impaired passengers. Furthermore, stations provide the capability to evacuate passengers from a maglev train in an emergency and a means of access for emergency response personnel to a maglev train and the guideway.

5.1 SAFETY CONCERNS

Important safety concerns for maglev stations include passenger slips and falls, fire protection, access/egress (normal and emergency), and communications.

Passengers could slip and fall while walking to the maglev vehicle boarding area, while waiting on the platform, or while boarding or leaving the vehicle. In addition, visually impaired persons may not detect the edge of the platform or the gap between vehicle and platform.

Station fire and lightning protection can prevent injury to passengers. Use of construction materials which resist ignition and do not support fire spread or smoke generation is essential. In addition, fire and smoke detection and fire suppression equipment should be provided to contain a fire that does occur. The design and operation of station ventilation equipment is also important in terms of limiting fire and smoke spread and providing fresh air to persons in the station.

Specific access/egress concerns at stations include the number, marking, and location of normal and emergency access and egress points. Adequate lighting is necessary to identify normal and emergency exits, as well as to minimize the likelihood of passengers slipping and falling. Stations must also provide access to emergency response personnel. Finally, a comprehensive station evacuation plan, including an efficient way to accommodate and evacuate individuals with disabilities, is also important (see Section 7.5, Emergency Plans and Procedures, of this report). Finally, maglev system station personnel should have a means of communicating with central control staff and with passengers waiting to board the maglev train.

5.2 GERMAN SAFETY REQUIREMENTS

Detailed requirements for maglev passenger stations were not considered to be within the scope of the RW MSB safety requirements. However, several chapters specify safety requirements for stations. The RW MSB glossary defines the station as having a platform for normal operational passenger boarding and disembarkation, which corresponds to the length of the train. Additional installations, provided in both approach directions beyond the length of the platforms, are to be used to evacuate passengers, if necessary, and to provide access to repair personnel.

Chapter 1, System Properties, Especially Safe Hovering, describes the safe hover concept, which is intended to allow the maglev train to maintain levitation until the next station, or at least until the next designated stopping place (if the station cannot be reached).

Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, requires that efforts be made to protect all persons who must stand near or cross over the guideway. This appears to apply to passengers waiting to board a maglev train at a station.

Chapter 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge, requires that all sections of the guideway where passengers may board and exit the vehicle be protected by permanent lightning protection systems, in accordance with DIN VDE 0185. This appears to apply to passengers waiting to board a maglev train at a station.

Finally, Chapter 12, Rescue Plan, states that stations are fundamentally well suited for normal passenger boarding and disembarkation; therefore, the existence of an infrastructure for rescue measures may be assumed. This is why, in principle, the vehicle may stop only at stations. Chapter 12 describes several requirements for stopping places which could by inference apply to passenger stations. (See Section 4.4, Guideway Access/Egress, of this report for further discussion of stopping places.) Finally, Chapter 12 states that alternative means of rescue can be provided, if they are kept in the vicinity of stations.

The draft MBO uses different terms for stations and stopping places from those used in the RW MSB. It uses the term "stopping place" when referring to requirements for "stations" and "auxiliary stopping points" in reference to "stopping places." The following discussion of the draft MBO requirements uses the terms used by RW MSB. The draft MBO requires that station boarding and disembarkation areas present no dangers to passengers. It states that, where possible, platforms should be at grade with the floor of the vehicle. Solid objects must be installed such that the safety clearance area remains intact. Exits must be safe, stations located along at-grade track should be accessible without steps, and elevated and depressed areas should be accessible by elevator. Finally, the draft MBO requires special installations to protect persons from dangers resulting from moving trains.

5.3 APPLICABLE U.S. SAFETY REQUIREMENTS

Currently, there are no FRA regulations for intercity railroad stations. However, 49 CFR, Part 37 [27], requires that new intercity rail stations be readily accessible to wheelchair users.

The AREA Manual of Railway Engineering [9] contains general requirements for stations. Safety-related requirements are described for waiting rooms and platform boarding areas. The AREA manual states that the general layout and circulation of passengers should be designed to be most efficient while giving adequate consideration to safety. For example, the AREA recommends that where passenger counts exceed 300 persons per hour, separate areas be provided for passenger boarding and exiting. Other functional requirements relating to safety are included for construction materials, lighting, air conditioning and ventilation, and graphics.

NFPA Standard for Fixed Guideway Transit Systems (NFPA 130) [20] contains extensive requirements for stations in terms of fire safety, emergency access and egress, and emergency equipment. This standard specifies provisions for construction materials, automatic sprinklers, ventilation, wiring, number and capacity of exits, emergency lighting, communications, standpipes, and fire extinguishers. The station requirements contained in NFPA 130 are adapted from requirements contained in the NFPA Life Safety Code (NFPA 101) [26]. Many states and localities incorporate the provisions of NFPA 101 as an integral part of their local building codes.

The UMTA emergency preparedness guidelines [12 and 13] contain recommendations for transit station lighting, access and egress, communications, ventilation and air conditioning, support equipment and systems (i.e., fire extinguishers and rescue equipment), flammable and combustible liquid/vapor intrusion, flood protection, graphics, and emergency power; the special needs of elderly and disabled passengers during emergencies are addressed in [13].

5.4 DISCUSSION/RECOMMENDATIONS

Although requirements for maglev passenger stations were not considered to be within the scope of the RW MSB, it does address a number of important safety concerns related to stations, in terms of protecting passengers from moving trains and lightning and in terms of access and egress. The draft MBO also addresses these safety concerns, and partially addresses the ADA requirements relating to persons with disabilities. The draft MBO appears to require elevators for elevated stations, and requires that the stations be accessible without steps. However, it uses the term "where possible" when referring to level platforms to provide access to disabled persons.

The AREA requirements could be considered appropriate for safe maglev station design in the United States. NFPA 130 and the UMTA emergency preparedness guidelines extensively address emergency-related station safety concerns.

For U.S. application, consideration should be given to:

- Investigating further the applicability of the German maglev station requirements to the U.S. operating environment.
- Requiring that the maglev system developer and operator use the station requirements contained in the AREA manual, NFPA 130, and UMTA emergency guidelines.
- Requiring the maglev system developer and operator to clarify the measures to be used to protect passengers from a moving train.

6. SIGNAL, CONTROL, AND COMMUNICATIONS

Signal, control, and communication (SCC) systems play key roles in maintaining the operational safety of all guided ground transportation modes. For high-speed, highly automated maglev systems, the SCC systems must be more sophisticated and less likely to fail than SCC systems of most other accepted transportation modes. No SCC system can be truly "fail safe," but, at an absolute minimum, it should provide the same level of operational safety that is demanded of existing automated fixed guideway operations in the United States.

The basic objectives of maglev SCC systems are to provide a safe and unobstructed vehicle travel path, i.e., route integrity; to maintain vehicle speed within designated operating specifications, i.e., safe speed enforcement; and to provide the necessary information and communication links to respond to emergencies.

The Transrapid SCC system consists of central-, remote- (i.e., wayside), and vehicle-based subsystems. The central control facility supervises vehicle operations, displays traffic information, coordinates vehicle propulsion control between central and wayside elements, and monitors other key wayside- and vehicle-based operational functions. Wayside- and vehicle-based functions include route control and vehicle position detection and vehicle control.

6.1 SAFETY CONCERNS

To prevent collisions, sudden stops, and other undesired events identified in the preliminary maglev safety report [1], the maglev SCC system must be able to ensure that the guideway is safe for operations. This task entails monitoring vehicles and personnel known to be on the guideway, detecting obstructions that may enter the clearance envelope of the guideway, and monitoring key guideway components, such as switch position. Once a route is allocated for vehicle movement, no conflicting movements should be permitted. Switches must be designed so they cannot move once a route is set, regardless of the reason, e.g., component failure or vandalism (see Section 4.3, Guideway Switch).

Positive collision-avoidance and obstruction-detection systems are needed to prevent critical or catastrophic consequences to the vehicle, its occupants, and the guideway. Obstructions that a vehicle (revenue or maintenance) could encounter include maintenance personnel, parts of the guideway, trespassers, birds, other animals, hail, ice, snow, water and debris such as downed electrical lines, tree limbs, and rocks. (For further discussion of obstructions, see Section 9.3, Shared Right-of-Ways/Intrusion.)

The SCC system must also be able to control the vehicles and guideway components so that the vehicles move only within the portions of the guideway that the monitoring task has designated as safe. The vehicle's automated control elements must be able to maintain the correct route of the vehicle and its velocity, acceleration, and deceleration within the approved speed limits of the SCC system and the design limits of the structure and vehicle. Adequate information to maintain safe operations must also be available to the operator for any manual operation scenarios planned.

The data links to and from the vehicle necessary for safe operation must be maintained for normal operation and loss of such data links must not lead to an unsafe condition. The significance of this requirement will depend on the degree of centralized versus decentralized control and the emergency response plans. The use of manual control, either in the event of loss of automatic control or to accommodate emergency response, must be fully analyzed for its implications.

The SCC system must be able to support the necessary responses to emergencies. For some emergencies, normal operations may no longer be possible, and normal lines of communication may be lost, thus placing additional demands on the remaining signal and control systems. The SCC system communications needed for various types of emergency scenarios must be addressed. The SCC system must facilitate access to and egress from the vehicle if passenger evacuation or rescue become necessary. The complex demands that may be placed on the SCC system by the responses of both the central control and on-board personnel in an emergency must also be considered.

Finally, a common concern in any highly automated SCC system is the use of microprocessors in areas where their uncontrolled failure could lead to unsafe situations. Adequate hardware and software validation and verification procedures must be utilized to reduce the likelihood of unsafe hardware or software failures and to ensure the planned level of fault tolerance.

6.2 GERMAN SAFETY REQUIREMENTS

The safe hover concept described in Chapter 1, System Properties, Especially Safe Hovering, of the RW MSB safety requirements places significant demands on the SCC system. The safe hover concept requires the SCC system to constantly maintain sufficient information on board so that the vehicle can determine its location, "know" its authority limits, and be stopped in a controlled manner in the event of a variety of failures, e.g., loss of communication with the wayside and/or with central control. This information is necessary to support the safety braking system required in Chapter 1 and the rescue plan requirements in Chapter 12, Rescue Plan.

Chapter 3, On-Board Energy Systems, requires that a power supply be available for the SCC system, as well as the levitation and guidance systems, even in the event of various and multiple faults.

Chapter 4, On-Board Control System, details the requirements for the on-board control system, which is expected to monitor and control the safety-related processes of train operation in conjunction with a central control facility. This system must compare control and actual values pertaining to the safety process, and accept data from and send data to the data transfer computer or the vehicle operating console. The system includes the safety computer, controls (such as door control), diagnostic systems, location system, operating console, auxiliary brake control, passenger emergency signal, and transmission installation. The on-board control system must initiate safe emergency braking when the vehicle safety system indicates an impermissible operating state resulting from a failure, e.g., data transmission loss. If any failure occurs, all systems critical to fulfillment of emergency braking must be sufficiently reliable to prevent another failure before the emergency braking is completed. Failure of the vehicle safety system itself must be prevented through interference-proof features.

In addition, Chapter 4 requires that the computer software for controlling safety-relevant functions comply with German Federal Railway (DB) regulation Mü 8004; all applicable rules for programming safety-relevant software must be observed. Validity and correctness of this software must be proven through comprehensive checks and tests.

Communication between the on-board safety computer and the operating console must be secure. Chapter 4 requires that safe transmission of safety relevant-signals, such as levitation and setting-down commands, be guaranteed by anti-coincidence signal lines or secured telegrams. The location and transmission installations must be monitored. Chapter 4 requires that the location installation provides the on-board safety computer with information to safely determine location, speed, and driving direction of the vehicle. The location installation outside the on-board safety computer consists of redundant channels, each being able to provide the safety computer with the necessary information. Identical readings from three different channels are required to update a vehicle position. If a channel failure results in less than three channels functioning correctly, an emergency stop must be initiated, and the remaining channels must be reliable enough to preclude any possibility of their failure before the vehicle stops. Furthermore, Chapter 4 requires that a fail-safe computer be used as the transmission computer, i.e., the installation responsible for receiving, processing, and forwarding safety-relevant data. Although details of this requirement are not given, Transrapid meets this requirement by using a 2 x 3 computer with data transmitted in secured telegrams with inverse telegrams also sent for verification of telegram accuracy. Transrapid permits one of the computers to fail without emergency braking, but a second failure initiates the emergency braking sequence.

Finally, Chapter 4 requires that displays for the operating console meet ergonomic requirements specified in DINs 33 400, 33 413, and 33 414; compliance with records and tests for those DINs is required to be documented. For other components of the on-board control system, the list of records and tests cited in Chapter 9 apply in order to prove compliance.

Chapter 8, Switch, details the requirements needed to guarantee the correct position of the switch. The position of the switch must be fail-safe before a train travels over it. Various position sensors are required, along with time and sequencing control. A locked switch must remain locked if a breakdown is at all possible. Control and safety installations should be separated whenever possible. (See Section 4.3, Guideway Switch, of this report.)

Chapter 9, Operations Control Equipment, outlines the requirements for safe operation on the guideway. Current, accurate information about obstructions on the guideway, the maximum speed allowed, and the position of relevant guideway elements must always be available on board the vehicle. Maximum speeds must not be exceeded, and minimum speeds must be achieved. Operation outside of safe guideway elements is forbidden. Rescue plan requirements related to speed may not be breached. System faults and the current braking curves must be accounted for when determining the operating speed. Continuous blocks are allowed if relevant safety information exists on the vehicle.

Chapter 9 specifies minimum operation points: operational control center and other operational points, either stationary or vehicle based. The operational points that record, transmit, or process safety-relevant information about the operational control system must be reliable signaling technology components that comply with DIN VDE 0831. However, safety-relevant systems that do not meet the DIN VDE 0831 requirement for two mutually independent functional units are allowed if safety-oriented action is taken upon failure of one functional element. For example, if two units are needed to guarantee the safety-oriented action, three units are required.

Chapter 9 also addresses issues concerning safety-relevant software and hardware issues: treatment of systematic errors, use of structured programming, and use of diverse redundant channels. It includes general guidelines for testing hardware and software. Hardware functional tests complying with DIN VDE 0831 are allowed with data processing programs if the programs can perform the tests completely and reliably. This chapter also lists code inspection requirements for software and indicates that it is expedient to generate and test the test cases with computer support.

In addition, Chapter 9 cites DINs VDE 0801 and 0831 and UIC 738, 2nd edition, Processing and Transmitting Safety Information, as applicable standards for software and hardware elements. Mü 8004 and DIN VDE 0801 are cited as standards for test and monitoring programs for computer equipment, software, and installations.

Finally, Chapter 9 defines what is allowed in an operational category called special operations, i.e., during construction, maintenance, testing, and response to breakdowns. First, the speed of passenger and special vehicles is limited to 50 kmph (31 mph). Second, the vehicle must be capable of being controlled either via visual observation from central control or from the vehicle itself by an on-board operator. Third, no passengers may be carried, except to the next stopping point, in response to a breakdown.

Chapter 10, Lightning Protection, Electromagnetic Capability, Electrostatic Discharge, requires lightning protection for safety-relevant systems, such as the operational control system elements, that prevents impermissible breakdowns and failures. The methods used to accomplish this protection must be comprehensive and verifiable. Section 3.6, Electrical Systems, of this report discusses this topic in greater detail.

Chapter 12, Rescue Plan, includes SCC requirements relevant to executing the rescue plan. The propulsion system must have a highly reliable shutdown capability to allow correct operation of the vehicle braking system during a propulsion failure. Lower and upper permissible speeds are the same as the speeds cited in Chapter 9. Two independent communication installations for voice contact between the control center and the vehicle are required. Chapter 12 describes the passenger emergency signal that is defined and required in Chapter 9. Chapter 12 also notes that the train operator or attendant must be able to initiate an emergency stop. Note: initiation of an emergency stop activates only the safety braking system; it does not immediately stop the vehicle. (See Section 3.4, Propulsion/Braking, of this report for additional discussion relating to emergency braking.)

The EBO contains requirements for signals, switches, section blocks, train control, and communication facilities. These provisions are similar to the more detailed and specific FRA requirements on the same subject, and offer no new or novel intent. The EBO also details various speed limits and restrictions based on vehicle design, train makeup and condition, operating conditions, and train control equipment. While different in content from the FRA requirements on the same subject, the overall intent does not offer a new perspective.

The draft MBO requires that the SCC system elements maintaining railway security be safe and comply with signal technology standards, but does not reference the specific standards. The SCC must be able to monitor door status, lead unit acoustical warning systems and signal lights (a minimum intensity must be established), communication between the vehicle and central control, and the safety systems that allow the vehicle to successfully stop at an aid stop. The safety systems must also be tested. If an operator's booth is provided, it must house the operating and information systems essential to the safety of the train, including communication capability with the central control facility.

The draft MBO also requires speed monitoring, either automatically or by a second person in the control cab, for any speed over 50 kmph (31 mph). If route integrity systems fail, speed is limited to no more than 50 kmph.

6.3 APPLICABLE U.S. SAFETY REQUIREMENTS

FRA safety requirements for SCC systems are described in 49 CFR, Part 236. This part contains sections concerning automatic block signal systems; interlocking; traffic control; automatic train stop, train control, and cab signal systems; and dragging equipment, slide detectors, and other similar protection devices. It also has an extensive definitions section.

The requirements fall into three broad categories: those that are technology independent, those that are railroad specific but easily transferrable to other areas, and those that are railroad specific and not applicable outside traditional railroad operations. Examples of requirements of Part 236 that are technology independent include those for legible plans to be stored in known locations and for locking of wayside signal installations. Examples of transferrable requirements are the various tests of wires, grounds, and timing devices; route locking; and speed control. Examples of requirements for which any transfer of intent is obscured by the specificity of the technology are track circuit feed at grade crossings, trip arm, height and distance from rails, and numerous definitions.

FRA requirements do not specifically cover microprocessors in control systems. However, 49, CFR, Part 235, allows the FRA to consider modifications to signal systems covered by Part 236. The FRA has used the intent of the existing regulations (i.e., to provide safe control systems with many checks and fault-tolerant systems) to regulate these new systems.

The FAA has safety requirements related to control systems on aircraft that may either be applicable to maglev systems or provide another perspective. The FAA approach is more performance based than the FRA approach. For example, 14 CFR, Part 25.671, Subpart (d), states that "the airplane must be designed so that it is controllable if all engines fail. Compliance with this requirement may be shown by analysis where that method has been shown to be reliable."

In addition, FAA Advisory Circular 20-115A requires that the methodology specified in the Radio Technical Commission for Aeronautics, RTCA/DO-178A, Software Considerations in Airborne Systems and Equipment Certification, be applied for software design relative to airplane control systems. Furthermore, FAA Advisory Circular 25.1309-1A, System Design and Analysis, while broader in scope than the control system subject, has sections that may be applicable to control systems for maglev trains.

Other federal agencies also have requirements that may be applicable to maglev software, firmware, and hardware design. These include the National Aeronautics and Space Administration (NASA), the Nuclear Regulatory Commission (NRC), and various divisions of the Department of Defense (DoD).

The Institute of Electrical and Electronics Engineers (IEEE) also has safety requirements that contain control system requirements and definitions of fail-safe systems, reliability, and redundancy.

6.4 DISCUSSION/RECOMMENDATIONS

The RW MSB contains more general safety provisions for SCC systems than do the FRA requirements and sometimes allows undefined latitude in determining compliance. However, the various DIN, DB, and UIC standards referenced for hardware and software design, validation, and verification for safety-relevant systems may present a thorough and fully acceptable means of ensuring a known level of safety. At a minimum, these foreign standards should provide a good basis with which to compare the existing U.S. safety requirements.

The FRA requirements for SCC systems, are, for the most part, not broad enough to be directly applied to the Transrapid maglev system. A major area not covered by Part 236 is software, hardware, and firmware design and operational regulations for microprocessors utilized in vital sections of the SCC system. A definition of what constitutes vital versus non-vital elements in microprocessors is needed, along with adequate separation standards for these elements. In addition, some form of design standards, and validation and verification methodology is needed along with test requirements for installation, periodic inspections, and modification checks for these types of systems and components.

Furthermore, consideration should be given to requiring positive verification that all vital elements of the SCC system are indeed fail safe or fault tolerant and that possible failure modes of the control system have been integrated with the emergency preparedness plans. The criticality of SCC verification was identified in Section 7, Findings, of the preliminary maglev safety review [1]. The definitions of fault-tolerant and fail-safe systems should be expanded to include complex computer-controlled systems without sacrificing the safety content in Part 236. In general, the various sections of Part 236 may need to be modified to safely accommodate both technological advances in SCC systems and the increased safety demands on SCC systems. In addition, new requirements should be added to this part to include validation and verification of computer software and hardware. Such changes to this part should also accommodate such evolving railroad systems as the advanced train control systems (ATCS).

Several federal agencies, such as the FAA, NASA, and NRC, are concerned with the behavior of safety-relevant systems. These agencies have established methods for regulating the hardware and software of computer-based control systems. The various requirements of these agencies should be reviewed for applicability before new FRA regulations are promulgated. American National Standards Institute (ANSI), IEEE, and DoD standards should also be reviewed.

The various chapters of the RW MSB discussed here list specific performance requirements for SCC systems acceptable for German application, i.e., control of the hydraulic switch. Performance-oriented SCC regulations and the implications of the criteria for acceptance should be considered when drafting new regulations.

The RW MSB provides a good basis for determining whether an adequate SCC system has been attained for maglev operations. However, in the use of any of the RW MSB requirements, consideration should be given to the following modifications:

- Clarifying the role of the train guard or conductor and the operator/attendant.
- Defining more clearly the response to a passenger emergency signal.
- Defining or reviewing, before operations are allowed, exactly who controls the vehicle, how they control it, and in what circumstances they control it.

- Investigating the implications of requiring second failure scenarios where the RW MSB requires that second failures not occur, such as during emergency braking.

- Investigating the implications of the RW MSB special (manual) operations speed limit of 50 kmph (31 mph) for the United States, given the restricted speed limits on portions of U.S. railroads and the manual override speed limits on automated U.S. transit systems.

- Requiring validation and verification of all software, hardware, and firmware that is part of SCC systems, and requiring determination and verification, by an accepted process, of the levels of fault tolerance that are necessary for each system. These requirements are specified in the RW MSB, but a more detailed understanding of the referenced European standards is necessary.

- Investigating further the performance-based acceptance criteria approach in developing regulations for SCC systems.

In addition to the analysis of foreign requirements (e.g., DINs, UIC), as cited in the RW MSB, two other studies are being performed which have relevance to potential SCC system safety concerns. The first study is directed at the evaluation of safe speed enforcement concepts. The second study is directed at the development of a methodology for the verification of fault-tolerant and fail-safe computer control systems. When these studies are completed, the results will provide additional information concerning the modifications that may be appropriate to current U.S. regulations.

7. PLANS AND PROCEDURES

The typical maglev system will be highly automated, and revenue operations will be coordinated by central control facility personnel. Central control and wayside facilities will interact with on-board control systems to maintain automated control of train operations during normal conditions and most emergencies.

Close coordination of revenue operations with the engineering department will be required to ensure that maglev vehicles, guideway, and other equipment and facilities (i.e., central control) operate safely as intended and that maintenance and service scheduling requirements are considered.

Vehicle and guideway maintenance procedures; system safety, quality assurance, and certification plans; and emergency response plans and procedures are also necessary for safe maglev system operation.

7.1 NORMAL OPERATIONS PROCEDURES

Procedures for maglev system revenue (and non-revenue) operation should be contained in the operating manual, which describes the various system tasks and functions, types of operation, and methods of handling malfunctions during system operation.

The central control facility will initiate and control the maglev train operations according to demand or selected schedules, using dual redundant computer systems. Control and informational monitoring panels will facilitate operations management by providing a visual display of operations and the means for implementing control functions.

7.1.1 Safety Concerns

The majority of maglev system operations are computer controlled. Nevertheless, constant monitoring by central control personnel is required to ensure that abnormal conditions are identified and corrected before they escalate into emergencies. Visual displays and other communications generated by the automatic computer control must contain sufficient and correct information to enable personnel to react to unusual conditions in a timely and effective manner.

Loss of communication between central control computer facilities and the wayside and/or vehicle computers and other equipment could allow the maglev train to start or stop at the wrong time, or fail to attain or exceed the speed necessary to reach stations or safe stopping areas. (This concern is also addressed in Section 6, Signal, Control, and Communications.)

Loss of radio contact between the central control staff and the maglev train crew may also affect the safety of passengers and crew.

7.1.2 German Safety Requirements

Because most maglev functions are computer controlled, the RW MSB contains technical safety requirements directed at maintaining operations by means of the on-board vehicle control (Chapter 4) and operational control equipment (Chapter 9). Chapter 9, Operations Control Equipment, states that, for routine operations, the operational readiness of guideway elements for a vehicle run consists of the following conditions:

- No vehicle is on the guideway.
- Moveable guideway elements are set.
- No other vehicles or other technical installations can get on the guideway.
- The guideway is not operationally ready for another run or blocked for some other reason.
- Information is available for location of guideway elements, local permissible maximum speed, and suitability of an auxiliary stopping point.

The location-dependent vehicle speed range is generated in conjunction with guideway operational readiness, and includes factors such as guideway safety data, vehicle internal data, status of levitation, guidance, and vehicle side braking installations. Section 6, Signal, Control, and Communications, of this report contains a more extensive discussion of the technical aspects of the operational control procedures, as addressed in Chapters 4 and 9 of the RW MSB.

The draft MBO requires that permission for maglev vehicle travel be granted only if the guideway is set, the guideway is clear, and there is no danger from other trains. The travel speed of the maglev vehicle depends on the existing construction, operational, and safety conditions. Above travel speeds of 50 kmph (31 mph), the guideway must be set up and technically safeguarded until the vehicle has cleared it completely or has come to a stop. Procedures for operation at 50 kmph or less are not described. Finally, standing vehicles must be safeguarded against unintentional movement.

The EBO assigns responsibility for train "sequencing" (distance between trains) to a dispatcher. Train control points with train operated or remotely controlled signals must be assigned to a dispatcher. Procedures are described for train movement (e.g., travel on the right side of double track, with specific exceptions), passing of stop signals, blocking of track which cannot be used, and communications. The train is permitted to approach, depart, or pass through only if the roadway is clear. If a clear track signal is disrupted or cannot be visually confirmed, safety must be guaranteed by operational directives or technical facilities.

The EBO also requires that train control points be linked by telephone, that train announcements by telephone be made by voice recordings on passenger train lines without section blocking equipment (dark territory), and that line telephones be installed along the open track "to the extent necessary."

Finally, the EBO cites allowable speeds for passenger trains. If train control equipment is provided and functional, the speed limit is 160 kmph (100 mph); otherwise, the speed is limited to 100 kmph (62 mph).

7.1.3 Applicable U.S. Safety Requirements

49 CFR, Part 217, requires that each railroad file one copy of its code of operating rules (and amendments), timetables, and timetable special instructions (and new issues to the latter two) to the Federal Railroad Administrator.

Part 218 prescribes minimum requirements for railroad operating rules and practices. These include protection of railroad employees who operate trains, locomotives, and other rolling equipment from opposing or following movements. Part 218 also prohibits tampering with locomotive-mounted safety devices, including event recorders and deadman controls.

Part 219 contains the FRA requirements concerning drugs and alcohol. The FRA prohibits possession or use of alcohol by railroad personnel while on duty, and forbids personnel from reporting for duty under the influence of or impaired by alcohol. It also prohibits any use of controlled substances not prescribed by a doctor.

Part 220 describes minimum requirements to be used by railroad employees for transmission and reception of voice communications by radio. These requirements establish standards for clarity and consistency of radio communications.

Amtrak and the commuter railroads use the Northeast Operating Rules Advisory Committee (NORAC) rules and timetable [28 and 29] for Northeast Corridor operations. For passenger trains operated over non-Amtrak-owned railroad track outside the Northeast Corridor, Amtrak train crews follow the rules and procedures of the individual railroad which owns the track. A number of railroads utilize the General Operating Code [30] to govern operations (with amendments for local conditions and facilities). The NORAC and General Code rules and procedures are based on the AAR Standard Code of Operating Rules [31]. In addition, Amtrak has issued a manual for on-board service employees, which describes rules of conduct and safety for supervisors and train attendants [32].

7.1.4 Discussion/Recommendations

The RW MSB addresses normal operating rules and procedures in the context of automatic train control, but does not specifically address procedures to be used by operating personnel, because these were considered beyond the technology-oriented scope of the document. The draft MBO and EBO requirements for operating procedures appear to be consistent with those of Amtrak. (A subsequent review of the Florida Maglev Demonstration Project operating and maintenance guidelines is planned.)

NORAC rules for operating crew and the Amtrak manual for on-board service personnel provide a baseline which could be used to ensure that the U.S. operating environment is considered in formulating maglev system operating rules and procedures.

Because of the general nature of the RW MSB, draft MBO, and EBO requirements, additional information is required before operating rules and procedures can be evaluated.

The requirements in 49 CFR, Parts 217, 218, 219, and 220, are applicable for maglev systems in the United States. In addition, consideration should be given to requiring that the maglev system operator use the Amtrak rules and procedures for operating personnel and on-board employees as a baseline for U.S. maglev regulations. This would ensure that the U.S. operating environment is considered for maglev train operations.

The results of the analysis of the foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations that may be appropriate for maglev vehicle operating rules and procedures.

7.2 VEHICLE MAINTENANCE PROCEDURES

Periodic, preventive, and corrective maintenance, as well as inspections and tests, are required to maintain maglev operational safety, availability, reliability, and efficiency. This is particularly important for the maglev system where system and subsystem fault tolerance is necessary to maintain the vehicle's safe hover capability.

7.2.1 Safety Concerns

Use of improper maintenance procedures, failure to perform scheduled inspections or tests, and failure to replace equipment could degrade the safety of vehicle operations and could cause safety-related equipment to malfunction or fail.

7.2.2 German Safety Requirements

The RW MSB safety requirements address design, construction, and controls of the maglev system. Chapter 4, On-Board Control System, requires that all safety-critical systems be tested before a vehicle is dispatched, and that the vehicle stop for maintenance if enough failures accumulate to reduce the system redundancy to the minimum required levels. It does not address methods of maintaining system quality and reliability; these are the responsibility of the system operator.

Similarly, the draft MBO and the EBO address pre-trip assessment and system operational checks, but do not address systematic inspection and periodic maintenance requirements.

7.2.3 Applicable U.S. Safety Requirements

FRA inspection requirements are contained in several parts of 49 CFR. Part 215.13 addresses pre-departure inspection, and Part 215.15 addresses periodic inspection. Subpart B of Part 229 specifies that periodic inspections and tests of locomotives be performed on a daily, annual, and biennial basis. These inspections include electrical and mechanical equipment. Inspection records must be maintained, but only until the next equivalent inspection report is complete. Part 217 requires that operational tests and inspections be conducted.

Part 218 addresses the protection of workers working on track and equipment where the possibility of equipment movement exists. It does not address inspection and maintenance practices that ensure high reliability.

7.2.4 Discussion/Recommendations

The RW MSB contains technical requirements that must be followed to ensure system safety and reliability and to ensure that the manufacturer designs a system which meets those requirements. However, the maglev system operator will be responsible for maintaining the system to standards that ensure safe and reliable operation. Failure to institute and continue a rigorous, comprehensive system inspection and maintenance program will result in poor reliability, and will increase the probability of dangerous system failures.

Current FRA regulations stress the use of operating practices and periodic inspections to minimize personnel injury and to prevent dispatch of faulty equipment. Therefore, the framework for maglev system maintenance requirements which meet the standards implied in the RW MSB is in place, but the provisions need to be strengthened and modified for maglev application. Stringent inspection and maintenance requirements are needed, with the burden of compliance on the maglev system operator. It is important to recognize that once a system is built, tested, and certified by the manufacturer as ready for revenue service, the system operator has the responsibility to maintain the system to the same standards that existed during pre-revenue service. Because operators might not expend the resources necessary to maintain safety and reliability without oversight, a team of trained inspectors may be necessary to conduct periodic inspections to enforce the regulations.

Consideration should be given to the following types of maglev vehicle maintenance requirements:

- Expanded periodic inspections to include all safety-critical systems, and permanent, as opposed to the present temporary, record keeping.
- Inspection and maintenance intervals based on operating and test experience, with FRA approval for changes to inspection intervals or scope.
- Inspection, preventive maintenance, and corrective maintenance procedures (to be developed by the manufacturers and followed by the operators) for identifying and eliminating potential critical failures.
- Maglev-specific qualification training and requalification training for inspectors and maintenance personnel.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations that may be appropriate for maglev vehicle maintenance.

7.3 GUIDEWAY MAINTENANCE PROCEDURES

Proper maintenance of the guideway superstructure and functional components is necessary to ensure safe maglev system operations. To be effective, guideway maintenance programs should include both routine, preventive procedures (including periodic inspection and testing) and corrective maintenance (including replacement of parts). The guideway maintenance program should also address special inspections to ensure guideway safety after storms, floods, fire, or earthquakes.

7.3.1 Safety Concerns

Use of improper maintenance procedures, failure to perform scheduled inspections or tests, and failure to replace inoperative or worn parts could cause safety-related equipment malfunctions or failures, thereby degrading the safety of vehicle operations. Guideway functional components such as the guide rail attachments and stator-pack mountings undergo high shear and tensile stresses, as they are subjected to the levitation, guidance, propulsive, and braking forces. Thus, these components should be inspected periodically to detect any impending separation of the attachments. The sliding surface is subjected to high stresses as the vehicle touches down on its support skids during emergency braking, and must be inspected for wear. To detect and correct guideway geometry variations which could cause maglev vehicle magnet contact, slide surfaces and supporting structures must also be inspected and maintained within the established limits.

To detect unsafe operating conditions and guideway structural damage caused by severe weather conditions and natural disasters, such as storms and earthquakes, inspections and tests must be conducted.

7.3.2 German Safety Requirements

Chapter 1, System Properties, Especially Safe Hovering, of the RW MSB specifies requirements for guideway inspection; it requires regular inspection of guideway supports and fixtures for stator packs and guide rails. Chapters 6, Stability Analyses (Guideway/Vehicle), and 7, Design, Production, and Quality Assurance of Mechanical Structures, require that the system detect failed stator-pack mounts so that corrective action can be taken. Chapter 7 requires that all structural elements relevant to guideway stability be accessible for inspection purposes, and references a Thyssen Henschel report for guideway maintenance.

The draft MBO requires that structural installations and technical equipment (e.g., the guideway) be demonstrably inspected regularly. The type, extent, and frequency of these inspections depend on condition, construction, and load of the installation. "A competent authority" (undefined) determines the group of people who will conduct the initial and recurrent tests.

7.3.3 Applicable U.S. Safety Requirements

FRA inspection requirements for railroad track are specified in 49 CFR, Part 213. This part prescribes speed limits for operation on various classes of track and describes various rail defects. It requires that designated qualified persons perform inspections and describes the specific experience, knowledge, and skills that personnel need to detect rail defects. Part 213 requires that Class 6 track (Amtrak Northeast Corridor) be inspected twice a week. Part 213 includes the frequency and manner of inspecting for deviations in tracks, switches, crossings, and rails. Special track inspections are also required after a fire, flood, severe storm, or other occurrences that could damage the tracks. Finally, it specifies record-keeping requirements, penalties for track violations, and inspection requirements.

7.3.4 Discussion/Recommendations

The RW MSB requirements for maglev guideway inspection and fault detection are appropriate, but should be expanded to include details about the frequency of and technique for inspecting and maintaining the guideway.

FRA procedural and inspection requirements are specified for railroad tracks. Because of differences in the design and configuration between railroad tracks and maglev guideways, the track-specific requirements in 49 CFR, Part 213, will have to be modified for application to maglev guideways. Both new specifications and appropriate inspection methods and procedures should be developed. However, the existing inspection documentation requirements contained in Part 213 appear to provide the appropriate level of information and records necessary.

The FRA requirements for special inspections after occurrences that could damage the track are directly relevant to any civil engineering structures, including maglev bridges, tunnels, and elevated and at-grade structures. Thus, these requirements would be directly applicable to maglev guideway inspection.

For U.S. application, consideration should be given to requiring that the maglev system developer and operator provide information about the frequency of and techniques for inspecting and maintaining the guideway.

The results of the foreign safety requirements analysis (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the modifications to U.S. regulations that may be appropriate for maglev guideway maintenance.

7.4 SYSTEM SAFETY, CERTIFICATION, AND QUALITY ASSURANCE

A System Safety Program is used to identify and resolve hazards to prevent personal injury and damage to vehicles, facilities, and equipment. The elements of the maglev system (i.e., vehicle; guideway; stations; signal, control, and communications; plans and procedures; personnel; and the operating environment) and their interaction must all be defined and analyzed on a continuing basis, to ensure that all hazards are identified and that new hazards are not introduced when system elements are changed.

A certification program is used to verify that actual system construction and installation comply with the requirements of the

System Safety Program. An oversight organization usually administers the certification program. This organization independently inspects and tests system elements to ensure that the System Safety Program Plan is followed, assesses overall system safety, and determines whether the system meets the requirements of the System Safety Program Plan prior to acceptance and subsequent operation of the system.

A Quality Assurance Program is normally used to oversee the construction, installation, and maintenance of maglev vehicles, guideway, etc., to ensure that the materials used are the proper quality and that the correct procedures are followed.

7.4.1 Safety Concerns

Because maglev systems are still under development, it is not possible to identify and resolve all potential system hazards. Sufficient operating data have not been available to quantify the probability of undesired events. In addition, some hazards can only be identified after the maglev system is built and installed. Excessive emphasis on the technical aspects of the maglev system may prevent identification of personnel, procedural, and environmental hazards.

Moreover, higher maglev train operating speeds, as well as the "safe hover" requirement that the train stop only at established stopping places, require a high standard of reliability for components and structures. For example, a safety-critical structural failure at high speed could cause loss of safe hover between stopping places, thereby complicating emergency evacuation. A rigorous System Safety Program is essential to ensure the high standard of reliability needed to minimize the likelihood of failures (e.g., structural, electrical, software). Component reliability affects the probability of failure and thus system safety. System safety could be degraded if materials quality is less than required, defective parts are supplied, or improper procedures are used to construct, install, operate, or maintain maglev system elements or components.

Furthermore, changes made in one or more maglev system elements or components may not be documented and may even negatively affect the previously certified system safety. A configuration management program could track such changes and ensure that documents reflect the actual system.

7.4.2 German Safety Requirements

The Transrapid system manufacturer (Thyssen Henschel) contracted the Swiss firm Basler and Hofmann to perform a system safety analysis of safety issues which pertain to the unique aspects of maglev technology [14]. (Section 2.6.1 of this report contains a brief summary of the Basler and Hofmann report.)

The RW MSB contains performance-oriented safety requirements that must be met by the maglev system developer. It addresses potential maglev system hazards from the technological perspective. For example, redundancy of safety-critical systems is specified in many cases to maintain safe hover.

As stated in Section 2, Safety Requirements Review Process, of this report, an independent certifying authority must examine, license, and certify the operation of each German transportation system. TÜV Rheinland is performing this function for technology- specific items for the Transrapid maglev system at Emsland, Germany, for the TVE facility; the Program Accompanying Safety Certification (PASC) process is being used. In addition, a process of determining "Readiness for Application" of the Transrapid technology is currently underway in Germany. Section 2 of this report discusses the PASC and "Readiness for Application" process.

Chapter 7, Design, Production and, Quality Assurance of Mechanical Structures, of the RW MSB specifies that the necessary quality be maintained by observing technical regulations, documenting procedures, and using qualified workers who are properly trained for the particular task.

The draft MBO requires that the system operator establish measures that will minimize the potential for accidents, minimize the consequences of accidents that do occur, support individual rescue, and facilitate the rescue of others. The operator is also required to summarize these measures (in terms of infrastructure, vehicles, service, and rescue), particularly for tunnels, and to present them to the "competent authority" (undefined) for approval.

The EBO states that the system operator is obligated to manage the maglev operations safely and to maintain the facilities, vehicles, and accessories in "a good, operationally safe condition." It also requires that new vehicles not be placed into service for the first time until they have been demonstrably tested.

7.4.3 Applicable U.S. Safety Requirements

The FRA has a clear line of responsibility for maglev system safety. The Florida Maglev Demonstration Project franchise calls for technical services by TÜV Rheinland with oversight by the FRA. Before commercial passenger service is initiated, the FRA, through the Florida Department of Transportation, will require that TÜV Rheinland and Transrapid certify that the project was designed and constructed in accordance with the System Safety Program, as well as with the plans and specifications submitted to FRA for review.

MIL-STD-882B [10] contains extensive information for the development and implementation of the System Safety Program. This military standard describes the types of analyses which can be performed to identify hazards, and reviews methods (design, safety and warning devices, special procedures, or any combination thereof) to resolve hazards throughout the system life cycle. MIL-STD-882B also contains a ranking system which can be used to estimate the severity and probability of hazards. (See Appendix B of this report for further discussion of system safety methodology.)

The American Public Transportation Association (APTA) has issued a safety audit program manual [33], which is intended to provide a means for rail transit systems to evaluate how well their system safety management programs are implemented. A major component of the manual describes guidelines for the development of a System Safety Program Plan for operational transit systems.

The FAA, in 14 CFR, Part 21, defines the type of certificates granted and requires that drawings and specifications, flight test documentation, etc. be submitted. Design change recertification, a pre-service quality assurance test on each aircraft, technical standard orders (TSO) for third-party manufactured parts, and a TSO administration system are also required; the latter includes general design criteria, materials and workmanship, and fabrication.

7.4.4 Discussion/Recommendations

Because its focus is the maglev technology developed for operation in Germany, the RW MSB does not consider a number of environmental, personnel, and procedural hazards that could affect the safety of U.S. operations. The Basler and Hofmann safety analysis does not identify personnel or procedural hazards; hazards that could affect the evacuation or rescue of passengers and crew are identified only in terms of a fire. The fault trees in Appendix C of the preliminary maglev safety review [1] illustrate the importance of including proper emergency planning and procedures for a variety of emergencies within a System Safety Program.

The draft MBO requirements for safety measures and rescue planning and the EBO requirements for system operator safety management and maintenance are consistent with those in the MIL-STD 882B System Safety Program requirements. However, the "competent authority" to which the measures must be submitted for approval is not defined in the draft MBO. The EBO requirement that new vehicles not be placed into service for the first time until they have been demonstrably tested provides an opportunity to identify and resolve safety hazards.

Proper material and construction quality must be provided to attain the expected reliability from the maglev system components. Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, of the RW MSB provides extensive guidance for a Quality Assurance Plan that is consistent with the AAR quality assurance requirements. This chapter specifies the inspection and testing procedures required to check the quality of all materials and procedures used for the maglev system. The requirements in Chapter 7, as well as the DIN references cited therein, appear similar to the AAR quality assurance requirements. The FAA quality assurance requirements could provide additional guidance because of the high tolerances required for aircraft.

For U.S. application, consideration should be given to:

- Requiring that any maglev system developer (and/or operator, as appropriate) submit a System Safety Program Plan which documents the procedures used to identify and resolve hazards, in addition to those that are technology-related. (This is understood to be a requirement for the Florida Maglev Demonstration Project.)
    - This hazard analysis should be on-going and should extend to the operating phase of the maglev system.
    - To identify hazards and provide documentation to management, these procedures should include, as appropriate, a preliminary hazard analysis, failure modes and effects analysis, fault tree analysis, interface hazard analysis, operating hazards analysis, and maintenance hazards analysis.
    - MIL-STD-882B and the APTA Safety Audit Program Manual or their equivalent should be used as guidelines by the system developer (and/or the system operator, as appropriate) to develop and implement the System Safety Program throughout the life cycle of the maglev system.
- Recommending that the System Safety Program Plan reference maintenance, quality control, and emergency response plans and procedures.

- Recommending that the System Safety Program Plan require that the system developer and/or system operator analyze, as appropriate, any proposed changes made to the maglev system elements or components that could affect system safety.

- Recommending that documentation containing the results of analyses of equipment and procedural changes be reviewed by maglev system management and all other appropriate personnel (i.e., operations, safety, and maintenance), to ensure that new hazards are not introduced.

- Requiring that changes to system operations and maintenance procedures be documented, kept on file, and submitted to FRA, according to Part 217, and that all such changes be incorporated in any operating and maintenance manuals and distributed to appropriate employees.

- Requiring that the maglev system developer and/or system operator formulate a Quality Assurance Program Plan, and/or demonstrating its equivalent to that specified in the AAR requirements for quality assurance.

- Reviewing further the FAA quality assurance requirements to determine their potential applicability to maglev systems.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, should provide additional information for FRA consideration in determining the U.S. regulations or guidelines that may be appropriate for maglev system safety, certification, and quality assurance plans.

7.5 EMERGENCY PLANS AND PROCEDURES

The operational handling of the traffic network is usually automatically controlled by the operational sequence, i.e., timetable data. In an emergency, operating staff in the central control facility can, if required, intervene and modify the timetable, thereby changing the operational sequence. If major scheduling problems occur, because of a vehicle breakdown or other emergency, the central control staff can correct or bypass faults via the timetable. Process computers in the central control facility assist the central control staff in an emergency by allowing a timely prognosis of the intended measures through simulations predicting the effect of alternative scheduling or timetables.

To coordinate the central control computer capabilities, as well as the human element, and to ensure the most effective response to emergencies, maglev system management and operating personnel must engage in careful advance planning and must develop procedures to handle a variety of emergencies. This emergency preparedness planning will enable maglev system and emergency response personnel to take timely and effective action and thus minimize consequences.

While the Transrapid system is designed to limit the probability of a critical system failure, emergency procedures are needed in case a system failure requiring partial or total system shutdown occurs or passenger evacuation/rescue becomes necessary.

7.5.1 Safety Concerns

Understanding the types of emergencies which may occur on the maglev system and their related hazards is necessary for developing an effective emergency response plan and procedures. Potential emergencies include vehicle fire; collision; stop; passenger illness; loss of communication between the vehicle, guideway equipment, or the vehicle operator and central control; high winds; an earthquake; guideway intrusion; and power failure. The location of the vehicle on the guideway affects the severity of the emergency and the ability to evacuate passengers. (The Transrapid system uses the concept of safe hover and programmed braking to enable the maglev train to reach designated stopping places designed to allow safe passenger evacuation.)

Even during circumstances which are under control (from the point of view of maglev and emergency response organization personnel), passengers may panic if they feel trapped, if communication is cut off, or if personnel are having difficulty reaching them. Medical, physical, or mental conditions of passengers could also be aggravated. Although many elderly and disabled passengers may have little difficulty using the maglev system under normal circumstances, mobility or other limitations may prevent them from moving with the speed, agility, and sureness needed to evacuate the maglev vehicle in an emergency.

The fault trees in Appendix C of the preliminary maglev safety review [1] illustrate the importance of advance emergency planning. Poor communication and coordination, as well as lack of knowledge or training in proper procedures, may delay evacuation or otherwise hinder emergency response.

7.5.2 German Safety Requirements

The RW MSB specifies safety requirements for emergency power, emergency lighting, fire protection, communications, and evacuation/rescue. The following discussion of the RW MSB requirements focuses on evacuation/rescue procedures as they relate to the Transrapid safe hover concept and programmed braking approach. Other RW MSB emergency-related requirements are discussed in Sections 3.7, Access/Egress, 3.8, Emergency Features and Equipment, 3.9, Fire Protection, and 4.4, Guideway Access/ Egress, of this report.

Chapter 1, System Properties, Especially Safe Hovering, indicates that it must be determined for each individual application whether a rescue plan utilizing programmed braking to a designated stopping place can be realized or whether other supplemental strategies are to be pursued, especially in terms of the planned rescue measures described in Chapter 12, Rescue Plan.

Chapter 12 defines an emergency as an event that can threaten personal safety and that requires evacuation measures to protect passengers. The RW MSB states that vehicle evacuation is necessary only if an additional emergency occurs after a stop on open guideway, and that a vehicle fire that cannot be extinguished is the only "real" emergency which requires evacuation. In the event of a fire, the RW MSB escape plan is to move passengers from one vehicle section to another through doorways past fire walls with a resistance of at least 30 minutes separating the sections.

Chapter 12 requires that the procedure to be followed in the event of a disruption in vital functions be specified in the operating instructions, services directives, and rescue plan for the maglev system in question. Requests for rescue services (to meet the train at the next station in the same direction or, if necessary, the next stopping place) are to be transmitted by the train operator to the central control facility using the communication system.

While stations are the preferred location for passengers to leave the vehicle, the RW MSB recognizes that designated emergency "stopping places" that have facilities for passenger evacuation and access to rescue services are necessary between stations. Chapter 12 describes particular safe hover requirements, the intent of which is to ensure that, in an emergency, the train will reach one of these stopping places or a station. In this context, safe hover requirements are discussed in terms of the acceleration and deceleration speeds necessary for the vehicle to reach a stopping place or a station. (See Section 4.4, Guideway Access/Egress, of this report for discussion of stopping place design and equipment safety requirements. Vehicle features and equipment which relate to emergency preparedness are discussed in Section 3.8, Emergency Features and Equipment.)

Chapter 12 does not provide for planned stopping between designated stopping places, but describes two situations which could occur, in the worst case. An unplanned stop between stopping places could result from either emergency braking that stops the train short of the stopping place (including a station) or emergency braking after restart from a stopping place. In those cases, if the stop is at grade, in a tunnel, or on a bridge, vehicle egress is by ladder, footbridge, or slide, or onto a widened bridge support. In other cases, vehicles are evacuated using on-board self-rescue equipment. As a minimum, one safety rope per exit must be provided; evacuation using ropes is limited to a guideway height of 20 m (66 ft). Alternatively, rescue slides can be provided for self-rescue. The RW MSB considers evacuation onto the guideway impermissible.

The RW MSB demonstrates an awareness that, as a last resort, other means of evacuating the vehicle in an emergency may be necessary, as it states that alternative "outside" means of rescue can be used depending on the infrastructure. Moreover, the RW MSB describes rescue plan requirements that access roads be constructed and landing sites for helicopters be provided, if necessary.

Finally, the RW MSB requires that the procedure to be followed in the event of a disruption in vital functions be specified in the operating instructions, services directives, and rescue plan for the maglev system in question.

The draft MBO states that, if for special reasons, various rules concerning guideway safety cannot be met, permission to travel may be granted only if suitable replacement measures are taken. In addition, it requires that for travel above 50 kmph (31 mph) the responsiveness of the person responsible for controlling the vehicle must be technically monitored; if that person fails to react, the vehicle braking process is automatically triggered. (As a substitute, a second person can perform the monitoring function.) If technical safeguards fail, the travel speed is limited to 50 kmph (31 mph).

The EBO describes two requirements that are emergency-procedure related: (1) trains may pass a stop signal only with special instructions, and (2) switches controlled by signals which are temporarily impaired must be secured or guarded by hand lock.

7.5.3 Applicable U. S. Safety Requirements

With the exception of emergency radio transmission requirements, the FRA does not address emergency procedures. 49 CFR, Part 220.47, specifies that the word "emergency" repeated three times must precede any emergency radio transmission, that such transmission must take priority over any other for its duration, and that the nature, degree, and location of hazards must be specified. Emergency transmissions must be used to report derailments, collisions, and other hazardous conditions which could result in death or injury, damage to property, or serious disruption of railroad operations.

Amtrak provides rule books [28 and 29] which contain emergency procedures for operating crews. These rule books describe the proper procedures to follow for various emergencies, and include instructions for operating emergency exits and procedures for passenger evacuation. Amtrak's manual for on-board service employees describes emergency-related policies and procedures for first aid, train emergencies, and evacuation [32].

Amtrak has also issued Emergency Evacuation for Amtrak Trains [23], which is used as a reference for employee and public agency (e.g., emergency response) personnel. This booklet contains entry and evacuation procedures for passenger locomotives and passenger cars. It illustrates the location of all passenger, baggage car, and locomotive emergency windows, and describes the procedures necessary to remove them. Passenger car and baggage car side and end entry doors, as well as locks and latches, are illustrated and operating procedures described. The booklet presents diagrams, entry and evacuation procedures, and special precautions for passenger and baggage cars and locomotives. Also included are information (locations of exits, ventilation, telephones, etc.) and emergency response, rescue, and evacuation procedures for tunnels in New York City and Washington, D.C. and for other tunnels that are more than 300 m (1,000 ft) long. Finally, the booklet describes electrical hazards from head-end power, catenary, and third-rail systems. Section 8.2, Training, of this report, describes additional materials related to Amtrak emergency-related procedures.

The UMTA emergency preparedness guideline documents [12 and 13] provide comprehensive assistance to rail transit systems for developing, documenting, assessing, and improving their emergency response capabilities and coordinating their efforts with emergency response organizations (i.e., fire departments, hospitals, police, etc.). The guidelines contain minimum recommendations, procedures, and criteria for the transit system to use when developing and evaluating emergency plans and procedures. Training recommendations for transit system and emergency response organization personnel are included. Finally, emergency features for system vehicles, stations, and trainway are described. The unique needs and special characteristics of elderly and disabled passengers are addressed in Reference 13.

NFPA 130, Fixed Guideway Transit Systems, [20] covers fire protection and life-safety requirements for systems, such as heavy and light rail transit and automated "people mover" systems, that operate on the right-of-way for mass movement of passengers within a metropolitan area. Its focus is on fire protection; however, requirements for emergency procedures and communications are also included.

The FAA safety requirements in 14 CFR, Part 25.803, require that, under simulated emergency conditions, all passengers (including the number of crew members required by the operating rules) in airplanes seating more than 44 passengers be able to evacuate from the aircraft to the ground within 90 seconds. Other portions of Part 25 contain provisions for emergency exits, lighting, etc.; those items are discussed in Section 3.8, Emergency Features and Equipment.

7.5.4 Discussion/Recommendations

The RW MSB relies on the safe hover concept to ensure that the maglev vehicle will stop only at stopping places that are equipped with facilities to evacuate passengers and that allow access by rescue services. However, the RW MSB does recognize that it must determined for each individual application whether such a rescue plan can be realized or whether other supplemental strategies are to be pursued, especially in terms of the planned rescue measures described in Chapter 12, Rescue Plan.

Chapter 12 considers that unplanned stops at points other than designated stopping places could occur only in a worst case scenario; it states that evacuation would be necessary only if another emergency occurs. However, it does not define what constitutes an emergency other than a fire (which RW MSB considers to be the only "real" emergency requiring evacuation); thus procedures are not described for other types of emergencies.

The RW MSB procedure during a fire is to move passengers from one vehicle section to another. However, for a crowded train, this procedure would be difficult. [Each Transrapid vehicle is designed to accommodate a total number of persons which is twice the maximum number of seats.] A fire in an end section may also block the exit and prevent passengers from leaving the section.

Chapter 12 of the RW MSB requires that vehicles be equipped with self-rescue devices for use as a last resort if the train is not able to reach a stopping place. However, the devices and procedures for their use do not address the special evacuation needs of elderly and disabled passengers. The RW MSB does acknowledge that other procedures for evacuating the train may be necessary if it is stopped on an elevated guideway segment without designated stopping places. The RW MSB allows alternative "outside" means of rescue, depending on the infrastructure and rescue plan requirements noted for access roads and helicopter landing sites. For U.S. application, other options that could be considered acceptable for maglev vehicle evacuation include rescue trains, lifting platforms, and rescue boats (for guideway segments located over water).

It is necessary that the maglev system developer and system operator work together with local response organizations to ensure that passenger evacuation can be accomplished in a timely and safe manner, considering the entire local operating environment. The RW MSB recognizes this by stating that firefighting and rescue organizations, hospitals, and police should be included in rescue planning. (See Section 3.7, Access/Egress, and 4.4, Guideway Access/Egress, of this report for further discussion of passenger emergency evacuation.)

Since operational procedures are outside the scope of the RW MSB, it does not explain what constitutes a disruption of a vital function and provides only limited guidance for the procedures that should be used (simply stating that rescue service personnel should be requested to meet the train at the next station or stopping place).

Unlike the EBO, neither the RW MSB nor the draft MBO describe the procedures to be used under manual control, i.e., at speeds under 50 kmph (31 mph), when the automatic control associated with the SCC system is inoperative. (See Section 6, Signal, Control, and Communications, of this report.)

Proper training of maglev system personnel and emergency response organization personnel is necessary to ensure that the proper actions are taken in a timely, safe manner (see Section 8.2, Training, of this report). Manuals which describe the location and procedures for operation of emergency equipment would also be useful to maglev personnel. The Amtrak evacuation procedure booklet provides a model of the type of information that should be included. As appropriate, passenger familiarization with procedures and emergency equipment could also lessen the possibility of confusion and panic and the use of incorrect procedures. (see Section 8.2, Training, of this report).

A separate effort has been initiated to develop emergency preparedness guidelines for high-speed ground transportation systems. These guidelines are intended to help passenger train operators and emergency response organizations evaluate their emergency plans and, if necessary, modify or supplement those plans as appropriate.

For U.S. application, consideration should be given to:

- Requiring that the maglev system developer and system operator jointly prepare an emergency preparedness plan that addresses procedures for other types of emergencies, in addition to those described for passenger evacuation and fire addressed in Chapters 11 and 12 of the RW MSB.
- Requiring that the maglev system emergency plan contain the following elements: statement of policy, definition of scope, agreements with emergency response organizations, maglev system functions and responsibilities, emergency procedures, general response capability criteria, and supporting documentation.
- Requiring that the maglev system developer provide the system operator with manuals that describe the location and procedures for operation of emergency equipment.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining the U.S. regulations or guidelines that may be appropriate for maglev system emergency plans and procedures.

8. PERSONNEL

It is estimated the Florida Maglev Demonstration Project of the Transrapid maglev system will employ at least 300 persons in train operations, maintenance, baggage handling, and other areas. Personnel will be hired by the local operating organization. Prospective operations staff positions include Operations Manager, Operations Supervisor, System Operator, On-Board Operator, On-Board Attendant, and Station Clerk.

On-board train personnel will typically include one operator and four attendants. The on-board operator will not actively control the train; the central control facility, through an automated system, will control the train. The operator will normally perform only the routine command for station train departures, after consulting with train attendants. However, the operator will exercise manual control during certain emergencies or other abnormal operating conditions when the automated system is either inoperative or inappropriate for use. The attendants will monitor passenger boarding and off-loading and will close the doors when boarding is complete.

Maintenance staff positions and respective duties for which staff recruitment may be required include Maintenance Supervisors and Mechanical and Electrical/Electronics Technicians.

This section reviews safety requirements for personnel relating to qualifications and training.

8.1 QUALIFICATIONS/STAFFING

Persons who are hired as maglev operating and maintenance personnel must be able to perform normal procedures relating to their tasks and to carry out the proper procedures in an emergency.

The minimum number of personnel (i.e., on-board train attendants and maintenance personnel) required to ensure safe maglev operations has not yet been determined.

8.1.1 Safety Concerns

Personnel at the central control facility may not be able to correctly interpret every system fault and take appropriate action, particularly in an emergency. In addition, because of the high operating speed and curves, the on-board train operator may be unable to detect certain system faults or see hazards or obstructions. Inadequately trained mechanical and electrical maintenance personnel may not be able to detect or diagnose problems to decide whether preventive or proactive corrective measures are necessary. Insufficient staffing levels in the central control or maintenance facilities could contribute to personnel stress or fatigue.

8.1.2 German Safety Requirements

The RW MSB safety requirements are directed at maglev technology. Therefore, personnel qualifications and staffing levels are not presented with the exception of the requirement in Chapter 9, Operations Control Equipment, that the central control facility be continually occupied to the extent necessary by professionally trained, suitable, and competent personnel.

The draft MBO specifies that maglev service personnel directly involved with train operations be at least 21 years of age and, in accordance with their duties, have good reaction capabilities and adequate vision and hearing. Personnel must have no diseases which might impose a safety risk. (Other draft MBO personnel qualification requirements relating to training are discussed in Section 8.2, Training, of this report.)

The draft MBO also specifies that the prerequisite training and experience needed to operate the vehicle and ensure the safety of the passengers be established according to the destination of the vehicle, technical equipment, and the structural, operational, and safety conditions of the guideway. In addition, it specifies that one person be responsible for each guideway section; that employee must ensure that the pre-established conditions for safety are present: (1) the guideway is clear, (2) the guideway is safe, and (3) there is no danger from other trains. Finally, the draft MBO requires that an operations employee be present at the central control facility, at all times, to initiate the necessary operational and rescue procedures in the event of a breakdown or an emergency.

The EBO specifies requirements for "operations officers;" included are managers, supervisors, dispatchers, station agents, "tractive unit drivers," train conductors, etc. These personnel must be at least 18 years old, carry a timepiece, and have access to written directives about their duties. They must be used in a number commensurate with safe operation, and personnel files must be kept for each. In addition, personnel must be physically fit for service and free of disease and must have special qualities appropriate to their service. Physical qualification examinations are required. Sharpness of vision, ability to distinguish colors, and hearing requirements are also described.

8.1.3 Applicable U.S. Safety Requirements

The FRA does not regulate qualifications or staffing levels for railroad personnel except locomotive engineers. 49 CFR, Part 240, requires that railroads establish a formal process to evaluate the competence of locomotive engineers and determine that they are competent before they operate a train. Each railroad must submit a program for locomotive engineers which addresses selection of designated supervisors, selection of classes of service, evaluation of safety conduct, evaluation of hearing and visual acuity, education, testing, operational monitoring, and procedural aspects of the certification program.

Part 219 contains the FRA requirements concerning drugs and alcohol. The FRA prohibits possession or use of alcohol by employees while on duty, and forbids them to report for duty under the influence of or impaired by alcohol. It also prohibits any use of controlled substances not prescribed by a doctor.

Amtrak trains are operated with various crew combinations. Train operating crews include engineers, firemen, conductors, and assistant conductors). The Amtrak train attendants must always follow the instructions of the train conductor.

In 14 CFR, Parts 61 and 63, the FAA describes certification requirements for aircraft pilots and flight crew members other than pilots. These requirements include flight tests and instruction and prescribe the minimum hours of flight experience needed for ratings.

8.1.4 Discussion/Recommendations

Because of its intentionally limited scope, the RW MSB briefly addresses personnel qualifications and staffing levels in terms of central control personnel training and on-board train attendant first aid and rescue training.

Historically, the FRA has not regulated railroad personnel qualifications; this has been the responsibility of the individual railroads. Many of the provisions in the RW MSB, draft MBO, and EBO address a number of personnel issues (e.g., age, responsibilities) which could provide a starting point for evaluating maglev system personnel qualifications and staffing levels. In addition, Amtrak and FAA requirements provide a baseline to develop personnel qualifications and staffing levels.

The maglev system operators should develop a program for on-board train operators that complies with the certification program for locomotive engineers specified in 49 CFR, Part 240, and develop an alcohol and drug control program which meets the FRA policy in 49 CFR, Part 219.

In addition, for U.S. application, consideration should be given to:

- Reviewing the Amtrak requirements for personnel qualifications and staffing levels to determine their applicability to maglev central control and on-board personnel.
- Reviewing the FAA certification requirements for aircraft pilots and other flight crew members described in 14 CFR, Parts 61 and 63, to determine potential applicability, particularly in terms of minimum hours of operating experience, to maglev train operators.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, should provide additional information for FRA consideration in determining the U.S. regulations or guidelines that may be appropriate for maglev operating and on-board service personnel qualifications and staffing.

8.2 TRAINING

For the Florida Maglev Demonstration Project, Transrapid technical staff experts will provide training for operations and maintenance personnel. Training should be conducted for all operations personnel in normal and emergency procedures before maglev operations begin. Maintenance training should include proper inspection, testing, and maintenance procedures. All new employees should be trained before they begin work, and refresher training should be provided periodically. Training exercises can provide a means to evaluate the knowledge and skills of personnel for normal and emergency procedures.

8.2.1 Safety Concerns

Maglev system personnel who are unaware of or who do not follow proper operating and maintenance procedures may cause injury to passengers and damage to maglev system equipment. For example, a train crew member who attempts to close vehicle doors while persons are still boarding could cause passenger injury. Maintenance personnel who fail to properly inspect and repair equipment may contribute to unnecessary hazards.

Unless the maglev train crew is properly trained, they may not be able to recognize emergency situations. Moreover, if central control staff and train crew personnel do not adequately respond to an emergency by carrying out the appropriate procedures or do not know where to locate or how to operate emergency equipment, passengers may be injured or existing injuries or conditions aggravated.

8.2.2 German Safety Requirements

Chapter 9, Operations Control Equipment, of the RW MSB safety requirements specifies that the central control facility be continually occupied to the extent necessary by professionally trained, suitable, and competent personnel.

Chapter 12, Rescue Plan, requires that the on-board train attendants be trained in first aid procedures and be demonstrably and repeatedly trained in the means of rescue. Chapter 12 also requires that periodic rescue exercises be conducted, particularly for rescue operations involving unforeseen stops between designated safe stopping places.

The draft MBO requires that personnel be tested before they perform their duties independently to ensure that they possess the necessary knowledge and qualifications. The maglev system operator is then required to continually monitor the employees to ensure that they retain their knowledge and qualifications.

Records (i.e., examinations, tests, and monitoring documentation) must be kept as proof.

The EBO requires that operations officers, including "tractive unit drivers" (i.e., train operators), supervisors, dispatchers, and inspectors, be adequately trained to perform their duties according to regulations. Appropriate assurance is required that these persons possess the necessary knowledge and skills. Finally, personnel must pass a test and demonstrate their ability to drive a tractive unit before they are permitted to operate it alone.

8.2.3 Applicable U.S. Safety Requirements

49 CFR, Parts 217 and 218, require that each railroad instruct its employees in operating practices and rules.

Part 220.25 requires that employees who use radios must be provided with a copy of the railroad radio communication rules and instructions for their proper use.

Part 240 includes requirements relating to the education, testing, and operational monitoring of locomotive engineers. Part 240.123 requires that initial and continuing education be provided to engineers in the following subject areas: personal safety, operating rules and procedures, mechanical condition of equipment, methods of safe train handling, and relevant Federal safety rules. Parts 240.125 and 240.127 contain requirements for testing engineers: periodic written testing in the five subject areas, and testing of knowledge and applied performance skills. Finally, Part 240.129 requires that the performance of certified engineers be monitored; each engineer must be given at least one unannounced test each year.

Amtrak conducts training programs for employees which include operating, maintenance, and emergency procedures. In addition to locomotive engineer training, Amtrak provides instruction to conductors and other on-board personnel, as well as dispatchers.

Each new Amtrak employee attends a 15-day new-hire training program, which includes operating rules, first aid, equipment, assisting the handicapped, and safety. An examination is given. As part of the training program, Amtrak includes a 4-hour "Emergency Situations" training course [34] for conductors, assistant conductors, and on-board service personnel. This course provides initial employment and annual refresher training, defines employee responsibilities, and covers different types and locations of emergency situations, as well as proper actions to take. The course consists of lecture/discussion, audio-visual, role play, and hands-on training.

Amtrak has also produced a pilot training program for tunnel and evacuation emergencies to provide orientation to non-Amtrak and non-railroad employees [35]. The scope of this program is limited to Amtrak routes through CSX territory with tunnels that are at least 300 m (1,000 ft) long. It is a familiarization program (Train-the-Trainer) rather than "How-to" training. The program consists of classroom training augmented by videotapes [36] and handouts, including Amtrak's Emergency Evacuation from Amtrak Trains procedure booklet [23].

The UMTA emergency preparedness guidelines documents [12 and 13] contain extensive recommendations for transit system and outside response organization personnel, as well as passenger awareness education. These guidelines note that only after adequate training can personnel be expected to effectively carry out an emergency plan and make optimum use of facilities and equipment.

NFPA 130 [20] requires that emergency plan training be provided for system and participating agency personnel. Exercises and drills must be conducted and critiqued at least twice a year. The emergency personnel response must be critiqued after each actual emergency.

The International Society of Fire Service Instructors (IFSTA) has recently published a training manual for emergency response personnel that includes a chapter on extricating passengers from a train. [37]

8.2.4 Discussion/Recommendations

Although Chapter 7, Design, Production, and Quality Assurance of Mechanical Structures, specifies training requirements for central control personnel, the only training provision for the on-board train crew in the RW MSB is the Chapter 12 requirement that train crew attendants receive training in first aid and rescue. However, the EBO and draft MBO specify appropriate training requirements for on-board employees (including the locomotive engineer) in normal train operations.

For U.S. application, maglev system operators should develop a training program that complies with the requirements in 49 CFR, Part 240, for the locomotive engineer certification program, as well as develop the appropriate training program for on-board train operators.

In addition, consideration should be given to:

- Reviewing Amtrak training programs for operating and maintenance procedures including classroom instruction and hands-on training to assist in evaluating training programs to be used by the maglev system operator.
- Requiring that the maglev system operator develop a training program which describes the content and methods used to train central control personnel, on-board train attendants, and other personnel, as appropriate. This training program should include equipment familiarization, as well as normal and emergency procedures.
- Developing criteria, for emergency training for maglev system personnel, using the information in Amtrak training materials, the UMTA emergency preparedness guidelines, NFPA 130, and IFSTA as a baseline.

- Requiring that the maglev system operator submit to the FRA for evaluation, an emergency preparedness plan which includes its training program for operating and emergency response personnel.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, should provide additional information for FRA consideration in determining the U.S. regulations or guidelines that may be appropriate for maglev system personnel training.

9. OPERATIONAL ENVIRONMENT

The Transrapid maglev system uses magnetic forces to levitate and propel the vehicle along the guideway. The electromagnetic suspension technology (EMS) uses vehicle-mounted electromagnets to generate attractive forces under the guideway that raise the main vehicle body up off the guideway.

The initial Transrapid train configuration proposed for the Florida Maglev Demonstration Project consists of five sections: four sections accommodating 98 passengers each and a separate section for containerized baggage. Up to three sections, depending on the length of the platform, can be added to increase capacity, as in a proposed application for California and Nevada.

The majority of maglev guideways constructed are expected to consist of elevated sections. Elevation of the guideway is utilized to eliminate grade crossings, discourage intrusion, and minimize the impact on the local environment, residences, and businesses. Portions of the elevated guideway could cross over wetlands, woodlands, deserts, farms, major roads, and railroad tracks, depending on the local environment. Route alignments are planned to minimize disruptions to residential areas and, where possible, to utilize easements along power transmission line rights-of way and highway corridors.

A climate control system will provide a protective and comfortable environment for passengers within the interior of the vehicle. For the Florida Maglev Demonstration Project, the exterior environment is expected to be hot, humid, and subject to frequent thunderstorms.

This section addresses the following environmental functional areas:

- Electromagnetic Interference and Electromagnetic Compatibility (EMI/EMC)
- Electromagnetic Field (EMF) Emissions
- Shared Right-of-Ways/Intrusion
- Route Alignment
- Lightning/Electrostatic Discharge
- Exterior/Interior Noise

9.1 ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY (EMI/EMC)

Electromagnetic fields (EMF) and electromagnetic (EM) radiation over a broad range of frequencies are associated with various electrical power facilities and equipment, communication systems, and office or household devices. At low frequencies (60 Hz) and long wavelengths, the effects of electric and magnetic fields on objects and people may be considered separately. At higher frequencies and shorter wavelengths, electric and magnetic fields are coupled as electromagnetic radiation.

This section discusses the effects of EM radiation on the interactions between electrically powered subsystems. The potential harmful physiological effects on humans and animals of EMF emissions are discussed in Section 9.2, Electromagnetic Field (EMF) Emissions.

9.1.1 Safety Concerns

Failure-free operation of safety-critical electrical and communication systems in the presence of EM radiation is essential to ensure safe operability. Therefore, electromagnetic interference and compatibility should be examined from two perspectives: (1) mutual compatibility of safety-critical components and subsystems within the maglev system and (2) interference and compatibility with systems external to the maglev system.

Electromagnetic energy radiated into the environment may affect other susceptible systems. Inadvertent, undesirable effects of electromagnetic energy emitted by a system on other systems or subsystems are known as electromagnetic interference (EMI). Individual safety-critical subsystems subjected to high levels of EMI must be able to function without causing other system failures (internal and external) resulting from high levels of interference. Likewise, any electrical safety-critical system having several subsystems must continue to function (i.e., must not fail or fail in a safe manner) in spite of electromagnetically generated energy emitted from other system components. This electromagnetic compatibility (EMC) can be ensured by requiring equipment to limit generation of EMI to levels below established thresholds and by requiring that same equipment to operate in an environment where other equipment generates interference up to the threshold levels.

EMI/EMC considerations for maintaining safe hover are addressed in Section 3.3, Levitation/Lateral Guidance. However, EMI/EMC of other safety-critical vehicle systems and with the external environment must also be considered. Electromagnetic radiation from the maglev system could directly affect public safety by disrupting communications or control systems external to the system; conversely, radiation from the external environment could disrupt internal system operation.

9.1.2 German Safety Requirements

Chapters 1, System Properties, Especially Safe Hovering, and 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge, of the RW MSB safety requirements address the effects of EMI/EMC on safe hover. Chapter 10 also requires that design, construction, and operation of maglev trains prevent impermissible electromagnetic emissions into the environment. The RW MSB requires formulation of an EMC plan that includes: effects from the environment that can be expected under proper operating conditions; modularly structured representation of the interaction between the safety relevant systems, with identification of disruption sources and "drains" (i.e., loads); conditions under which the safety records are applicable without electromagnetic effects; specified breakdown intervals for safety-relevant and non-safety-relevant systems or subsystems; EMC measures adopted (e.g., shielding plan and overvoltage limitation); and a review of their effectiveness. However, the EMC plan was not available for review for this report.

Chapter 10 also cites DINs VDE 0873, VDE 0875 for radio interference, E DIN VDE 0839, VDE 0843, VDE 0847, and VDE 340 839 for immunity to interference (compatibility). The RW MSB includes two notes on radiated interference values which concern noise signals and measurement.

9.1.3 Applicable U.S. Safety Requirements

The system supplier is responsible for coordinating both internal and external electromagnetic compatibility. Internal compatibility requires compliance with specification developed by the system integrator, while compatibility with external systems entails compliance with requirements of other authorities, e.g., the Federal Communications Commission (FCC) [38] and telephone companies [39].

The FRA does not currently have any regulations pertaining to EMI/EMC but UMTA has done research related to radiated electromagnetic emissions of rail transit vehicles [40, 41, and 42]. This research cites a number of existing standards relating to EMI including Military Standard (MIL-STD) 461B [43], American National Standards Institute Society (ANSI) Standard C63.4 [44] and International Electrical Engineers (IEEE) Standard 302-1969 [45], but concluded that the standards provided for testing only stationary objects and did not provide for testing moving vehicles on rails. As a result, UMTA issued a suggested test procedure, adapted and extended from the existing standards, which can be applied to measure radiated emissions from a moving rail transit vehicle under typical operating conditions. [42].

The FCC has the authority to curtail operation of any system with emissions that interfere with the environment. 47 CFR, Telecommunications, Part 15, Radio Frequency Devices [39], contains FCC regulations for Radio Frequency (RF) interference and compatibility. Part 15.3 defines incidental radiators as devices that generate RF energy although not designed to do so (e.g., dc motors, switches), and unintentional radiators as devices that generate RF energy for use within the device but are not intended to emit RF energy by radiation or induction.

Part 15.5(c) states that an operator of a device that causes harmful interference must cease operations when notified by an FCC representative and is prohibited from operation until the harmful interference is corrected.

Parts 15.13, 15.15, and 15.17 call for "good engineering practice" to reduce emissions and to limit equipment susceptibility to emissions from authorized radiation sources.

9.1.4 Discussion/Recommendations

The RW MSB requirements address EMI/EMC hazards to safety relevant-systems by requiring the prevention of failures and breakdowns from electromagnetic influences from the environment and components inside the system. Where this is not possible, measures must be taken to prevent impermissible breakdowns and failures. The RW MSB requirement for the preparation of an EMC plan provides a means to determine that these measures are comprehensive and can be verified. Although the EMC plan elements specified in Chapter 10 are appropriate, a judgment on EMC hazards cannot be completed until the EMC plan is prepared by the manufacturer for the specific operating location of the system.

The contents of the German standards (i.e., radio interference and immunity to interference) cited in Chapter 10 appear to be consistent with the FCC requirement in 49 CFR, Part 15 that equipment emissions not cause harmful interference with other systems. However, a detailed review of the German standards, as cited in the RW MSB, was beyond the scope of this report.

The procedures used at Emsland to measure radiated emissions of the Tranrapid vehicle are similar to the UMTA recommended procedure; initial indications are that there are not any excessive emissions that would cause interference either in Europe or in the United States. However, a final determination cannot be made until the results of the tests at Emsland are examined in detail. The German data should be compared with measurements of radiated emissions from U.S. rail transit vehicles and with background measurements made along proposed maglev routes or existing electrified railroad routes. The FRA and the FCC will then be able to use these data to determine what requirmemts for limiting radiated electromagnetic emissions will be required for U.S. maglev system application.

In addition to the RW MSB EMC requirements, the FRA should consider the following items to ensure EMI/EMC safety for U.S. maglev systems:

- Require that the maglev system manufacturer/operator comply with the FCC requirements in 49, CFR, Part 15 or demonstrate equivalence.
- Review the EMC plan for the specific local operating environment.
- Review the results of the Emsland tests for the Transrapid vehicle to ensure that worst case conditions were included in the measurements, and recommend additional tests if appropriate.

The results of the analysis of foreign safety requirements (e.g., DINs, UIC) and two other research studies which are currently underway will provide additional information for FRA consideration in determining the regulations or guidelines appropriate for ensuring EMI/EMC maglev safety.

9.2 ELECTROMAGNETIC FIELD (EMF) EMISSIONS

Common sources of EMF in the United States and worldwide are power generating stations, power distribution and transmission lines, communication facilities, home electrical appliances, and office devices. In addition, the natural environment is a source of background levels of both steady (ac) and variable (dc) electrical and magnetic fields, and of electromagnetic radiation [46, 47, and 48].

Sources of EMF emissions from the electromagnetic suspension (EMS) type maglev system (primarily low-frequency alternating electric and magnetic fields) include the levitation, propulsion, and guidance magnets on the guideway, power generation and distribution substations, switching segments, and the central control facility [49, 50, and 51].

9.2.1 Safety Concerns

Although no direct evidence exists that specifically links EMFs to adverse health effects, a number of recent studies have identified potential safety concerns involving exposure to EMFs [46, 47, and 48]. Of particular concern are the potential effects of magnetic fields at extremely low frequency (ELF), ranging from 0 to 300 Hz, as defined by the International Non-Ionizing Radiation Committee of the International Radiation Protection Association (IRPA/INIRC) [52] including power lines in the United States (60 Hz) and Europe (50 Hz). At such low frequencies, the electric and magnetic fields caused by alternating currents can be considered separately.

The electrical properties of the human body are such that external electric fields can be attenuated substantially upon penetration (by factors of roughly 10 million). Also, metal walls, fences, and enclosures can effectively shield people from both dc and ac electric fields. However, because the human body is permeable to dc and ac magnetic fields, the health effects of magnetic fields are a greater concern. Defining the nature and severity of ELF/EMF potential or suspected health hazards is difficult, given the diversity and complexity of reported biological responses, e.g., hormonal, reproductive, immuno-suppressive, and heart rate changes. Potential adverse effects include various types of cancer, depressed melatonin levels, and shifts in circadian rhythm that may cause fatigue and affect human alertness and reaction time.

Because of similarities in power generation and distribution, the safety impact of EMF emissions from the EMS type of maglev system is presently considered to be similar to that of other electrified urban and intercity transportation systems and facilities that also utilize electrical power collection and delivery. Research is in progress to document and compare these EMF levels and characteristics [49]. Field levels and configuration, location, and frequency characteristics generated by the propulsion, levitation, and guide electromagnets used by the EMS maglev system will be compared with those of exisitng light and heavy rail systems (i.e., overhead catenaries, pantographs, third rail, and power switching and conditioning systems).

U.S. railroad systems must comply with Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) safety requirements (see Section 9.2.3). However, there is currently not enough knowledge about EMF health hazards to issue final regulations or guidelines limiting exposure to EMFs for the following reasons:

- Specific electric and/or magnetic field exposure characteristics that could be hazardous are unknown.
- It is difficult to separate effects due to an individual's EMF exposure history due to artificial sources from other changes in the earth's magnetic field ($\leq$1 G), such as those induced by solar activity (magnetic storms). The human body also generates EMF from natural bio-activities and responds to external EMFs with induced electric and magnetic fields.

- The specific mechanisms by which EMF interacts with biological systems are not yet well understood and have not been established, although they are under active investigation.
- It is unclear if any adverse bio-effects discovered would be reversible, transient, or permanent, and how and to what extent chronic or acute EMF exposures could affect maglev personnel and passengers, or the public.

9.2.2 German Safety Requirements

Chapter 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge, of the RW MSB safety requirements document, addresses hazards to operations, safety-relevant subsystems, and persons primarily caused by lightning discharges, electrostatic discharges, and EMI. Therefore, operational safety issues of EMI/EMC concerning vital subsystems, as opposed to operators and public health and safety issues, are the main focus of this chapter. Because the RW MSB considers the potentially adverse effects on implanted heart pacemakers (and other electronic or magnetic implants) to be an EMC/EMI issue, Chapter 10 addresses these effects in the following manner:

- "High speed maglev trains must be built and operated in such a way that no impermissible electromagnetic effects are emitted into the environment or the interior of vehicle and buildings."
- No known direct hazard to persons exists "if the emissions satisfy the technical norms."
- "No special requirements" are necessary for heart pacemakers.
- The boundary around the maglev installation which pertains to "environment", as opposed to the "system" (i.e., the interface area), has not been defined.

As cited in the RW MSB, Part 1 of DIN VDE 0848, Hazards from Electromagnetic Fields [50], contains definitions and prescribes EMF test equipment and measurement and calculation procedures. Part 4 includes limits for protecting persons in the frequency range of 0 to 30 kHz. This range is much broader than the ELF portion defined by IRPA/INIRC [52] (0 to 300 Hz), and includes the Voice Frequency (VF) range (.3 to 3 kHz) and the Very Low Frequency (VLF) portion of the electromagnetic spectrum (3 to 30 kHz). The IABG report on stray magnetic fields and electromagnetic radiation measurements on TR07 [51] presents results extending over a broader electromagnetic spectral region (up to 3.5 GHz), which includes the RF and Microwave (MW) portions, as well.

Part 4 of DIN VDE 0848 also addresses both direct and indirect EMF effects on healthy people. "Direct" effects involve exposure of persons to the EMF, while "indirect" effects are those due to exposure of persons as a result of approaching or touching electrically conductive objects that generate EMF voltages. Requirements for those persons who need special protection (e.g., those with a heart pacemaker or other electronic implants or aids) are still "in preparation."

Specific electrical field strength limits in the 0 to 10 Hz range for direct effects on healthy people, as specified in Part 4 of DIN VDE 0848, are 40 kV/m rms (root mean squared[2]) and 60 kV/m peak value; however, for short-term exposure (not more than 2 hours per day), limits of 1.5 times higher are permissible. These limits are not applicable to TR07, since this low frequency end of the EMF spectrum does not contain the maglev network power frequency (50 Hz and harmonics) nor the control frequencies (0 to 250 Hz) which vary with speed.

Part 4 of DIN VDE 0848 indicates that the corresponding direct effects limits for magnetic fields from 2 Hz to 30 kHz vary inversely approximately with the .4 power of frequency: the higher the frequency, the lower the exposure limits. Limits for direct effects at 0 to 2 Hz have not yet been established, nor have magnetic field limits for indirect effects for frequencies from 0 to 30 kHz. DIN VDE 0848 noted that limits for indirect effects are "in preparation."

The draft MBO and EBO requirements do not address any health and safety issues caused by occasional (passengers) or chronic (operating personnel) EMF exposures, and are therefore not relevant to this subject area.

9.2.3 Applicable U.S. Safety Requirements

In general, U.S. railroads are required to comply with applicable EPA and OSHA requirements. Because of limited knowledge, neither the EPA nor OSHA have promulgated safety requirements limiting public or occupational exposure to EMF. The FRA, in cooperation with the EPA and the Department of Energy (DOE), initiated an extensive multi-year research program to define the EMF characteristics for maglev and other competing high-speed rail systems proposed for U.S. applications (see Section 9.2.4).

The NFPA National Electrical Code (NEC, NFPA 70) [21] requires utilities to design transmission lines in a way that limits grounding currents from induced fields in the largest moving vehicle to less than 5 mA. Other trade and professional associations (e.g., IEEE) are currently studying EMF safety issues.

The Center for Medical Devices and Radiological Health, within the Food and Drug Administration (FDA), which regulates the safety of home and office electrical devices, has issued a labeling guideline for medical devices emitting either or both static and time-varying magnetic fields above .5 mT (5 G). Posted warnings are required to protect persons with pacemakers or other susceptible implants from magnetic resonance imaging (MRI) devices that exceed these field levels. Reference 53 reviews existing and proposed exposure guidelines for dc (i.e., stable polarity) and time varying magnetic fields, as well as their rationale. Certain types of cardiac pacemakers and metallic implanted prosthetic devices, as well as magnetizable tools, are susceptible to steady magnetic fields, such as those associated with superconducting, EDS (repulsive) maglev systems. Recommended exclusionary warnings posted now vary between 5 G and 10 G, but the National Council for Radiation Protection

(NCRP), Measurements Scientific Committee 67 has not yet issued guidelines for users of prosthetic devices.

In 1989, the Florida Department of Environmental Regulations established standards, which were codified in 1990, for electric and magnetic fields from high voltage (69 KV and above, including substations) transmission/distribution power lines (see Table 9-1). These ac magnetic field strengths are lower than the ambient static (dc) geomagnetic fields of about 500 to 700 mG; however, power line ac electric fields are much higher than natural fair-weather electric potential differences of 100 to 300 V/m, though exceeded during lightning (electric storm) discharges.

To date, Florida and New York are the only states to issue interim limits on magnetic fields along power line right-of-ways. (As shown in Table 9-1, the Florida limits range from 150 to 250 mG, and the limit in New York is 200 mG.) These states and five others (Minnesota, Montana, New Jersey, North Dakota, and Oregon) have issued regulations limiting electric fields within and at the edge of the right-of-way for power lines (see Table 9-1). The table indicates that the higher the power line voltage, the lower the currents and associated magnetic field levels. Several states (including California, Nevada, and Texas, which are considering maglev or electrified high-speed rail projects) are also moving in this direction [55].

In 1990, the IRPA/INIRC published interim EMF guidelines [52] (see Table 9-2) for electric power frequencies (50/60 Hz) based on earlier World Health Organization findings. These interim guidelines refer to public and occupational exposure to EMF effects, assuming "whole body" induced currents which cause potential bio-effects. Lower exposures have not been proven to be safe and are the subject of ongoing research.

The United Kingdom National Radiation Protection Board has adopted 20 G at 50 Hz rms for public and occupational exposure levels. The German industry practice limits the EM field to 50 G at 50 Hz

Table 9-1 Existing State-Level Transmission Line Electric and Magnetic Field Limits*

AGENCY	JURISDICTION	60-Hz ELECTRIC FIELD LIMIT, kV/m — Within ROW	60-Hz ELECTRIC FIELD LIMIT, kV/m — At Edge of ROW	60-Hz MAGNETIC FIELD LIMIT, mG — At Edge of ROW	COMMENTS
Florida Dept. of Environmental Regulation (1989)	69 kV and above, including substations	8 (≤230 kV) 10(500 kV)	2	150 (≤230 kV) 200 (500 kV) 250 (d.c. 500 kV) (a)	Codified regulation adopted after a public rulemaking hearing in 1989
Minnesota Environmental Quality Board (1976)	200 kV and above	8	None	None	Not codifed as formal regulation
Montana Board of Natural Resources and Conservation (1984)	Above 69 kV, with exception for lines 230 kV and below that are 10 miles or less (b)	7(c)	1 (d)	None	Codified regulation adopted after a public rulemaking hearing in 1984
New Jersey Commission on Radiation Protection (1981)	No formal transmission line routing process	None	3	None	Used only as a guideline for evaluating complaints
New York State Public Service Commission (1978 for E field) (1990 for B field)	125 kV and above and 1 mile or longer, or 100-125 kV and 10 miles or longer	11.8 7 or 11 (c)	1.6	200 (≤345 kV) (e)	Explicitly implemented in terms of a specified right-of-way width
North Dakota Public Service Commission	115 kV and above	9	None	None	Informal requirement
Oregon Energy Facility Siting Council (1980)	Above 230 kV, more than 10 miles, and routed through two or more political subdivisions	9	None	None	Codified regulation, adopted after a public rulemaking hearing in 1980

* Applied on a case-by-case basis unless otherwise noted

Notes:
(a) d.c. = double circuit
(b) Exclusions/exemptions not specified
(c) At road crossings
(d) Landowner may waive limit
(e) Interim standard

Source: Adapted from W/L Associates Compilation, Reference 55

Table 9-2 IRPA/INIRC Recommended 50/60-Hz EMF Exposure Limits, 1990

EXPOSURE CHARACTERISTICS	ELECTRIC FIELD STRENGTH, kV/m	MAGNETIC FLUX, mT (a)
Occupational		
Whole Working Day	10	0.5
Short Term	30 (b)	5 (c)
For Limbs	--	25
General Public		
Up to 24hr/day	5	0.1
Few hours/day (d)	10	1

NOTES:

(a) To convert mT to G, multiply figures by ten; to convert mT to mG, multiply by 10,000.

(b) Short-term occupational exposure to rms electrical field strengths between 10 and 30 kV/m is permitted provided the rms electric field strength does not exceed 80 kV/m for the whole working day.

(c) Maximum exposure duration is 2 hours per working day.

(d) These values can be exceeded for a few minutes per day, provided precautions are taken to prevent indirect effects.

Source: IRPA/INIRC, Reference 52

(based on a graphic extrapolation. Other countries have adopted similar interim guidelines for power frequency EMF exposure limits.

9.2.4 Discussion/Recommendations

In 1990, the FRA established cooperative research programs with the EPA and the DOE Argonne National Laboratory (ANL) to investigate the potential health effects associated with maglev technolgies. These programs will evaluate the health impact of EMF emissions from transportation systems by comparison with other home and work environments, and will conduct laboratory experiments involving maglev-like field exposures of cells and animals.

Comprehensive measurements and analyses of the magnetic fields created by the Transrapid TR07 maglev vehicle and the characteristic ELF (or EMF) environments for existing and proposed electrified heavy and light rail and other mass transit systems have been initiated and findings will be the subject of future reports.

Preliminary results for the EM field measurements performed under contract to the FRA show that magnetic fields of 10 to 300 mG exist in the Transrapid TR07 vehicle, about 50 mG near the guideway, and 10 mG at the periphery of electric power substations and stations (which are within fenced perimeters). The average magnetic field inside the vehicle is largest near the floor and below 50 Hz (100 mG above the floor to 20 mG at head level). Magnetic fields are higher in the passenger area (about double) than in the train operator cab in the passenger area. These results indicate that average magnetic fields, at and near, the maglev subsystem locations are no higher than those typical of household appliances, power distribution and transmission lines, and common occupational environments. Existing German data on low frequency and static stray magnetic fields for the TR07, at 10 to 20 cm (4 to 8 in) from the levitation, propulsion, or guide magnets [51], are below 10 to 20 G, but are as high as 50 G for the stationary vehicle (largest during hover) and below 32 G for the moving vehicle. A forthcoming report will present the results of a detailed comparison of the German and U.S. EMF data measurements.

Although the variation of magnetic field levels near the magnets, depending on vehicle speed is documented, in-vehicle TR07 fields as a function of location and speed are not reported in Reference 51, nor are their health and safety implications discussed. An early 1978 study on the TR05 (IVA Train) concluded that there was no hazard of interference with pacemakers in the passenger areas and on the train [54]. (Note: Documentation submitted as part of the MTI Proposal for the Florida Maglev Demonstration Project stated that no interference was observed for two pacemaker types tested on the TR06, on a seat and on the cabin floor, for all operating conditions.) However, it is not clear to what extent and in what respects the TR07 prototype and the actual revenue service maglev vehicle proposed for the Florida Maglev Demonstration Project differ in EMF intensities and frequencies from either TR05 or TR06. In addition, no measurements were reported either in the central control facility or in other areas (i.e., transformer yard, wayside stations) where workers with electronic implants might be exposed to higher EMF levels. Since preliminary U.S. measurements for the TR07 vehicle indicate that the intensity of magnetic and electric fields is within the range typical of EMF emissions for home and office electrical devices, posted warnings within or near the maglev may not be needed. However, for U.S. application, the effects of transients and complex frequency contents/ characteristics should be investigated and proven safe by the maglev system developer and system operator.

The results of current research will provide baseline data on EMF emission characteristics for comparing maglev with other proposed high-speed rail and mass transit technologies, with existing systems, and with urban home and office EMF environments.

The National Electrical Code (NFPA 70) imposes a de facto limitation on E field gradients over roadways, or electrified rail beds of 7 to 8 kV/m, and could also apply to maglev and high-speed-rail power lines. However, these requirements are not appropriate for vehicle systems, since moving levitated vehicles are not grounded and the electrical fields vary with power levels, speed, acceleration level, braking mode, and vehicle orientation.

In addition, German authorities have recognized the importance of potential EMF effects on human health and safety; a study has been performed that summarizes the status of these research findings [56].

The EMF safety issues addressed specifically in Chapter 10 of the RW MSB are limited to requiring compliance with DIN VDE 0848, sections of which are still "in preparation." (Note: Part 4 of DIN VDE 0848 also refers to DIN 40 200 and DIN VDE 0870, Part 1.) The vulnerable segment of personnel (e.g., with magnetizable tools), passengers, and the general public (e.g., persons with pacemakers, magnetizable steel implants, prostheses, braces, wheelchairs) has not yet been defined, and would depend on the characteristics of the magnetic field emitted.

For U.S. application, consideration should be given to:

- Requiring that the maglev system developer comply with the existing interim IRPA/INIRC and Florida state limits on public and occupational exposures to ac (at 60 Hz power frequency and harmonics) electric and magnetic fields, until the maglev EMF safety research is completed, and/or national EMF safety requirements are established. The Transrapid TR07 measured EMF levels appear to comply with existing state [Florida] requirements, as well as the interim IRPA/INIRC guidelines.

- Requiring that the effects of transients and frequency be investigated and proven safe by the maglev system developer and system operator.

- Issuing, in cooperation with the EPA and OSHA, an interim policy statement for the maglev system developer and operator that specifies the allowable EMF exposure levels for personnel, passengers, and the public.

- Defining the maglev system facility boundaries in relation to the public environment so that EMF warning signs can be posted, if and where necessary (e.g., near or within power substations or within the central control facility), to alert vulnerable passengers or employees.

- Providing, in cooperation with the FDA Center for Medical Devices and Radiological Health, guidance to the maglev system operator for posting warning or exclusionary signs, if and where needed, to protect individuals vulnerable to EMF.

- Requiring that the effects of transients and frequency be investigated and proven safe by the maglev system developer and system operator.

9.3 SHARED RIGHT-OF-WAYS/INTRUSION

The maglev guideway right-of-way may be shared with other transportation modes, such as conventional and high-speed railroads, interstate highways, and local and state roads. Pipelines, high-voltage power transmission lines, and waterways may also be co-located near the guideway. Shared right-of-ways and corridors offer economic advantages and in some locations may be the only option available for securing a viable maglev right-of-way.

9.3.1 Safety Concerns

A particular concern associated with shared right-of-ways is the impact of an event on the adjacent system that structurally affects or intrudes into the operational envelope of the maglev system. These events include maglev vehicle impact with debris or objects which fall or are thrown onto the guideway; intrusion by vehicles (rail or automotive), fallen power transmission lines, pipeline ruptures or fire; and electromagnetic and electrical interference between operating systems. Such events are hazards which must be detected and prevented whenever possible.

Guideway intrusion by unauthorized persons is another concern. Unauthorized persons who intrude onto the guideway could damage maglev guideway components and could be hit by the maglev vehicle. Unauthorized persons may also damage or remove equipment located at guideway stopping places (i.e., access/egress points); this could delay personnel response in an emergency and hinder passenger evacuation.

9.3.2 German Safety Requirements

The only German safety requirement that specifically addresses the safety of shared right-of-ways is the EBO requirement for protection of railroad grade crossings.

The RW MSB addresses intrusion (i.e., obstructions) prevention in Chapter 1, System Properties, Especially Safe Hovering and Chapter 9, Operational Control Equipment.

Chapter 1 requires that the possiblity of obstructions on or along the guideway, through which the clearance limits are violated be ruled out; elevating the guideway is indicated as one approach. Chapter 1 also requires that the distance between the guideway and buildings or trees must be determined as a function of the speed and environmental situation.

Chapter 9 contains safety requirements for detecting obstructions on the guideway. This chapter states that the guideway is operationally ready only when the guideway elements are free of obstructions and precautions have been taken to prevent obstructions from getting onto the guideway. Chapter 12, Rescue Plan, requires that designated stopping places be protected against unauthorized access.

The draft MBO requires that "aid stops" (i.e., designated stopping places) be safeguarded against unauthorized boarding.

The EBO prohibits persons from damaging railroad installations, operating facilities or vehicles, opening gates without permission, causing obstructions to traffic, or otherwise engaging in activities which disrupt or endanger operations.

9.3.3 Applicable U.S. Safety Requirements

The FRA safety requirements do not address shared right-of-ways or right-of-way security. Only state and local authorities prescribe railroad grade crossing protection.

U.S. railroad practice is not to fence right-of-ways except where special protection is warranted (e.g., to protect against intrusion by persons in urban areas or by animals from adjacent farmland). The AREA Manual for Railway Engineering [9] contains specifications for fences but does not indicate their location, except for snow fences.

9.3.4 Discussion/Recommendations

Chapters 1, 9 and 12 of the RW MSB, the draft MBO, and the EBO provide a baseline for developing requirements that could ensure the safety and security of right-of-ways in the United States.

Shared right-of-way safety and intrusion prevention are important issues associated with high-speed train operations. Several studies underway are examining safety issues associated with these concerns. Safety issues related directly to a maglev system using the same right-of-way as another mode of transportation (e.g., railroad and highway), power transmission lines, or pipelines will be identified. Risks of undesirable events involved will be assessed. The ability of state-of-art technology (e.g., sensors, barriers) to mitigate risks will also be evaluated. These studies will provide additional information for FRA consideration in further evaluating the maglev safety of shared right-of-ways and overall right-of-way security.

9.4 ROUTE ALIGNMENT

Maglev route alignment may include elevated sections of guideway through undeveloped farmland and woods, and over uplands (with water table below the surface) and lowlands (marshes and swamps, creeks and streams, and ponds). Climatic conditions (e.g., wind, rain, snow, sleet, ice, extreme heat and cold, and lightning) may further aggravate the difficulties inherent with these route alignments and can make even the most routine alignments difficult.

9.4.1 Safety Concerns

Route alignments that involve rapid grade changes or are subject to strong winds may have an impact on maglev system safety. For example, extreme heat or cold, or earthquakes could cause fluctuations in vehicle and guideway structural loads (see Sections 3.1, Structural Integrity, 4.1, Support Columns and Foundations, and 4.2, Guideway Geometry). Firm footings for guideway column foundations are necessary to maintain the structural integrity of the guideway platform surfaces.

If there is a propulsion failure, the grade of the guideway, in combination with wind forces, if not accounted for in the system design, could prevent a maglev train from reaching a station or other stopping place. In addition, provisions for emergency response personnel access and egress are necessary for guideway sections located over inaccessible areas. Safety concerns relating to shared right-of-ways and intrusion are discussed in Section 9.3.1.

9.4.2 German Safety Requirements

Chapter 1, System Properties, Especially Safe Hovering, Chapter 5, Load Assumptions, and Chapter 6, Stability Analysis (Guideway/ Vehicle), of the RW MSB safety requirements contain provisions relating to route alignment safety concerns. Chapter 1 states that areas subject to earthquakes be bypassed whenever possible; otherwise methods are described which must used to determine route alignment. It also indicates that elevating the guideway can rule out the possibility of obstructions. (See Section 9.3, Shared Rights-of-Way of this report for additional discussion of obstructions.) Chapters 4 and 5 address subsoil movement, ground pressure movement, wind stress, column location, snow/ice, and thermal forces. Sections 4.1, Support Columns and Foundations, and Section 4.2, Guideway Geometry, of this report discuss the requirements in these chapters in more detail.

The RW MSB also addresses route alignment factors that could affect emergency response and evacuation. Chapter 1 states that, depending on the topography, even if a breakdown or emergency is combined with a propulsion failure, it should be possible to formulate a stopping place plan such that, under worst case conditions, the vehicle is able to reach the next designated stopping place, provided that the vehicle was previously running within the specified speed range. Chapter 6 states that, if possible, stopping points should be provided only along straight track. Chapter 12, Rescue Plan, states that, if the alignment allows emergency evacuation without stopping places provided for that purpose, designated stopping places are not necessary. In this case, the entire guideway segment in question can be considered a stopping place. However, the RW MSB requires that the quality of the evacuation be the same on the guideway as at designated stopping places; that is, communication, firefighting, evacuation, and first aid equipment must be provided, as well as a telephone line linked to the central control center and, depending on local conditions, a third rail to be provided on the guideway to maintain auxiliary power after the train stops. Requirements relating to designated stopping places for ensuring emergency response personnel access and passenger evacuation are discussed in more detail in Section 4.4, Guideway Access/Egress, of this report.

9.4.3 U.S. Safety Requirements

49 CFR, Part 213, contains FRA requirements related to general route alignment safety. The track geometry provisions of these requirements are described in Section 4.2, Guideway Geometry, of this report. In addition, Part 213.55 specifies deviation limits for Class 6 (176 kmph [110 mph]) tangent and curved track alignment. Part 213.33 requires that each drainage or other water carrying facility be maintained and kept free from obstruction to accommodate expected water flow for the areas concerned. Part 213.37 requires that vegetation adjacent to the roadbed be controlled so that it does not become a fire hazard to track carrying structures, obstruct visibility of railroad signs and structures, interfere with railroad employees performing normal track-side duties, prevent proper functioning of signal and communication lines, or prevent railroad employees from visually inspecting moving equipment from their normal duty stations.

The AREA Manual for Railway Engineering [9] includes considerations to be used in choosing route alignment in terms of rise and fall, gradients, and curvature compensation. In addition, this manual describes culvert design requirements to ensure that water flow will not affect the trainway, as well as measures for vegetation control.

9.4.4 Discussion/Recommendations

The RW MSB safety requirements address route alignment safety in two areas: (1) topography in relation to emergency braking and (2) designated stopping places. The requirements for emergency braking and stopping places appear sufficient. Sections 3.4, Propulsion/Braking and 4.4, Guideway Access/Egress, of this report contains more discussion of these functional areas.

To prevent erosion and flooding which may affect the alignment of the maglev guideway, the maglev developer and operator should comply with the design requirements contained in 49, CFR, Part 213.33 and the AREA manual associated with drainage. In addition, the requirements contained in Part 213.37 and the AREA manual should be complied with to ensure that vegetation hazards are controlled (see also Section 7.4, Guideway Maintenance).

The results of the analysis of foreign safety requirements (e.g., DINs, UIC) and two other research studies which are currently underway will provide additional information for FRA consideration in evaluating route alignment safety.

9.5 LIGHTNING/ELECTROSTATIC DISCHARGE

Lightning is a high-voltage electrostatic discharge between an electrostatically charged cloud and the ground. A lightning strike may consist of a succession of multiple strikes, each typically lasting about 80 microseconds, with a peak current as large as 500,000 A. There may be a succession of as many as 40 such multiple strokes over a one-second period. A direct strike can be highly destructive, causing melting or shattering of the object struck, with the potential of a subsequent fire. An indirect stroke, because of the magnitude of its rapidly changing electromagnetic field, can have destructive effects on sensitive electrical/electronic equipment.

Static electrical charges are generated whenever two dissimilar materials are in relative motion to each other, e.g., an ungrounded maglev vehicle and the atmosphere. The greater the relative velocities and sizes, the larger the charges. Uncontrolled discharge of such charges can be hazardous to personnel and electrical/electronic equipment.

The effects of both lightning and electrostatic discharges can be minimized by approved methods of electrical shielding and grounding.

9.5.1 Safety Concerns

Without adequate preventive measures, lightning strikes could have critical or even catastrophic consequences for passengers, the vehicle, and the wayside power, control, and communication systems. On-board personnel and passengers could be injured by lightning penetrating the passenger compartment or other areas of the train. Lightning could also cause fire, equipment damage, or loss of safe hover. Power failure could result from damage to the power supply, power distribution, or long-stator propulsion systems. Furthermore, vehicle and guideway switch control could be lost if any part of the train communication system, which includes radio links to and from wayside stations, is disabled by lightning.

Available data indicate a much higher incidence and magnitude of lightning strikes in the United States than in Germany. For example, in central Florida, the incidence is 18 strikes per sq km per year, while in Germany it is 3 strikes per sq km per year. Germany is located in the temperate zone, where the magnitude of lightning current averages 25,000 A. Florida is located in the tropic zone, where the magnitude of lightning current averages 45,000 A.

During high-speed operations, when maglev vehicles are not in contact with the guideway, vehicles could acquire a large electrostatic charge. This could result in electric shock and injury if passengers touch the maglev vehicles before the vehicles delevitate or are grounded to discharge the static charge.

9.5.2 German Safety Requirements

Chapter 1, System Properties, Especially Safe Hovering, and Chapter 10, Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge, of the RW MSB safety requirements address protection against lightning. Chapter 10 also includes requirements for electrostatic discharge.

Chapter 1 addresses the primary threat to individuals from a direct lightning strike and the secondary threat of personal injury from system breakdown (i.e., loss of safe hover) caused by lightning. To minimize the primary threat, the RW MSB requires that the vehicle be protected by a high-conductivity path that will safely route any lightning current around the passenger compartment. Furthermore, whether the guideway is constructed of steel or concrete, a clearly defined path must exist for the lightning current from the levitation/ guidance system to the guideway and to ground. This path must be easily accessible and must include the vehicle body structure, levitation bogies, guidance magnets (or braking skids), and the air gap through which the lightning discharge passes into the guide rail, the long stator, or the guideway slide surface. The secondary threat of system breakdown (i.e., loss of safe hover) must be countered by potential equalization, shielding or line transposition, shielding of equipment, and overvoltage protection.

Chapter 10 expands on the concepts described in Chapter 1. It provides examples of measures to address direct hazards to persons, operating systems, safety-relevant systems, and property. Chapter 10 suggests a methodology for verifying that the lightning protection plan is adequate. Included are applicable standards to be used for installing and implementing protection from lightning strikes: VG 96900, VG 96901, DIN VDE 0183, and DIN VDE 0185.

In addition, Chapter 10 addresses static electric charge and its effects on persons who may come into contact with a statically charged vehicle. This chapter includes recommendations that charge levels be calculated, technical or operational measures for dissipating charges be developed, and non-metallic material be conductive, but does not include specific methods for electrostatic charge dissipation. Also included are the provisions of the following standards: DIN VDE 0100, Part 410, for protection against dangerous body currents for power installations with nominal voltages of up to 1000 V; DIN 54 345, which contains information concerning electrostatic behavior of textiles; and ZH1/200, which contains guidelines for avoiding detonation hazards caused by electrostatic charges.

Chapter 2, Propulsion Including Energy Supply, requires that substation grounding systems be connected to the guideway lightning protection system.

9.5.3 Applicable U.S. Safety Requirements

No FRA requirements exist for protecting trains against static electricity or lightning because the metallic bodies of passenger cars and their direct connection to rails through bogies and wheels eliminate lightning and static electricity hazards.

The FAA requirements for protection of aircraft against lightning are contained in 14 CFR, Part 25.581. This part pertains to lightning protection of flight critical/essential electrical/ electronic systems, both those mounted on and within an aircraft. It requires that all metallic components be properly bonded to the frame and be designed to be safe during lightning strikes, i.e., to minimize the effect of a strike or to direct the strike so it does not endanger the aircraft. FAA Advisory Circulars 20-136 (AC 20-136) and 20-53A (AC 20-53A) provide guidance for complying with these requirements.

AC 20-136 [50] provides information and references relevant to (1) acceptance criteria/protection levels, (2) protection (hardening approaches) against the indirect effects of lightning, and (3) verification methods. Hazards addressed include those caused by the indirect effects of lightning to both exterior and interior aircraft equipment, and associated wiring. AC 20-136 applies to new aircraft and equipment designs, modifications of existing aircraft or equipment, and applications of existing (off-the-shelf) equipment on new aircraft. Applicable subsystems addressed include, but are not limited to, power distribution and generating equipment, electronic and electromechanical devices, electronic engine and flight controls, as well as associated interconnecting wiring and/or cables. This document also describes, in considerable detail, the test procedure requiring specialized electrical equipment capable of typically producing a pulse of 200,000 A at a maximum rate of rise of 10^{11} A/s with specific mathematically defined waveforms. It recognizes that such tests are not always practical, and suggests an alternative, less severe regime: injection of a relatively smaller current (double exponential pulse, swept continuous wave, or damped sine wave) into the aircraft skin, and determination of the transient response of critical electronic components to a severe lightning stroke by extrapolation. It also states that a purely analytical approach is difficult to substantiate.

AC 20-53A [51] complements AC 20-136 by noting that extremities and other projections are more likely locations where surfaces of the vehicle may have to carry large amounts of energy due to a lightning strike. It also discusses in detail current characteristics for testing and analysis for both direct and indirect effects due to lightning. Although the emphasis of this document is on the protection of fuel tanks, it applies equally well to protection of sensitive electronic equipment.

Requirements for protecting wayside station communications are included in Section 6, Signal, Control, and Communications, of this report. In this regard, FAA Standard 019b [52] contains detailed guidance on lightning protection, grounding, bonding,and shielding of facilities housing electronic equipment.

NFPA 78, Lightning Protection [53], NFPA 77, Static Electricity [54], and local building codes contain requirements which could be applied to maglev guideways, stations, wayside structures, and central control facilities.

9.5.4 Discussion/Recommendations

The RW MSB lightning protection requirements generally conform with well-established engineering practices and are therefore considered appropriate for U.S. application. To demonstrate the adequacy of the requirements, Thyssen Henschel performed a computer analysis which concluded that the functioning of individual components for the Transrapid system would not be impaired by a lightning strike. On the practical level, lightning tests, performed at the DB facility in Munich, demonstrated that all critical components continued to operate, but that some minor problems encountered remain to be addressed. To ensure that the maglev vehicle system as a whole can withstand the effects of lightning, an impulse test (simulating lightning under controlled conditions) prescribed in detail by the FAA Advisory Circulars, should be conducted for at least the first maglev production vehicle and the guideway to substantiate that all safety-critical systems can withstand the effects of both direct and indirect lightning strokes. Since the maglev vehicles are in certain ways similar to aircraft, with the added operating condition that they travel near the ground at very high speeds and are entirely computer-controlled, the FAA Advisory Circulars are considered the most appropriate existing documents for adoption, with appropriate regard for the differences in configuration of aircraft and maglev vehicles.

Although the RW MSB notes that passengers and operating personnel should not be subject to static discharge from the vehicle, it does not indicate the specific conditions under which the vehicle must be grounded to discharge a static charge.

Compliance with the requirements in the FAA Advisory Circulars 20-136 and 20-53A, the FAA Standard 019b, NFPA 77 and 78, and local building codes could provide adequate lightning and electrostatic discharge protection for maglev guideways, stations, wayside structures and installations, and central control facilities.

For U.S. application, consideration should be given to:

- Requiring that the maglev developer submit the results of an impulse test to demonstrate that the maglev system is able to resist the direct and indirect effects of a lightning stroke.
- Requiring that the maglev developer review pertinent FAA and NFPA 78 requirements and demonstrate that the RW MSB provisions are equivalent in terms of lightning protection.
- Requiring that the maglev developer review NFPA 77 requirements and demonstrate that the RW MSB provisions are equivalent in terms of static discharge protection.
- Requiring that the maglev developer indicate the conditions and methods under which the maglev vehicle will be grounded to discharge static charges.

The results of the analysis of the foreign safety requirements (e.g., DINs, UIC), as cited in the RW MSB, will provide additional information for FRA consideration in determining what modifications to U.S. regulations or guidelines may be appropriate for maglev vehicle lightning protection and static charges.

9.6 EXTERIOR/INTERIOR NOISE

Noise is measured in terms of three factors: sound-level volume (dB), tone, and duration. Unlike conventional railroad operations, the maglev train does not normally come into contact with the guideway. Accordingly, noise from wheel contact with the rail, particularly from wheel squeal on curves, is eliminated. However, maglev trains can generate noise while accelerating or braking, and electrical equipment (e.g., motors, air condenser fans) may generate noise even when the train is stopped. Moreover, at high-speeds, aerodynamic noise sources include air turbulence, structural radiation from appendeges, and vibration.

Noise generation for maglev vehicles has two significant elements: exterior noise that affects persons along the wayside, and interior noise that affects occupants of vehicles.

9.6.1 Safety Concerns

Because of the nature of the maglev vehicle design, potentially unacceptable noise levels occur during operation at high speed when aerodynamic noise becomes the primary noise component.

The safety concern for exterior noise is high noise levels that potentially can physically harm abutters, maintenance personnel, and other persons at station platforms and along the guideway.

The safety concern for interior noise is high noise levels that potentially can physically harm passengers and can distract the operator and other operating personnel.

9.6.2 German Safety Requirements

Neither the RW MSB safety requirements, draft MBO, nor EBO address the impact of interior or exterior noise. Noise is being addressed by other means in the German certification process.

9.6.3 Applicable U.S. Safety Requirements

49 CFR, Part 210, covers railroad noise emission compliance regulations. This part invokes the requirements of the Environmental Protection Agency, in 40 CFR, Part 201. Sounds emitted by warning devices such as horns, bells, or whistles are exempt from these requirements.

Part 210 requires that exterior noise must be limited to 90 dB(A) measured at 30 m (98 ft) for any locomotive built after 1979. However, a footnote adds that "the purpose underlying the FRA's enforcement of these noise standards is to reduce the impact of rail operations noise on receiving properties. In some instances, measures other than the 30-meter test approach may more effectively reduce the noise levels at receiving properties; therefore, FRA enforcement efforts will focus on abatement procedures that will achieve a reduction of receiving property noise levels to less than 65 dB(A)."

For interior noise, 49 CFR, Part 229.121, lists the acceptable levels for locomotive cab noise. For example, continuous noise is defined and limited to 115 dB(A). An 8-hour time weighted standard of less than 90 dB(A) with additional conditions is required. The method of conducting noise measurements is also listed.

14 CFR, Part 25.771 specifies the FAA noise requirements for pilot compartments of "transport" aircraft. Section (c) states, "vibration and noise characteristics of cockpit equipment may not interfere with safe operation of the airplane."

The American Public Transit Association (APTA) <u>Guidelines for Rapid Transit Facilities</u> [55] contains a comprehensive discussion of both exterior and interior noise of vehicle equipment and structures (e.g., stations, tunnels). These guidelines present a series of design goals in terms of dB(A) for vehicle interior and exterior noise levels (which depend on location of the train), vehicle equipment (e.g., propulsion, full-service brake operation), and exterior noise in above-ground and underground stations and in tunnels.

In addition, UMTA has developed a guideline manual for assessing transit noise and vibration impact [56].

9.6.4 Discussion/Recommendations

From a system safety perspective, exterior noise levels are a low priority. However, since the FRA has adopted the EPA standards and has been applying them successfully, there is no reason not to apply these same requirements to maglev syustems. Noise measurements of the Transrapid vehicle from 25 m (82 ft) at 300 kmph (186 mph) are 86 dB(A), well within the EPA limits. Even if future measurements indicate noise levels in excess of 90 dB(A) at 30 m (98 ft), the FRA should consider, independent of the specific transportation technology whose noise is in question, maintaining the overall intent of these regulations to limit abutters to 65 dB(A) exposure. Thus, noise abatement measures, such as noise barriers or operational procedures, could be considered for U.S. application in meeting the overall intent of these regulations.

Although geared toward lower speeds, the APTA noise guidelines should be reviewed further to determine their applicability to maglev systems. In addition, the UMTA manual contains information on conducting noise assessment that may be applicable.

The noise signatures and impact areas for aviation-related operations are sufficiently different from those for maglev operations that the FAA exterior noise standards may not be applicable to maglev operations.

Because of the potential stress that high-speed operations may place on the maglev train operator, depending on the operator's specific duties and the level and type of automated control, interior noise levels are a greater safety concern than exterior noise levels. In addition to the current noise level allowed for the operating compartment, consideration should be given to the intent in the FAA regulation that requires noise characteristics to be conducive to safe operations. It appears that the Transrapid maglev train, as well as wheel-on-rail high-speed trains such as the TGV and ICE, does provide the operator with a quiet operating compartment conducive to safe operations and meets the current FRA noise-level requirement for operating compartments.

The results of the analysis of foreign safety requirements, as well as another study which specifically addresses noise generated by the very high speeds of maglev trains, will provide further information for FRA consideration in determining the appropriate safety requirements for maglev noise emissions.

10. FINDINGS

As noted in the introduction to this report, the regulatory process currently underway to ensure the safety of magnetic levitation transportation systems in Germany, in particular the Transrapid technology, is extensive. What is being undertaken in Germany appears to ensure an equivalent level of safety to what is expected in the United States for similar ground transportation technologies. The challenge lies in transferring the experience of other countries, in this case Germany, in their pursuit of safety, to the United States regulatory environment. For example, if the FRA chooses to develop performance-oriented regulations similar to some of those contained in the RW MSB, the implications of the criteria for enforcing such regulations must be considered.

The detailed findings of this report are listed in the discussion/recommendations portion of each section and are not repeated here. However, there are some basic points resulting from this review that are worth highlighting.

First, the RW MSB addresses many areas not normally regulated by the FRA. With little precedent to go on for this totally new concept of surface transportation, this effort deserves distinctive recognition.

Second, in addition to the RW MSB, the Maglev Construction and Operating Regulation (MBO) draft document reveals how Germany is considering adapting certain basic safety requirements found in its existing German Federal Railways Railroad Construction and Traffic Regulations (EBO). This effort at transferring existing experience in the steel wheel/steel rail mode to the magnetic levitation mode provides a good example of how the intent of some U.S. safety regulations could be transferred from the rail environment to the maglev environment.

Third, as with any new technology, the experience gained from operation is key to maintaining and enhancing safety over the life of any new project. Application of maglev technologies new to the United States will require a pre-revenue test period. This will provide the opportunity to identify and resolve any system-related safety hazards that may have been missed by the initial system safety analysis, prior to revenue operations. Monitoring of safety concerns should be required throughout the life of the project to identify and resolve any new safety issues that may develop. Operational data, as it also becomes statistically significant, will be used to recalibrate the various models and update the assumptions used to analyze safety and project maintenance requirements during the planning process. Such efforts will enhance safety while reducing unnecessary maintenance burdens on the operating system.

Finally, the FRA will now look to applying the technology specific regulations developed during the "Project Accompanying Safety Certification" (PASC) and the "Readiness for Application" processes of the German authorities to the United States and its circumstances, in such a manner as to assure an equally rigorous application of safety.

11. REFERENCES

1. Dorer, R.M. and W.T. Hathaway, Preliminary Safety Review of the Transrapid Maglev System. Prepared for Office of Research and Development, Federal Railroad Administration (FRA), U.S. Department of Transportation (U.S. DOT) by Volpe National Transportation Systems Center/Research and Special Programs Administration (VNTSC/RSPA), Cambridge, MA. Interim Report, Report No. DOT/FRA/ORD/90/09. November 1990.

2. RW MSB, High-Speed Maglev Trains Safety Requirements, Cologne, Germany. March 1991. English translation published by FRA/VNTSC/RSPA. Report No. DOT/FRA/ORD-92/01. February 1992.

3. Railroad Construction and Traffic Regulations (EBO), German Federal Railway (DB), Federal Republic of Germany. Effective May 28, 1967, 1982 edition.

4. Maglev Construction and Operating Regulation (MBO), Approval Working Group, MVP, Federal Republic of Germany. Draft. December 12, 1988.

5. Code of Federal Regulations, Title 49, Transportation, Parts 200-240. Federal Railroad Administration. Office of the Federal Register, National Archives and Records Administration. October 1, 1990.

6. Rail Passenger Equipment; Reissuance of Guidelines for Selecting Materials to Improve their Fire Safety Characteristics. [Docket No RSPC-84-1, Notice 3], Federal Railroad Administration. Federal Register, Vol. 54. No. 10, January 17, 1989, pp. 1937-1840.

7. Association of American Railroads (AAR), Manual of Standards and Recommended Practices, Various Sections and Revision Dates. Mechanical Division, Operations and Maintenance Department, Washington, D.C.

8. AAR, Field Manual of AAR Interchange Rules, January 1991.

9. American Railway Engineering Association (AREA), Manual for Railway Engineering. Volumes I and II. Washington, D.C. 1990.

10. Department of Defense, Military Standard 882B, System Safety Program Requirements. Washington, D.C. 1984. Notice 1, July 1987.

11. Code of Federal Regulations, Title 14, Aeronautics and Space, Part 25, Airworthiness Standards: Transport Category Airplanes. Federal Aviation Administration. Office of the Federal Register, National Archives and Records Administration. January, 1, 1991.

12. Hathaway, W.T., S.H. Markos, and R.J. Pawlak, Emergency Preparedness Guidelines for Rail Transit Systems. Prepared for Urban Mass Transportation Administration (UMTA), U.S. DOT, by RSPA/TSC, Cambridge, MA. Final Report, Report No. UMTA-MA-06-0152-85-1. March 1985.

13. Hathaway, W.T., S.H. Markos, and J.N. Balog, Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers. Prepared for UMTA, U.S. DOT, by RSPA/TSC, Cambridge, MA. Final Report, Report No. UMTA-MA-06-0186-89-1. August 1989.

14. Basler and Hofmann, Safety Concept for the Maglev Train, Transrapid, Analysis-Evaluation-Measures. Final Report and Appendices. Zurich, Switzerland. March 16, 1990.

15. Institute for Railroad Technology. Technical Readiness, Transrapid Magnetic High-Speed Railway, Safety of Trans-rapid System, Parts 1 and 2 (including Bibliography). Germany. Document no. GG 900924-0220. September 7, 1990.

16. Thyssen Henschel. Transrapid Revenue Service Vehicles. Technical Report, Document no. NT/2396/07/90. Germany. July 23, 1990.

17. Thyssen Henschel. Revisions for Assessment of Readiness for Application by German Federal Railway (DB). Included in Letter to Arne Bang. March 20, 1991.

18. Dommasch, D.O., S. Sherby, and T. Connolly, Airplane Aerodynamics, Pitman Publishing Corporation, New York. 1967.

19. Code of Federal Regulations, Title 49, Transportation, Part 38, ADA Accessibility Specifications for Transportation Vehicles. Department of Transportation, Office of the Secretary. Office of the Federal Register, National Archives and Records Administration. Volume 56, No. 173. September 9, 1991.

20. National Fire Protection Association (NFPA), NFPA 130, Fixed Guideway Transit Systems. Batterymarch Park, Quincy, MA. 1990.

21. NFPA, NFPA 70, National Electrical Code, Batterymarch Park, Quincy, MA. 1990.

22. DIN 5510, Preventive Fire Protection in Railway Vehicles: Part 1, Levels of Protection, Fire Preventive Measures and Certification; Part 4, Structural Design of the Vehicles; Part 5, Electrical Operating Means; Part 6, Auxiliary Measures, Function of the Emergency Brake Equipment, Information Systems, Fire Alarm Systems, Fire fighting Equipment. Standards Board for Rail Vehicles (FSF), German Institute for Standards. 1988.

23. Amtrak, Emergency Evacuation from Amtrak Trains. NRPC 1910, November 1989.

24. Amtrak, Specification for Flammability, Smoke Emissions and Toxicity. Specification No. 352, January 29, 1990.

25. Amtrak, Specification for High Performance Wire and Cable Used on Amtrak Passenger Vehicles, Specification No. 323. March 23, 1990.

26. NFPA, NFPA 101 Life Safety Code, Batterymarch Park, Quincy, MA. 1988.

27. Code of Federal Regulations, Title 49, Transportation, Part 37, Transportation Services for Individuals with Disabilities. Department of Transportation, Office of the Secretary. Office of the Federal Register, National Archives and Records Administration. Volume 56, No. 173. September 9, 1991.

28. Amtrak, NORAC Operating Rules, Second Edition. January 1, 1991.

29. Amtrak, Timetable No. 3, Schedules and Special Instructions, Revised September 9, 1991.

30. Various Railroads, General Code of Operating Rules, Second Edition, Effective October 29, 1989.

31. AAR, Standard Code of Operating Rules, Washington, D.C. Adopted January 1986. Copyright, 1985.

32. Amtrak, Manual for On-Board Service Employees (Manual A). February 1, 1990.

33. American Public Transit Association (APTA), Rail Safety Audit Program Manual, Washington, D.C. 8-14-89.

34. Amtrak, Employee Training Program: Emergency Situations, Course CSE-001. January 1985, revised November 1988.

35. Amtrak, Tunnel and Evacuation Emergencies on Amtrak Trains; Non-Amtrak Employee Orientation, Pilot Program Instructor's Guide (SAFE 015). December 5, 1990.

36. Amtrak, "Keeping on Track, Amtrak Emergency Guidelines," Videotape, 30 minutes. March 1990.

37. International Fire Service Training Association (IFSTA), Principles of Extrication, Fire Protection Publications, Oklahoma State University, Stillwater, OK. 1990

38. Code of Federal Regulations, Title 47, Telecommunications, Part 15, Radio Frequency Devices. Federal Communications Commission. Office of the Federal Register, National Archives and Records Administration. October 1, 1990.

39. Ball, W.C and C.K. Poarch, Telephone Influence Factor (TIF) and its Measurement. Paper 60-1195. Originally presented at AIEE Fall General Meeting, Chicago, IL, October 9-14, 1960.

40. Sing, F., C. Edelson, and F. Holstrom, The UMTA Rail Transit EMI/EMC Program: Overview and Summary. Prepared for UMTA, U.S. DOT by RSPA/TSC, Cambridge, MA. Final Report, Report No. UMTA-MA-06-0153-85-4. February 1987.

41. Holmstrom, F.R. and C. Edleston, Radiated Interference in Rapid Transit Systems, Volume I: Theory and Data. Prepared for UMTA, U.S. DOT by RSPA/TSC, Cambridge, MA. Final Report, Report No. UMTA-MA-06-0153-85-10. April 1988.

42. Holmstrom, F.R, Radiated Interference in Rapid Transit Systems, Volume II: Suggested Test Procedures. Prepared for UMTA, U.S. DOT by RSPA/TSC, Cambridge, MA. Final Report, Report No. UMTA-MA-06-0153-85-11. June 1987.

43. Department of Defense, Military Standard: Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference (MIL-STD 461B). Washington, DC. April 1, 1980.

44. American National Standards Institute (ANSI), American National Standard: Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 1 kHz to 1 GHz (ANSI C63.4-1980), ANSI and IEEE, New York. May 1980.

45. Institute of Electrical and Electronics Engineers (IEEE), Standard Methods for Measuring Electromagnetic Field Strengths for Frequencies below 1000 Mz in Radio Wave Propagation. Standards 302-1969. Revised and Redeignated in 1991: Field Strength in Radio Waves Propagation. Standard 291-91.

46. Office of Technology Assessment, Biological Effects of Power Frequency Electric and Magnetic Fields, U.S. Congress, Report No. OTA-BP-E53. May 1989.

47. "Pursuing the Science of EMF." EPRI Journal, Vol. 15. January/February 1990.

48. EPA, Evaluation of the Potential Carcinogeneity of Electromagnetic Fields, EPA 6-90/005B. October 1990.

49. ERM, Interim Report on Magnetic Field Testing of TR07 Maglev Vehicle and System Conducted August 1990. August 1991.

50. DIN VDE 0848: Part 1, Hazards from Electromagnetic Fields Methods for Measurement and Calculation, February 1982; Part 4, Safety of Electromagnetic Fields; Limits of Field Strengths for the Protection of Persons in the Frequency Range from 0 to 30 kHz. October 1989. German Institute of Standards.

51. IABG-TM-90027, Magnetic Stray Fields and Electromagnetic Radiation Fields of the TR07 Transrapid Vehicle. Proprietary Report. August 1990.

52. IRPA/INIRC, Guidelines on Protection Against Non-Ionizing Radiation, Chapter 6, Interim Guidelines on Limits of 50/60 Hz Electric and Magnetic Fields, Eds.: A.S. Duchene, J.R.A. Lakey and M.H. Repacholi, Pergamon Press. 1991.

These guidelines were first published as "IRPA/INIRC Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnectic Fields" were first published in Health & Physics, Volume 58, No. 1, pp. 113-122. January 1990.

53. Miller, G., "Exposure Guidelines for Magnetic Fields," American Industrial Hygienists Association Journal, Vol. 48 (12): 957-968. 1987.

54. TÜV Rheinland, "Safety Technical Evaluation of the Emission of Magnetic Fields by the IVA-Train, Especially in Consideration of the Impairment of Pacemakers," Opinion No. 947/EL 125/78, Doc. No. AG-900213-0145, by Dipl. Eng. Fischer. July 1978. Proprietary Report.

55. W/L Associates, "An Overview of International, National and State-Level EMF Levels." Prepared for the Dept. of Natural Resources, State of Maryland. July 31, 1991.

56. Institute for Electrical Accident Research, Information 2/89, The Effect of Electromagnetic Fields on Humans, Doc. No. AA-900830-212, Federal Republic of Germany.

57. Federal Aviation Administration (FAA), Advisory Circular: Protection of Aircraft Electrical Electronic Ssytems against the Indirect Effects of Lightning. AC No: 20-136. 3/5/90.

58. FAA, Advisory Circular: Protection of Airplane Fuel Systems against Fuel Vapor Ignition due to Lightning. AC No: 20-53A. 4/12/85.

59. FAA, (Standard) Lightning Protection, Grounding, Bonding, and Shielding Requirements for Facilities. FAA-STD-019a. 9/26/85.

60. NFPA, NFPA 78 Lightning Protection Code, Batterymarch Park, Quincy, MA. 1989.

61. NFPA, NFPA 77 Static Electricity, Batterymarch Park, Quincy, MA. 1988.

62. APTA, Guidelines for Design of Rapid Rail Transit Facilities. Washington, D.C. 1981.

63. Harris Miller Miller & Hanson, Inc., Guidance Manual for Transit Noise and Vibration Impact Assessment. Prepared for U.S.DOT, UMTA. Draft Report. July 1990.

12. GLOSSARY

These definitions are an exact duplicate of those contained in the translation of Chapter 0, Regulations for High-Speed Maglev Trains, contained in the document High-Speed Maglev Trains Safety Requirements (RW MSB), issued March 1991.

A. Terms Pertaining to High-Speed Maglev Trains

Operating brake system	Device for generating thrust reversal in order to operationally brake the vehicle by means of the linear motor (see also the note at the end of the section "Definitions Specifically Relating to High-Speed Maglev Trains").
Bending switch	Guideway element to enable a change of track using horizontal elastic deformation of the corresponding portion of the guideway.
On-board control system	The on-board control system comprises all functions and installations of the operational control system and of vehicle control that are located on the vehicle.
EMS technology	Electromagnetic levitation technology. Both the levitation and guidance functions are performed by virtue of magnetic fields--whose intensity can be controlled--with an attractive effect between levitation magnets or guide magnets and their reaction surfaces on both sides of the guideway.
Guideway	Part of the stationary installation, consisting of foundation, guideway pillar, and guideway girder.
Guideway element	In the sense of operational control, the smallest unit of the guideway network that can be distinguished in terms of safety engineering.

Guideway pillar	Structural element on which the girders of the guideway are positioned and which transmits the introduced forces to the foundation.
Guideway girder	Beam-shaped, discretely positioned structural element of the guideway for levitation and guidance and thus for track guidance of the vehicle.
Vehicle	Collective term for units that can run independently under conditions of technical safety.
Vehicle operating console	Control installation in the vehicle for piloting same.
Block brake system	Installation for fixed positioning of the hovering or set-down vehicle (see also the note at the end of the section "Definitions Specifically Relating to High-Speed Maglev Trains").
Escape velocity	Minimum limiting speed at which the vehicle can reach the next stopping point even during the maximum conceivable breakdown or emergency situation.
Guide magnet	Transverse flux magnet with massive core for generating and absorbing magnetic guidance forces.
Speed range	Location-dependent range of speed in which the vehicle must run during normal operation.
Slide rail/surface	Sliding surface of the guideway which absorbs the mechanical forces from the bearing skids.
Stopping point	Track segment for stopping the vehicle, either as a station or as a stopping place with installations for evacuating passengers and allowing repair personnel to intervene.
Stopping place	Stopping point located outside stations for stopping the vehicle through application of emergency braking. The length of this track

	area is based on the vehicle length and the dispersion of the braking path.
Step-up chopper	Voltage converter to supply the on-board power network from the linear generator.
Linear generator	Installation for vehicle-based inductive generation of electrical energy from the kinetic energy created by vehicle motion.
MBO	Maglev Construction and Operating Regulation, Draft, status as of December 12, 1988.
Motor winding	Cable winding to generate the traveling field, inset in the stator pack grooves.
Emergency	Situation through which personal safety can be threatened.
Nutstein	Mounting element for the stator pack.
Primary spring suspension	Spring/shock absorber system between levitation and guide magnets and the corresponding levitation bogies.
Switching segment	Actively switchable line segment of long stator supplied from the corresponding converter.
Switch station	Switching element for activating the respective switch segment.
Levitation frame	Smallest complete functional unit of the levitation and guidance system.
Lateral guide rail	Functional surface on guideway girder which acts as reaction rail for the magnetic field generated by the guide magnets and which absorbs the proportional forces required to carry out the guide function. It is also used as a reaction rail to absorb forces from the auxiliary brake and as a slide surface to absorb the mechanical forces from the guide skids.

Secondary spring suspension	Spring/shock absorber system between the levitation bogies of the levitation/guidance system and the coach body.
Safe hovering	Preservation of levitation function even in the event of maximum conceivable breakdown and/or emergencies for limited and short-term continued operation, at least as far as the next attainable stopping point.
SIAB	Safety shutoff of the propulsion.
Safety braking system	Installation for performing emergency braking after the emergency stop instruction is triggered (see also the note at the end of the section "Definitions Specifically Relating to High-Speed Maglev Trains").
Station	Stopping point for operational boarding and deboarding, which is also a stopping point for stopping the vehicle when emergency braking is performed. A station has a boarding/deboarding platform corresponding to the length of the train, with due regard for positioning accuracy, as well as additional installations in both planned approach directions for evacuating passengers and allowing repair personnel to intervene. The length of this track area is based on the maximum acceleration and braking deceleration distance in the event that the vehicle, due to a breakdown situation, has not achieved escape velocity after starting out, but instead emergency braking is applied.
Stator pack	Element of the long stator, attached to the guideway support, for holding the motor winding. With an integrated levitation and propulsion function in EMS technology, the stator packs constitute the reaction elements of the levitation magnets.

Term	Definition
Breakdown	Breakdown is a distance of regular operation which can lead to an emergency.
Chopper	DC chopper converter to generate controllable direct currents.
Leviation/guidance chopper	DC chopper converter to generate controllable direct currents for the levitation or guide magnets.
Levitation/guidance system	Vehicle subsystem in which the levitation, guidance, and vehicle-related part of the propulsion function is generated.
Emergency stop	Emergency braking effected by operating personnel, by means of safety-engineering installations or on the basis of technical breakdown/failures, until the vehicle is stopped at a stopping point that can be reached safely. Exception: See "Emergency braking."

B. Safety-Engineering and Other Terms

Term	Definition
Operational control system	Functions and installations whose purpose is the safety, control, and guidance of vehicle operations, as well as communication between them.
BLT	Operational control system.
BOStrab	Ordinance on the Construction and Operation of Streetcars (Streetcar Construction and Operation Ordinance - BOStrav), BGBl [Federal Legal Gazette] I, 1987.
DB	German Federal Railroad.
EBO	Railroad Construction and Operating Regulation, BGBl II, 1967. First Ordinance Amending the Railroad Construction and Operating Regulation (EBO), BGBl II, 1969. Second Ordinance Amending the Railroad Construction and Operating Regulation (EBO), BGBl I, 1981.
EVU	Power company.

Highly reliable	See safe life.
Safe life	During the anticipated service life, neither the product as a whole, nor any of its critical subfunctions may fail (see VDI [Association of German Engineers] 2244, May 1988).
MSRUe	Relating to process measurement and control technology.
Redundancy	Presence of more functionally capable means in one unit than would be necessary to perform the required function (see DIN 40 041, Dec. 1990).
Fail-safe	Ability of a technical system to remain in a safe state or to immediately switch to another safe state in the event of certain types of breakdown (see VDI/VDE [Association of German Engineers--Association of German Electrical Engineers] 3542, Folio 1, Dec. 1988).
Safety	Safety is a situation in which the risk is no greater than the tolerated risk (see DIN VDE 31 000, T 2, Dec. 1987).
Availability (momentary)	Probability of encountering a unit at a given time within the required service life in a functionally capable state (see DIN 40 041, Dec. 1990).
Availability (stationary)	Average operating time between two failures divided by the sum of the average operating time between two failures and the average length of breakdown (see DIN 40 041, Dec. 1990).
Reliability	Condition of a unit with regard to its suitability for meeting the reliability requirements during or after predetermined intervals under given service conditions (see DIN 40 041, Dec. 1990).

APPENDIX A. SUMMARY OF RW MSB SAFETY REQUIREMENTS

The document High Speed Maglev Trains Safety Requirements consists of 13 chapters which were last issued in March 1991. The first chapter of the document serves as a general introduction, while the other 12 cover specific safety engineering requirements pertaining to maglev trains that demand special clarification. In addition to technical requirements, Chapters 1 through 12 list tests/records, equally applicable standards, and in some cases, other literature. (Note: In some cases, the chapters combine test/records and equally applicable standards under one heading.) The following text contains summarizes the primary contents of each chapter of the RW MSB safety requirements, based on the English translation of the text.

CHAPTER 0 Regulations for High-Speed Maglev Trains

The RW MSB indicates the intention that the safety requirements be accorded status of a "recognized engineering standard," reflecting the state of the art in safety engineering for high-speed maglev trains. The safety requirements in the RW MSB document are to be applied to high-speed maglev trains using electromagnetic suspension (EMS) technology with Transrapid-type long-stator propulsion. Definitions are included which specifically relate to high-speed maglev trains and to safety engineering and other terms.

It is noted that the requirements are valid beginning March 1, 1991.

CHAPTER 1 System Properties, Especially Safe Hovering

This chapter states that the essential feature of a maglev system is no-contact levitation and guidance by magnetic force. Safe hovering is defined as the property allowing the maglev vehicle to maintain levitation in a consistently safe manner in all conceivable breakdowns and/or emergencies; that is, the vehicle shall maintain levitation capability sufficient to reach the next station or designated stopping places, even if propulsion failure occurs. This levitation capability allows the vehicle to reach a point where programmed braking will stop the train only at points along the route which permit implementation of a rescue strategy (i.e., facilities for passenger evacuation and intervention by repair personnel).

The RW MSB sets forth technical requirements to prevent occurrences which, in the broadest sense, lead to inopportune braking (loss of safe hover): loss of levitation/guidance function, "racing" or sticking of magnets, failure of programmed braking function, and violation of clearance limits. In addition, the necessity of maintaining levitation during a vehicle fire and in a lightning strike is noted. The remainder of this chapter highlights environmental (e.g., earthquakes, severe weather, etc.) and organizational requirements (e.g., guideway securement and inspection), and discusses braking and the rescue plan as they affect safe hovering. (These subjects are covered more extensively in subsequent chapters of the RW MSB requirements.)

CHAPTER 2 Propulsion Including Energy Supply

This chapter describes the long-stator propulsion system, electrical safety requirements, propulsion unit reliability, and other propulsion requirements associated with the guideway in order to maintain safe hovering.

Chapter 2 requires that the propulsion subsystem present no danger to persons in the event of a breakdown. Accordingly, the failure of the power supply must not cause or facilitate a safety engineering failure that cannot be overcome by the operational control equipment. Chapter 2 also presents general design criteria for propulsion unit design voltage, as well as criteria for feeder and long-stator cable, stator pack mounting, cable winding mounting, feeder switch stations, grounding systems (for system elements with nominal, medium, and low voltage), ground fault detection installation, and propulsion control and guidance.

Specific requirements for electrical safety including protection against dangerous body currents, disconnection, overload, and short-circuit protection are also described.

21 DIN standards, VDI 2244, and VDMA standard 24169 are cited as equally applicable standards.

CHAPTER 3 On-Board Energy Systems

This chapter covers on-board vehicle energy subsystems with requirements for electrical safety, on-board circuits, and their subsystems. These subsystems include no-contact or conventional energy transmission; energy conversion using rectifiers, choppers, or transformers; energy storage units; and energy distribution with switching and protective devices, as well as cables and lines.

Emphasis is on the on-board circuits for supplying energy systems to ensure that levitation and guidance functions maintain safe hover until a safe stopping point is reached. Chapter 3 includes requirements to ensure the supply of all data processing, open-loop, and closed-loop controls.

Electrical safety requirements are similar to those contained in Chapter 2. In addition, overload and short-circuit protection with respect to fire protection are discussed.

Chapter 3 includes extensive requirements for energy conversion, storage (battery) capacity, recharging and protection, re-energizing, fans, and monitoring. Redundancy of circuits and other systems in relation to system faults, energy distribution requirements which address switch cabinets or boxes with fault state detection and protection equipment, cables and lines, short-circuit and ground fault lines, protective conductors, plug connections, and central switch cabinets are also described. The operating console must comply with the requirements in specified DIN standards; other parts of the control system must comply with records/tests listed in Chapter 9. This chapter cites eight DIN standards and MÜ 8004 as equally applicable standards.

CHAPTER 4 On-Board Control System

This chapter contains requirements for the vehicle computer, on-board controls (including levitation, set down, communication and door control), location, diagnosis, operating console, auxiliary brake control, passenger emergency signal, and transmission installation on vehicle.

DS 804, DS 899/59, DIN 1072, and UIC 651 are cited as equally applicable standards. One specification and three technical reports are referenced as other literature.

CHAPTER 5 Load Assumptions

This chapter defines loads as forces of inertia and forces resulting from wind, temperature, support settling, etc. which generate stresses in the structure, i.e., tensions or deformations. Interface loads are also considered. Loads acting on the vehicle are vehicle side interface loads; those acting on the guideway are guideway side loads.

DS 804, DS 899/59, DIN 1072, and UIC 651 are cited as equally applicable standards. One specification and three technical reports are referenced as other literature.

CHAPTER 6 Stability Analysis (Guideway/Vehicle)

This chapter states that a stability analysis contains proof that in all possible combinations of loads or building and operating conditions (1) adequate safety of all structural parts against failure is ensured (strength analysis); (2) guideway parts are unable to change position as a result of tilting, lifting, or sliding, and that no soil movement can occur in the area of foundation (positional safety analysis); and (3) no changes (shifts, torsion as a result of warping and/or subsoil movement and bearing shift) occur in the geometry of the functional surfaces that could result in impermissible operating conditions (deformation analysis).

Depending on their frequency of occurrence, the RW MSB classifies loads into primary (P), secondary (Se), and special (Sp) which are further defined. Vehicle loads are listed in Sections 3 and 4 of this chapter. A table summarizes loads for three types of load: force of gravity, aerodynamic forces, and other; guideway and guideway equipment loads are listed in Sections 4 and 5 of Chapter 5. A table summarizes external guideway loads.

Various loads for vehicles and guideways and guideway equipment, as contained in the tables, are combined for further study to determine the most unfavorable combination for each. The most unfavorable combinations are selected to determine the potential stress for anticipated loads. Safety factors are used to determine the probability that the loads or load combinations applied to the corresponding record will occur, and the severity of consequence of component failure.

Finally, Chapter 6 states that permissible deformations must be established for the bearing/glide skids to prevent magnet-guideway contact in normal operations; to ensure danger-free emergency braking during a breakdown; and in the event of an earthquake, to ensure a dead stop by the vehicle without personal injury.

Four DIN standards and DS 804 are cited as equally applicable standards. A reliability, maintenance, and service life guideline and a technical report are referenced as other literature.

CHAPTER 7 Design, Production, and Quality Assurance of Mechanical Structures

The objectives of this chapter are to ensure (1) fulfillment of stability documentation as it applies to design, materials, and production technology; (2) assurance of the guideway geometry necessary for no-contact running (normal operation), as well as for running with skid contact (partial or full set-down during operation) and/or magnet contact; and (3) guarantee that no hazard emanates from the vehicle or guideway through mechanical influence. Accordingly, this chapter contains requirements for vehicle and guideway structural design, and production (including assembly) and quality assurance. Vehicle production and quality assurance requirements cite several technical regulations and address materials, semi-finished goods, connections, and documentation. Guideway production and quality assurance requirements cite technical regulations and specify that a separate quality assurance program must be formulated for the assembly of the guideway functional elements.

Eight DIN standards, three DS standards, seven DVS standards, and VDI 2330 are cited as equally applicable standards. Seven technical reports relating to the Transrapid guideway are referenced as other literature.

CHAPTER 8 Switch

This chapter discusses the bending switch system. The object of the requirements is the safe running over the switch, but not the fail-safe operation on the switch (see Chapter 9 for switch operation).

The RW MSB requires that the switch can only be in a fail-safe (i.e., secured) position before a train runs over it; five conditions are described which constitute the fail-safe position. It also describes requirements for closure of the end position in the event of failure, reliability of switch setting gear synchronism, and fail-safe reporting of the switch by the operational train equipment.

The EBO, ESBO, ESO, draft MBO, two DS standards, four DIN standards, TRB, TROL,ZH1/153, and Ad Codes of Practices are cited as equally applicable standards.

CHAPTER 9 OPERATIONAL CONTROL EQUIPMENT

This chapter contains requirements for the construction, equipment, function, and operation of the technical installation, as well as for methods applicable to safety-relevant (vehicle and guideway) functions of operational control equipment.

The operational control equipment provides information concerning normal operations which includes condition and status of operation points (including the operational control center, guideway, and vehicle), safety oriented failure behavior, and correct functioning of hardware and software. The standard mode of operating is defined as "normal," while special operations include breakdowns, construction or maintenance, or operationally necessary tests. The RW MSB defines the guideway, guideway elements and the term operational readiness. The chapter also defines different objectives for the operational control equipment for guideway and vehicle safety.

DIN VDE 0831 and DIN V VDE 0801, MÜ 8004 and UIC 738 R are cited as equally applicable standards.

CHAPTER 10 Lightning Protection, Electromagnetic Compatibility (EMC), and Electrostatic Discharge (ESD)

This chapter describes characteristics of lightning strikes, electromagnetic compatibility (EMC), and electrostatic discharge (EMD), and protection requirements to protect against potential adverse effects.

Chapter 10 addresses direct lightning hazards to persons from vehicles (protection and grounding) and the operating system (including protection of guideway sections where persons board or exit), direct hazards to safety-relevant systems to prevent impermissible failures and breakdowns whenever possible, and hazards to material property (to prevent property damage). DIN VDE 0185 (with supplements), DIN VDE 0183, VG 96900 and VG 96901 are cited under records/tests/equally applicable standards.

The objective of the EMC requirements is that no impermissible electromagnetic effects are emitted in the environment or interior of vehicles and buildings. A plan is required to address EMC protective measures. Records/tests/equally applicable standards cited are seven DIN standards and VG 95372.

Electrostatic requirements are contained in three notes to the statement that electrostatic charges and subsequent discharges must be expected because of no-contact operation and high operating speed. Records/tests/equally applicable standards cited include DIN VDE 0100, DIN 54 345, and ZH1/200.

CHAPTER 11 Fire Protection

The requirements in this chapter are intended to protect passengers, the crew, and rescue personnel. Chapter 11 contains safety engineering specifications for fire protection through requirements for supporting structures, fire walls, fitting and lining elements (materials and arrangement), batteries and cabling, electrical operating equipment, fire alarm system, firefighting installations, and prohibitions and danger notices.

Class 4 (highest level) as described in DIN 5510, Part 1 is cited for fire protection; Parts 4, 5, and 5 are also cited.

Records/tests list 8 tests (e.g., monitoring, fire propagation, heat transfer, etc.). DINs 4102, Parts 2, 4, 5; 060; 18 200; the draft MBO; DS 899/35; UIC 564-2; ATS 1000.001; and FAR Part 25 (49 CFR, Part 25) are cited as equally applicable standards.

CHAPTER 12 Rescue Plan

This chapter describes requirements for the rescue of persons in a maglev emergency requiring evacuation. While stations are preferred for passenger evacuation, evacuation may be necessary at other locations. The Transrapid safe hovering concept provides for safe stopping areas to be located between stations. Detailed requirements for safe hovering as it relates to the ability of the vehicle to reach safe stopping areas are specified in this chapter.

Chapter 12 presents requirements for vehicle escape routes; signs and warnings; communication, firefighting, evacuation, and first aid equipment; and a passenger emergency signal.

This chapter also describes extensive requirements for stopping area position intervals, length of the disembarking area, communication and access points for rescue personnel, evacuation speed, and monitoring. Provision is also made for evacuation in acceleration areas (adjacent to stations), and during an unplanned stop between designated stopping areas. Alternate evacuation options must be specified in the rescue plan.

Finally, Chapter 12 discusses proximity of firefighting and rescue service, hospitals, and the police; provision of access roads and landing sites for helicopters; preparation of alarm systems and operational plans; as well as training for on-board conductors; submission of a unified rescue plan for inspection by the appropriate supervisory authority or designated expert; and the conduct of periodic rescue exercises.

The submission of a unified rescue plan for inspection by the appropriate supervisory authority or designated expert and the conduct of periodic rescue exercises are noted under records/tests. DIN 5510, FAR Part 25 (49 CFR, Part 25) and the draft MBO are cited as equally applicable standards.

APPENDIX B. SYSTEM SAFETY METHODOLOGY AS APPLIED TO MAGLEV SYSTEMS

System Safety methodology was used to perform the review of the suitability of the German safety requirements for application to maglev systems, as proposed for U.S. operations. This appendix briefly reviews the systematic process used to identify and resolve safety concerns (hazards) which may lead to an undesired event or potential casualty. A more complete description of the system methodology as applied to maglev systems is contained in the Preliminary Safety Review of the Transrapid Maglev System, prepared by VNTSC for the FRA (Report No.: DOT/FRA/ORD-90/09).

The first step defines the system in terms of the physical and functional characteristics necessary to understand and evaluate the system elements. These elements (vehicle; guideway; stations; signal, control, and communications; procedures; and environment) are then examined to identify potential safety concerns, undesired events, and their probable cause or contributing factors.

Next, the severity and probability of the identified hazards and undesired events are assessed in terms of the severity of the expected consequence (C) and the probability (P) of occurrence. The severity or magnitude of an undesired maglev event will depend on two factors: (1) when the event is likely to occur in the maglev operating cycle and (2) whether the undesired event is time-dependent and can be controlled.

A commonly recognized classification system used to categorize hazards is the Military Standard: System Safety Program Requirements (Mil-Std. 882B). The VNTSC preliminary maglev safety review adapted this classification system (see Figures B-1 and B-2) to assess the severity and probability of ten major undesired events which could lead to a potential maglev casualty. The probability of a maglev undesired event is difficult to calculate because no publicly available database exists.

Table B-1 Risk Assessment Estimates

EVENT DESCRIPTION	OPERATIONAL PHASES INVOLVING PASSENGERS			
	Passenger StationTransfer	Leaving/Arriving Station	Accessible Areas of Guideway	Inaccessible Areas of Guideway
Fire/Explosion in Vehicle	IID	ID	ID	ID
Fire in Other Critical Element	IIIC	IIIC	IIC	IC
Vehicle Collision with Object	IIC	IIC	IC	IC
Vehicle to Vehicle Collision	IID	IID	ID	ID
Vehicle Leaves Guideway	IIE	IIE	IE	IE
Sudden Stop	N/A	IIIC	IIC	IC
Does Not Slow/Stop at Station	N/A	IID	N/A	N/A
Stranded on Guideway	N/A	IID	IIC	IC
Inability to Rescue Occupants	IIID	IID	IID	ID
Passenger Illness/Injury	IIIC	IIC	IIC	IC

LEGEND:

I	Catastrophic	A	Frequent
II	Critical	B	Probable
III	Marginal	C	Occasional
IV	Negligible	D	Remote
		E	Improbable
		N/A	Not applicable

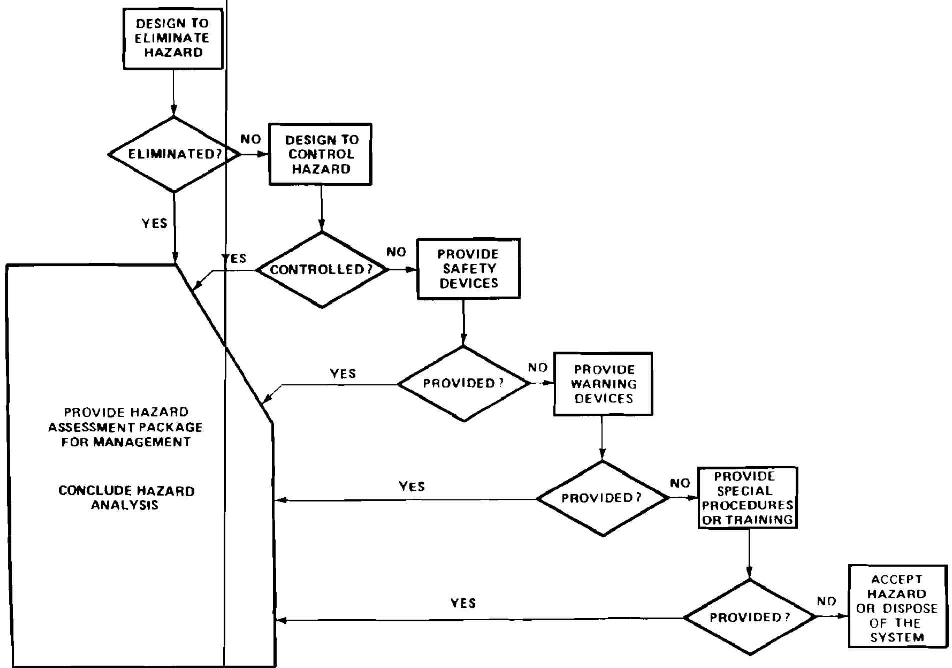


Figure B-4 Hazard Reduction Precedence

introduction of safe procedures, personnel training, or a combination thereof. The severity also can be reduced by mitigation and control measures such as fire extinguishers and sprinklers used to control a fire once it occurs.

The final step in the system safety process is follow-up. It is necessary to monitor the effectiveness of recommended hazard prevention and control measures and to ensure that new hazards are not introduced as a result. In addition, whenever changes are made to any of the system elements, a safety analysis should be conducted to identify and resolve any inadvertently introduced safety hazards.

A more extensive discussion of system safety methodology is contained in System Safety Engineering and Management*.

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* Roland, Harold E. and Brian Moriarty, System Safety Engineering and Management, Second Edition, John Wiley and Sons, New York,