U. S. Department
of Transportation
Federal Railroad Administration

Safety of High Speed Magnetic Levitation Transportation Systems

Office of Research
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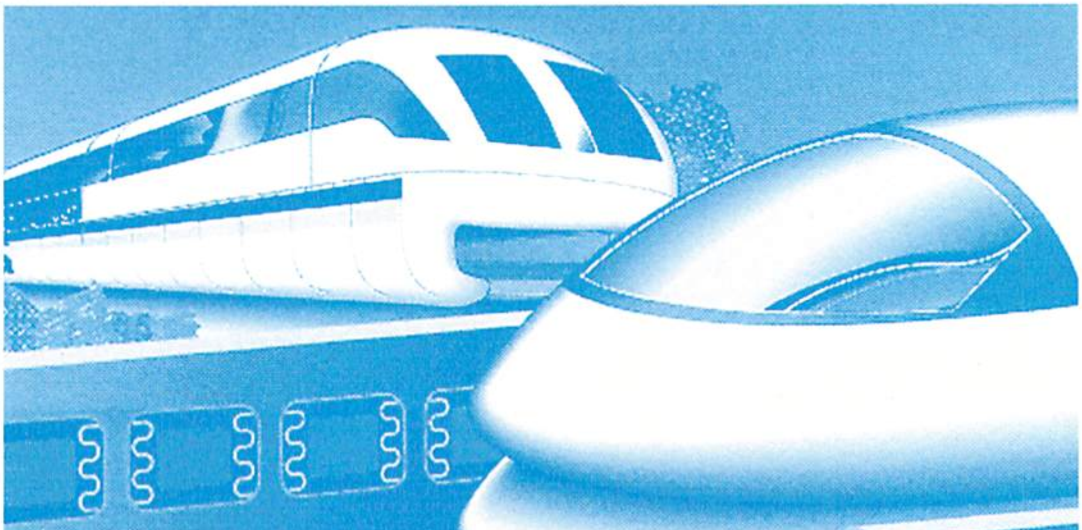
Washington, D.C. 20590

Comparison of U.S. and Foreign Safety Requirements for Application to U.S. Maglev Systems



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Final Report
September 1993

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NOTICE

In numerous places, this report discusses whether various aspects of the technologies that are the subject of this report comply with Federal safety laws and regulations. Those discussions, which reflect the seasoned judgment of commentators qualified in their fields, do not constitute rulings by the Federal Railroad Administration's Office of Safety or its Office of Chief Counsel concerning compliance with the law.

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13. ABSTRACT (Maximum 200 words)

This report presents the results of a systematic review of the safety requirements selected for the German Transrapid electromagnetic (EMS) type maglev system to determine their applicability and completeness with respect to the construction and operation of maglev systems in the United States.

The German safety requirements for high-speed maglev systems are documented in the High-Speed Maglev Trains Safety Requirements, Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen (RW MSB), Railroad Construction and Traffic Regulations (EBO), and the draft Maglev Construction and Operation Regulation (draft MBO). A major focus of this report is the evaluation of German Standards Institute standards (DINs) cited in the RW MSB.

A review of the RW MSB, the EBO, and the draft MBO safety requirements, as they relate to seven major maglev system functional areas has been performed. These requirements have been compared and assessed to identify similarities to and differences from equivalent U.S. and international transportation-related regulations, standards, specifications, and/or guidelines, and certain general industrial requirements. Unique aspects of the U.S. operating environment have also been considered.

Findings are presented regarding proposed safety requirements for the construction and operation of high-speed maglev systems in the United States. These findings are intended to assist FRA in establishing safety requirements for U.S. maglev systems.

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PREFACE

The use of magnetically levitated (maglev) vehicles for high-speed guided ground transportation has been proposed for passenger operations in the United States. As a result, a need exists for the assessment of the safety implications of this new form of technology to ensure passenger safety. This assessment is the responsibility of the Federal Railroad Administration (FRA), which is charged with ensuring the safety of U.S. maglev systems under the provisions of the Rail Safety Improvement Act of 1988.

The third in a series of reports addressing high-speed maglev transportation safety, this report, Comparison of U.S. and Foreign Safety Requirements for Application to U.S Maglev Systems, contains the results of a detailed review of safety requirements to evaluate their suitability to maglev operations in the U.S. environment. A major focus of this report is the evaluation of German Standards Institute standards (DINs) cited in the German document 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 of 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.

In the initial development of U.S. safety rulemaking for maglev systems, the FRA plans 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 maglev technology.

This report was sponsored by the U.S. Department of Transportation (US DOT), the Federal Railroad Administration (FRA), Office of Research and Development, Arne J. Bang, Program Manager. The report was prepared by Arthur D. Little, Inc. (ADL) and Parsons Brinckerhoff Quade & Douglas, Inc. (Parsons Brinckerhoff), under the direction of Stephanie H. Markos, of the Volpe National Transportation System Center (Volpe Center), US DOT.

The authors wish to acknowledge the contributions of Keith A. Birch, Sara L. Sullivan, Judith I. Nathans, E. Verra Sloane, Rita M. Keohane, and Wendy S. McIntosh of ADL; Daniel B. Mesnick and Sara L. Sullivan, formerly of ADL; John A. Harrison, Thomas Taylor, Edward E. Gilcrease, Garry E. Clark, R.E. Wright, Denise Godley, and Keith Sullivan of Parsons Brinckerhoff; and Garry E. Clark and R.E. Wright, formerly of Parsons Brinckerhoff.

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SYSTÈME INTERNATIONAL (SI) UNIT DEFINITIONS AND CONVERSIONS USED IN THIS REPORT

DISTANCE (ENGLISH-TO-SI CONVERSION):

1 inch (in)	= 2.54 centimeters (cm)	= 0.025 meters (m)
1 foot (ft)	= 30.5 centimeters (cm)	= 0.305 meters (m)
1 yard (yd)	= 91.4 centimeters (cm)	= 0.914 meters (m)
1 mile (mi)	= 1.61 kilometers (km)	= 1,610 meters (m)

ELECTRICAL QUANTITIES:

Electric Fields

1 volt/meter (V/m)	= 0.01 volts/centimeter (V/cm)
1 kilovolt/meter (kV/m)	= 1000 volts/meter (V/m)
1 kilovolt/meter (kV/m)	= 10 volts/centimeter (V/cm)

Magnetic Flux Densities (English-to-SI Conversion)

10,000 gauss (G)	= 1 tesla (T)
10 milligauss (mG)	= 1 microtesla (μT)
1 milligauss (mG)	= .1 microtesla (μT)
0.01 milligauss (mG)	= 1 nanotesla (nT)

Electromagnetic Frequency Bands

1 cycle per second	= 1 hertz (Hz)
1,000 cycles per second	= 1 kilohertz (kHz)

Ultra Low Frequency (ULF) Band	= 0 Hz to 3 Hz
Extreme Low Frequency (ELF) Band	= 3 Hz to 3 kHz
Very Low Frequency (VLF) Band	= 3 kHz to 30 kHz
Low Frequency (LF) Band	= 30 kHz to 300 kHz

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LIST OF ABBREVIATIONS

AA	Aluminum Association
AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
ABS	Automatic Block System (Railroad)
AC	Advisory Circular (Federal Aviation Administration)
ACI	American Concrete Institute
AISC	American Institute for Steel Construction
AISI	American Iron and Steel Institute
Amtrak	National Railroad Passenger Corporation (U.S.)
ANSI	American National Standards Institute
APTA	American Public Transit Association
AREA	American Railway Engineering Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASQC	American Society for Quality Control
ASTM	American Society for the Testing of Materials
ATC	Automatic Train Control
ATCS	Advanced Train Control Systems
ATO	Automatic Train Operation
ATP	Automatic Train Protection
AWI	American Welding Institute
BSI	British Standards Institution

LIST OF ABBREVIATIONS (cont.)

BS	British Standard
CTC (1)	Canadian Transport Commission
CTC (2)	Centralized Train Control
DB	German Federal Railways
DIN	German Standards Institute
DS	Railroad Regulations issued by the German Federal Railways (DB)
DVS	German Welding Institute
EBO	Railroad Construction and Traffic Regulations (German)
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
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
47 CFR	Code of Federal Regulations, Title 47, Federal Communications Commission
49 CFR	Code of Federal Regulations, Title 49, Transportation
FAA	Federal Aviation Administration
FCC	Federal Communications Commission (U.S.)
FDA	Food and Drug Administration (U.S.)
FHA	Functional Hazard Analysis
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FRA	Federal Railroad Administration

LIST OF ABBREVIATIONS (cont.)

FTA(1)	Federal Transit Administration (formerly Urban Mass Transportation Administration)
FTA(2)	Fault Tree Analysis
GPS	Global Positioning System
HSGGT	High Speed Guided Ground Transportation
ICE	Intercity Express (German)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRSE	Institute of Railway Signal Engineers (U.K.)
ISO	International Standards Association
MBO	Maglev Construction and Operating Regulation, Draft (German)
MBTA	Massachusetts Bay Transportation Authority
MIL-HDBK	Military Handbook (U.S.)
MIL-STD	Military Standard (U.S.)
MIL-STD 882	Military Standard (U.S.): System Safety Program Requirements
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards (U.S.)
NEMA	National Electrical Manufacturers Association (U.S.)
NESC	National Electrical Safety Code (ANSI C2) (U.S.)
NFPA (1)	National Fire Protection Association (U.S.)
NFPA (2)	National Fluid Power Association (U.S.)
NIST	National Institute of Standards and Technology (U.S.)
NRPC	National Railroad Passenger Corporation (Amtrak)

LIST OF ABBREVIATIONS (cont.)

ORE	Office for Research and Experiments (of the UIC)
PASC	Project Accompanying Safety Certification
Pehla RL	Joint Test Laboratory. Owned by German Electrical Industry
QA	Quality Assurance
QC	Quality Control
QRA	Quantitative Risk Analysis
Requirements	Includes regulations, guidelines, standards, requirements, specifications, and practices
R-O-W	Right-of-Way
RTCA	Radio Technical Commission for Aeronautics (U.S.)
RW MSB	Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen (High-Speed Maglev Trains Safety Requirements)
SAE	Society of Automotive Engineers (U.S.)
SNCF	French National Railways
TGV	Train à Grand Vitesse (High-Speed Train, French)
TQM	Total Quality Management
TRB	Technical Regulations for Pressure Vessels (German)
TRGL	Technical Regulations for High Pressure Gas Lines (German)
TÜV Rheinland	Technischer Überwachungs-Verein Rheinland e.V. (German)
VDI	Association of German Engineers
VDE	Association of German Electrical Technicians
VDMA	Institute for Plant and Machinery Construction
UIC	International Union of Railways

LIST OF ABBREVIATIONS (cont.)

UITP	International Union for Public Transport
UL	Underwriters Laboratory (U.S.)
UMTA	Urban Mass Transportation Administration (Name changed, in December 1991, to Federal Transit Administration [FTA])

1. INTRODUCTION

1.1 BACKGROUND AND SCOPE

Under current legislation, the Federal Railroad Administration (FRA) has the responsibility for safety assurance of any maglev or high-speed rail system operated in public service in the United States. As part of its work to exercise this responsibility, the FRA, supported by the Volpe National Transportation Systems Center (the Volpe Center), is conducting a series of studies to identify and evaluate appropriate regulations, standards, and guidelines governing the construction, operation, and maintenance of high-speed ground transportation systems, including magnetic levitation (maglev) systems. Appropriate requirements may include existing U.S. regulations, standards or guidelines, or foreign equivalents considered suitable for application in the U.S. operating environment. Where no appropriate requirement exists, the FRA may consider the introduction of new regulations or guidelines. The term "requirements" is used in this report to include all applicable regulations, guidelines, standards, practices and codes.

This report presents the results of a systematic review of the safety requirements selected for the German Transrapid electromagnetic type maglev system to determine their applicability and completeness with respect to the construction and operation of maglev systems in the United States. Germany has been the leader in developing safety requirements for high-speed maglev systems.

The German safety requirements for high-speed maglev systems are documented in the High-Speed Maglev Trains Safety Requirements, (Regelwerk Magnetschnellbahnen--Sicherheitstechnische Anforderungen), known as the RW MSB [1], Railroad Construction and Traffic Regulations (EBO) [2], and the draft Maglev Construction and Operation Regulation (draft MBO) [3]. The RW MSB was prepared by a working group comprised of maglev technology development organizations and an independent safety assurance organization Technische Überwaschung Verein-Reinland (TÜV), which is assisting in the development of maglev safety requirements in Germany. The RW MSB safety requirements concentrate on maglev technology-specific safety issues, and do not cover all issues to the same level of detail. The working group has also been working with the developers of the German Transrapid maglev technology on the continuing development and refinement of maglev safety requirements. This activity includes involvement in field tests of maglev systems and subsystems at the Emsland maglev test track (TVE). The end objective of these activities is the certification of maglev systems as being in compliance with all applicable safety requirements, and acceptable for public passenger service in Germany.

Several work efforts to analyze the applicability of German maglev safety requirements for U.S. maglev operations have been undertaken for the FRA. The first effort conducted was a preliminary safety review of the Transrapid system [4]. That report described the Transrapid TR07 maglev system, identified undesired events which could lead to a potential maglev casualty, described countermeasures, and provided an initial listing comparing safety requirements potentially suitable for application to maglev system technology, as proposed for

U.S. operations. The second work effort was a review of the RW MSB safety requirements, and requirements contained in the EBO and draft MBO, to assess their potential applicability to maglev systems proposed for U.S. operations [5]. As a result, it was recommended that a more comprehensive in-depth analysis of foreign industry safety requirements was required.

Accordingly, this report documents the results of the review of safety-related technical requirements referenced in the RW MSB, and other international and U.S. safety requirements which could be applicable to high-speed maglev system construction and operations in the United States.

The scope of the work effort presented in this report is as follows:

- Review of safety requirements applicable to German high-speed maglev systems as as they relate to maglev system element functional areas. The requirements are contained in the following topic areas, as contained in the March 1991 version of the RW MSB document:

    - 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

Appendix A contains a brief summary of the contents of each RW MSB chapter.

- A comparison of all safety requirements cited in the RW MSB document with the equivalent U.S. regulations, standards, specifications, and/or guidelines for each major maglev system functional area. Functional areas which are not addressed, or are only partially addressed in the RW MSB document are included. In these cases, U.S. and international safety requirements applicable to guided transportation systems in general were reviewed.

- An assessment of the safety requirements identified in each functional area regarding their applicability to maglev systems proposed for U.S. operation. Identification of similarities and differences, the impact of the U.S. operating environment and identification of needs for further study are included.

- Development of findings regarding proposed safety requirements for the construction and operation of high-speed maglev systems in the United States. These findings are intended to assist FRA in establishing safety requirements for U.S. maglev systems.

- Description of recommended further studies, as noted.

1.2 ORGANIZATION OF THIS REPORT

This report comprises a detailed review of safety requirements applicable to the 29 specific maglev system elements, described as "Functional Areas."

More specifically, the report is organized as follows:

Chapter 2 describes the technical approach to performing the study including document acquisition, the review process describing what factors are taken into account, and how the results of each review have been documented.

Chapters 3 to 8 present the individual reviews for each of the 29 maglev system functional areas. The reviews present the following information:

- Description or definition of the functional area, including the interface with related functional areas.

- A safety baseline describing what safety requirements should accomplish in the functional area.

- A description of the relevant safety requirements identified.

- A comparison and assessment of the applicability of the safety requirements to proposed U.S. maglev systems.

- A summary of the findings of the review, regarding the applicability of safety requirements for proposed U.S. maglev systems and the need for new or modified requirements.

- Recommended further studies, if relevant.

The groups of functional areas reviewed are:

Chapter 3. General (system-wide) safety

Chapter 4. Vehicles

Chapter 5. Guideway

Chapter 6. Operations control, communication, and electric power systems

Chapter 7. Personnel and operations

Chapter 8. Emergency preparedness

Chapter 9 provides a summary of the findings of the study regarding the need for and content of safety requirements for high-speed maglev systems and services in the United States.

Appendix B lists the technical standards, regulations, specifications, codes, and guidelines referenced in this report, indicating the pertinent maglev system functional areas and as applicable, where they are referenced in the RW MSB chapters.

2. TECHNICAL APPROACH

2.1 OVERVIEW

This chapter provides a description of the technical approach used to perform this study. This includes a brief description of the sources of information and documentation, the procedure for carrying out the reviews of safety requirements, and the content of the reviews.

For the purpose of this review, safety-critical high-speed maglev systems, subsystems and components have been divided into 29 functional areas as listed in Table 2-1. A detailed review is presented for each functional area.

2.2 INFORMATION AND DOCUMENTATION SOURCES

The primary source of safety requirements for evaluation and review was the document, High-Speed Maglev Trains Safety Requirements (RW MSB), prepared by the German maglev safety working group. This document is comprised of thirteen chapters which specify safety requirements that should be satisfied for the operation of high-speed maglev trains in Germany. This document is referred to as the "RW MSB" throughout this report.

The review and comparison of requirements is based on the version of the RW MSB dated March 1, 1991 published as an English translation by the FRA [1].

The second source of German safety requirements for evaluation and review was approximately 250 German documents of technical requirements referenced in the RW MSB as being applicable to specific functional areas of an electromagnetic-type maglev system. These German requirements can be divided into two general groups: requirements that are transportation-specific, usually to conventional railroads, but also to aerospace applications; and those that provide technical requirements for materials, and design, manufacturing and testing procedures applicable to many industries or products. The German requirements are published by a variety of organizations. The names and the nature of the principal sources of technical requirements referenced in the RW MSB are briefly described below:

- Deutsches Institute fur Normung (DIN) (German Standards Institute) develops technical standards for all types of materials, and design, manufacturing and testing processes. The functions of DIN in Germany are equivalent to those of the American National Standards Institute (ANSI) and the American Society for the Testing of Materials (ASTM) in the U.S. The DIN standards cited in the RW MSB relate primarily to mechanical and civil engineering. Only a few are specific to a transportation mode, such as DIN 5510, Preventive Fire Protection in Railway Vehicles.

- Verbands Deutscher Electrotechniker (VDE) (German Association of Electrical Engineers) publishes a wide range of general technical standards for electrical engineering. Many VDE requirements are published jointly with DIN (designated

TABLE 2-1. HIGH-SPEED MAGLEV FUNCTIONAL AREA REVIEWS

Reference	Title
	General Safety
101	System Safety
102	Reliability and Availability
103	Quality Assurance
104	Certification
105	Computer Safety for Vehicle and Operations Control Systems
	Vehicle
201	Vehicle and Cab Structural Integrity
202	On-Board Operator and Crew Compartments
203	Passenger Compartment Interior Fittings and Components
204	Passenger Vehicle Doors and Entryways
205	Fire Safety
206	Suspension Design and Construction
207	Brake Installation and Performance
208	Vehicle-Guideway Interaction
209	Inspection and Maintenance
210	Interior Vehicle Noise
	Guideway
301	Guideway Design and Construction
302	Guideway Inspection and Maintenance
303	Guideway Switch
304	Right-of-Way Security
	Operations Control, Communications, and Electric Power Systems
401	Operations Control System Design
402	Operations Control System Inspection and Maintenance
403	Communication Systems
404	Electric Safety and Power Supply
405	Electromagnetic Interference and Electromagnetic Compatibility
406	Lightning Protection
	Personnel and Operations
501	Qualifications and Training
502	Operating Rules and Practices
	Emergency Preparedness
601	Emergency Plans and Procedures
602	Emergency Features and Equipment, including Access and Egress

DIN-VDE), or are published separately by DIN and/or the International Electro-technical Commission (IEC). The document itself is unchanged in these cases of multiple publishers. VDE requirements are usually equivalent to the Institute of Electrical and Electronic Engineers (IEEE), and the National Electrical Manufacturers Association (NEMA) requirements in the U.S. A few VDE requirements are railroad specific, notably VDE 0831 (Electrical Equipment for Railway Signalling), and some VDEs specific to railroad electric traction systems.

- Verbands Deutscher Ingenieure (VDI) (German Association of Engineers) requirements are general technical standards used in the engineering industry. Like the DINs, the functions of VDI requirements are similar to those of ANSI and ASTM in the U.S.

- Deutscher Verband for Schweisstechnik (DVS) (German Welding Association) develops requirements for welding and the design of welded structures. Its functions and requirements are similar to those of the American Welding Institute (AWI) in the United States. The DVS requirements referenced in the RW MSB are mostly railroad specific and concerned with welded railway rolling stock structures.

- A number of railroad-specific requirements issued by German Federal Railways are referenced in the RW MSB. These include the DS series for structures and materials and the MUe 8004 signal system specification. The purpose of these requirements is similar to that of the manuals for rolling stock, signal systems, and track and structures issued by the Association of American Railroads (AAR) and the American Railway Engineering Association (AREA). The railroad-specific requirements in the DIN, VDE and DVS series can also be compared to requirements contained in the AAR and AREA manuals.

A few other more specialized sources for requirements not mentioned above are also referenced in the RW MSB. These are all requirements developed by professional or industry associations and have general industrial applications.

A third source of safety requirements for this review was the International Union of Railways (UIC) Code. This Code applies in Europe and certain other countries to conventional railway vehicles, including high-speed wheel-on-rail trains. Conventional and high-speed trains operated by most European railways meet or exceed the requirements of the UIC Code. The functions of UIC in Europe are approximately equivalent to those of the AAR in North America, including developing and publishing technical requirements. The Code covers a wide range of technical requirements for rolling stock, signal systems, and electrical equipment, including some that are not addressed in detail in the RW MSB, the draft MBO, EBO or other requirements referenced in the RW MSB. Finally, a small number of other international transportation safety requirements of particular interest and relevance were identified and included in the study.

Almost all the safety requirements referenced in the RW MSB, plus selected UIC Code publications, and other foreign or international safety requirements were acquired for review. English translations of most requirements were obtained, but where no translation was available, the German-language original was obtained. In a very few instances, a source for a document referenced in the RW MSB could not be identified, or the document was out of print, and could not be obtained. A full listing of these documents is provided in Appendix B referenced to functional areas and the chapter and paragraph of the RW MSB in which they were cited.

The requirements documents were acquired from the issuing organization or one of a number of commercial firms specializing in technical documentation services. The commercial firms were particularly useful in obtaining English translations of DIN and VDE publications. A total of about 250 individual requirement documents were obtained, of which 35 were only available only in German. Every effort was made to ensure that the requirements reviewed were the current issue at the time of acquisition in mid-1991.

When each requirements document became available, the content received a brief initial review, to enable identification of the U.S. equivalents. U.S. equivalents include the pertinent portions of the existing FRA railroad safety regulations (listed in Table 2-2), relevant regulations of the Federal Aviation Administration (FAA), and other U.S. government agencies; and publications of industry associations and other requirements-setting organizations.

2.3 SAFETY REVIEW APPROACH

The approach for carrying out the safety reviews is illustrated in Figure 2-1. A review was carried out for each functional area listed in Table 2-1 by a technical specialist in the subject. The review of each functional area started with the assembly of a package of documents consisting of:

- The relevant part(s) of the RW MSB requirements.
- Relevant requirements documents cited in the RW MSB requirements.
- Extracts from the EBO and draft MBO.
- U.S. equivalents to the documents cited in the RW MSB requirements, and/or other U.S., foreign and international safety requirements having relevance to the functional area, such as the UIC Code.
- Previous studies by the FRA and the Volpe Center.

TABLE 2-2. POTENTIALLY APPLICABLE FRA REGULATIONS (49 CFR)

Reference	Title
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 form 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

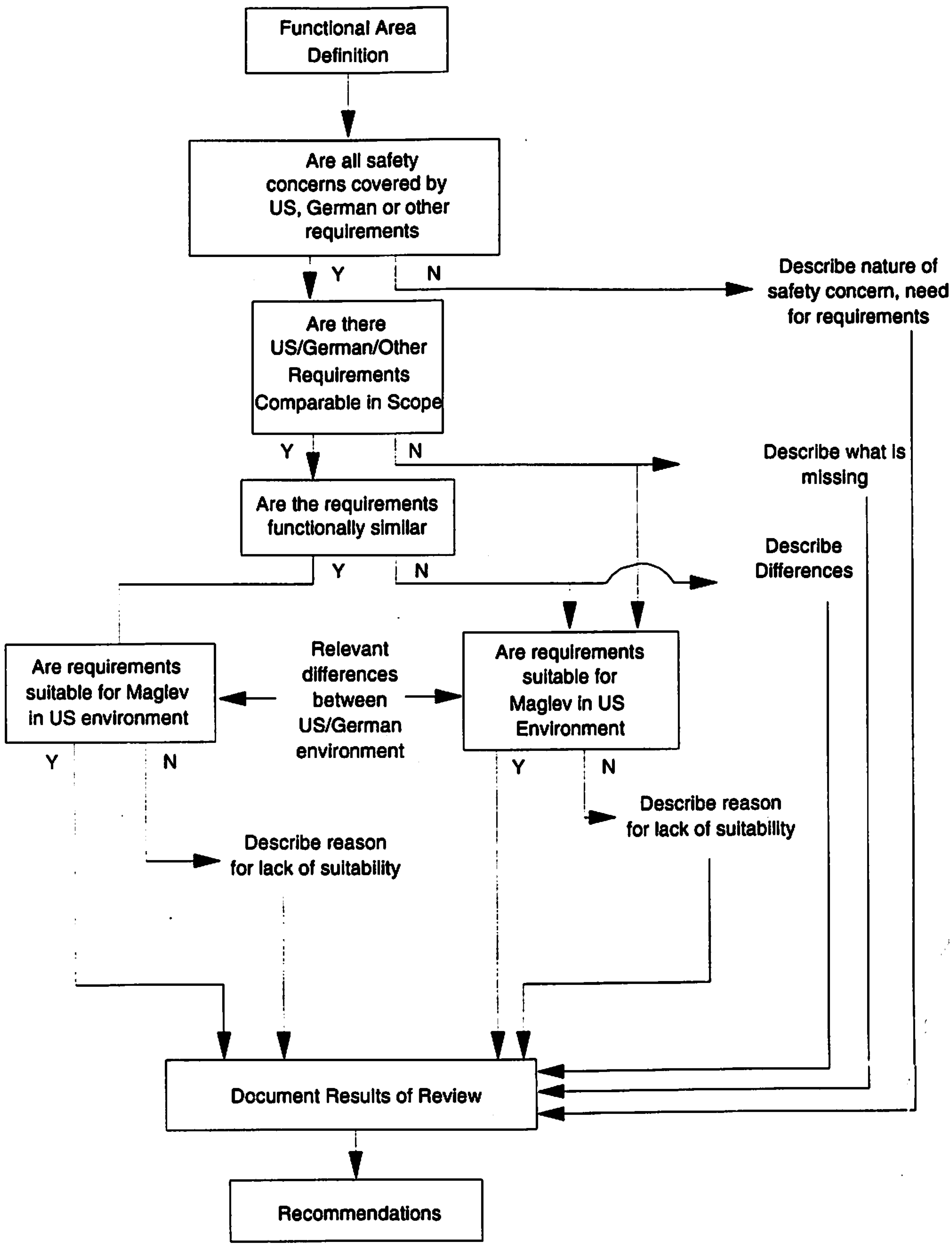


FIGURE 2.1. TECHNICAL REQUIREMENTS REVIEW PROCESS

The documents were reviewed to answer the following series of questions:

- **What safety concerns are associated with each functional area?** Safety concerns pertain to aspects of maglev system design, construction, or operation where a risk exists of adverse events that could cause casualties or property damage. The answers to this question for each functional area were expressed as a safety baseline, indicating where safety requirements appear to be warranted to protect against potential hazards.

  Useful sources of the answer to this question are four previous reports on HSGGT safety in the United States.

  - Preliminary Safety Review of the Transrapid Maglev System, November 1990 [4]

  - German High-Speed Maglev Train Safety Requirements-Potential for Application in the United States, February 1992 [5]

  - An Assessment of High-Speed Rail Safety Issues and Research Needs, December 1990 [6]

  - Maglev Signal/Control Assessment, April 1990 [7]

- **What are the relevant requirements in the U.S. and German documents, and how do they compare?** The relevant requirements from each source are described and significant similarities and differences are identified. Safety concerns which do not appear to be fully addressed by the RW MSB and other requirements are highlighted. The coverage of safety issues in the documents referenced in the RW MSB requirements varies. For example, electrical engineering technical requirements are covered in great detail, although electrical malfunctions are not a major cause of accidents and casualties in conventional guided ground transportation. In contrast, there is much less information on the subject of vehicle crashworthiness or accident survivability. These are clearly highly relevant subjects, and a number of technical requirements exist in the aviation and conventional railroad industries which are potentially applicable to maglev systems.

- **Are the identified safety requirements suitable for application to the U.S. high-speed maglev operating environment?** The U.S. environment may differ significantly from that in Germany in several important ways:

  - More severe weather environment
  - Greater risk of malicious damage by vandals
  - Different experience and/or education of operating employees
  - More stringent expectations on the part of passengers of the degree of protection from hazards

Where operating environment differences exist, safety requirements developed elsewhere may not be suitable for direct application in the U.S. Furthermore, safety requirements developed for conventional guided ground transportation systems may not be directly applicable to high-speed maglev systems, given significant differences in speeds, vehicle and train weights, degree of reliance on microprocessor controls for operation of support, guidance and train control systems, and other factors.

The answer to this question indicates which existing safety requirements are potentially applicable to U.S. maglev systems and which will need to be strengthened or revised to adequately address safety concerns.

The final step is to summarize the findings of the review regarding the need for and content of safety requirements for proposed U.S. high-speed maglev systems to address the significant safety concerns in each functional area.

The findings can be categorized as follows:

- No safety requirements are needed. There are no significant safety concerns associated with the functional area, and it is not a suitable subject for federal government regulations or guidelines.

- Application of an existing U.S. requirement is appropriate, for example from conventional railroad or aviation regulations, with or without modification. This approach is suitable when such existing regulations adequately address the safety concerns in a specific subject area.

- Adoption of German or other safety requirements is appropriate, with or without adaptation. This approach is applicable when such requirements adequately address all safety concerns in a functional area, there is no significant conflict with existing U.S. requirements, and there are no relevant operating environment differences.

- Development of new requirements specifically for maglev construction and operation in the United States is needed. This approach is appropriate only when the options described above are unable to address significant safety concerns in a functional area.

A standard six-point format has been developed to document the results of the reviews provided in Chapters 3 to 8 of this report.

- **Definition and Description of the Functional Area** provides a brief description of the functional area and, where necessary, detail regarding what is and is not included. This particularly applies where there may be some overlap or an interface with other functional areas, which are also briefly described.

- **Description of a Safety Baseline** provides a description in general terms of the potentially hazardous situations or events which must be avoided, and for which safety requirements may be desired.

- **Description of Existing Safety Requirements** provides a detailed description of the relevant content of all safety requirements identified. The safety requirements are described by origin -- Germany, United States, and other foreign and international requirements. The descriptions are accompanied by a table which lists the reference number, title, issuing organization, and applicability or intent of the requirement. Applicability or intent indicates the source of the requirements and the purpose from which they were developed. In particular, certain requirements have been developed for a specific transportation purpose; others are general industrial requirements applicable to a wide variety of industries or products. Most DIN and VDE requirements, and the equivalent requirements issued by ANSI, ASTM, and IEEE are for general industrial application and are not transportation-specific.

- **Comparison and Assessment** summarizes the similarities and differences between the requirements described in the previous step, their applicability and completeness in addressing the hazards identified in the Safety Baseline, and the extent to which their applicability is affected by differences in the U.S. and foreign-operating environments.

- **Findings** summarizes the results of the review regarding the need for and content of safety-related requirements within each functional area.

- **Further Studies** provides recommendations for further research where there is insufficient information available to properly assess the need for and content of safety requirements. This information is only provided where relevant and does not appear in all functional areas.

3. GENERAL SAFETY

3.1 FUNCTIONAL AREA 101 - SYSTEM SAFETY

3.1.1 Description of Functional Area

This functional area is concerned with the safety performance of the maglev system as a whole, and how the various subsystems and components work together to provide acceptable overall safety levels. In particular, system safety is concerned with the basic approaches adopted by a maglev system to control known guided transportation accident risks, such as collisions between vehicles and with objects on the guideway, fires, and loss of levitation or guidance. The risk of occurrence and severity of consequences from such adverse events must be managed so that overall safety targets are met.

This functional area provides an overall framework for evaluating maglev safety, and thus relates to all the functional areas discussed in this report. The relationship is particularly close with the following:

Functional Area 102, Reliability and Availability, provides guidance on how to achieve the required safety performance levels, while maintaining adequate service quality.

Functional Area 103, Quality Assurance, describes processes to ensure that the maglev system as constructed will provide the specified safety performance.

Functional Area 104, Certification, describes a process for delineating what tests and analyses have to be performed on a maglev system to demonstrate that it is in compliance with applicable safety requirements.

Functional Area 105, Computer Safety for Vehicle and Operations Control Systems, addresses system safety requirements applicable to computer systems performing safety-critical functions.

3.1.2 Safety Baseline

A high-speed maglev system operating in the United States must be, and be demonstrated to be, as safe or safer than other intercity public transportation modes. The risk of a passenger, employee or bystander becoming a casualty as result of maglev operations must be as low or lower than with the other modes, such as conventional rail or commercial travel.

To demonstrate that the required safety performance has been achieved, analyses are required to identify all possible safety threats, and assess the likelihood of occurrence and severity of consequences of accidents given a specific maglev system, subsystem and component design. Modifications must be carried out to achieve acceptability wherever risks exceed acceptable levels.

3.1.3 Description of Existing Safety Requirements

The existing requirements are listed in Table 3-1 and described below by origin under three headings: German, United States, and other foreign and international.

3.1.3.1 German Requirements

Chapter 0 of the RW MSB, Regulations for HIgh-Speed Maglev Trains, provides definitions used in the German maglev requirements.

Chapter 1 of the RW MSB, System Properties, Especially "Safe Hovering", provides a description of required system safety properties, especially "safe hovering." Safe hovering is a concept of maintaining vehicle levitation and guidance capability whenever the vehicle is operating, including after specified system malfunctions. With safe hovering, vehicle set-down can only occur at below a specified speed in a station or "safe stopping place." To ensure safe hovering, Section 3, Resulting Technical Requirements, states the following events must be ruled out with "adequate probability."

- Loss of levitation/guidance function
- "Racing" or magnet sticking
- Failure of the programmed braking function, including faults in the following subsystems:
  - Position location
  - Vehicle operational control equipment
  - Safety braking system
  - Violation of clearance limits

Chapter 1 of the RW MSB also describes the performance requirements for major subsystems of the maglev vehicle, especially the levitation and guidance systems including magnetic gap control to meet the safe hover requirement, and the safe programmed braking capability.

Section 1.4 of the draft MBO, Basic Rules, states that maglev operating installations and vehicles must be safe. Safety is assured if the requirements of the draft MBO are met, and the installations and vehicles follow the "recognized rules of technology."

Section 1.7 of the draft MBO, Safety Measures, states that the operator must specify measures to prevent the occurrence of accidents, minimize the consequences of any accident, and facilitate rescue in the event of an accident. Individual system features and measures must be combined into an overall concept and submitted to the competent authority. Section 1.7 also specifies the provision of an adequate number of auxiliary stopping places for a vehicle occupant evacuation, and that vehicle control systems must be structured so that vehicles can always reach the auxiliary stopping points.

TABLE 3-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 101 - SYSTEM SAFETY

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1	System Properties, Especially Safe Hovering	Maglev
German Government	Draft MBO	Section 1.4 Section 1.7 Section 2	Basic Rules Safety Measures General Requirements	Maglev
	EBO	Section 2	General Requirements	Railroad
Basler and Hofmann	Report SB 1661.00 Safety Concept for the Maglev Train	-		Maglev
DIN-VDE	31000 General Guide for Designing Technical Equipment to Satisfy Safety Requirements	Part 2		General
VDI	2244 Design of Safe Equipment and Machinery			General/Industrial
VDI/VDE	3540 Safety Terms for Automation Equipment			General/Industrial

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 3-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 101 - SYSTEM SAFETY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
Department of Defense	MIL-STD 1629A Procedures for Performing a Failure Mode, Effects and Criticality Analysis			Military/General
	MIL-STD 882B System Safety Program Requirements	- -		Military/General
FAA	14 CFR, Part 25 Airworthiness Standards Transport Category Airplanes Advisory Circular AC 25.1309-1A System Design and Analysis	Part 25-1309	Equipment, Systems and Analysis	Aviation
APTA	Manual for the Development of a System Safety Program Plan	-		Rail Mass Transit

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The EBO, Paragraph 2, General Requirements, requires that railroad installations and rolling stock must be structured so as to comply with the requirements of safety and order. Safety is assured if the installation and vehicles are in compliance with the EBO, and with the acknowledged rules of technology.

DIN VDE 31000, General Guide for Designing Technical Equipment to Satisfy Safety Requirements, describes basic safety concepts and defines safety terms. The concept that nothing is risk-free is introduced, leading to a requirement for technical products to be designed to have a safety performance that is below a defined risk limit.

VDI 2244, Design of Safe Equipment and Machinery, and VDI/VDE 3540, Safety Terms for Automation Systems, are both guides to safety assessment methodologies, and to techniques for achieving safety goals. VDI/VDE 3540 concentrates on defining terminology and concepts for both qualitative and quantitative risk assessment; Part 3 provides examples of risk assessments and analyses of systems. VDI 2244 is a more general guide to the design of equipment for safety. Techniques for safety assessment and measures for improving safety are defined and described, followed by several examples of applying the techniques to different safety situations. One example is aircraft control surfaces for which failure frequency thresholds are related to the consequences of failure, as shown in Table 3-2.

TABLE 3-2. FAILURE FREQUENCY THRESHOLDS FOR AIRPLANE CONTROL SURFACES

Failure Consequences	Failure Frequency Threshold
Catastrophic	$<10^{-9}$/hour
Hazardous	$<10^{-7}$/hour
Major	$<10^{-5}$/hour
Minor	$<10^{-3}$/hour

Source: VDI 2244

A report by Basler and Hofmann, Safety Concept for the Maglev Train [8] is a comprehensive risk analysis for a German Transrapid maglev route between Bonn and Essen. A fault tree and quantitative risk model is developed and used to select maglev system features to meet defined safety goals.

3.1.3.2 U.S. Requirements

The Military Standard System Safety Program Requirements (MIL-STD 882C) is a manual for managing system safety in new equipment. The primary safety assessment technique embodied in MIL-STD 882C is Preliminary Hazard Analysis (PHA). PHA involves the identification of hazards, using checklists and other methods, and a qualitative assessment of the frequency of occurrence and the severity of consequences of each hazard based on all available information. Remedial action is required where the severity/frequency combination exceeds acceptable thresholds. These actions can be in one of four categories, in order of precedence.

- Design for Minimum Risk
- Incorporate Safety Devices
- Provide Warning Devices
- Develop Procedures and Training

MIL-STD 1629A Procedures for Performing a Failure Mode Effects and Criticality Analysis (FMECA) is a manual for FMECA applied to military systems. Both qualitative and quantitative analyses are described.

FAA requirements contained in 14 CFR, Part 25.1309, Equipment Systems and Installation is a qualitative requirement for systems used in commercial aircraft. The principal requirements are as follows:

- The occurrence of any failure that would prevent continued safe flight and landing must be extremely improbable.

- Warnings information must be provided to the flight crew if any unsafe condition develops, and appropriate corrective actions must be defined.

- Compliance must be demonstrated through appropriate failure analyses and tests.

- Electric power supply to essential equipment must be shown to be adequately reliable.

The FAA Advisory Circular (AC) 25.1309-1A, System Design and Analysis, provides guidelines for the requirements in 14 CFR, Part 25.1309, with particular reference to safety assessment techniques that can be used to determine that a particular system or component complies with the requirements. Applicable techniques described include the following:

- Functional Hazard Assessment (FHA), which involves identifying, classifying and describing potentially hazardous failure conditions.

- Failure Modes and Effects Analysis (FMEA) and the very similar Failures Modes, Effects and Criticality Analysis (FMECA).

- Fault Tree (FTA) or Reliability Block Diagram Analysis.

- Qualitative Probability Assessment, similar to the frequency assessment portion of a Preliminary Hazard Analysis.

- Quantitative Risk Assessment (QRA), assigning quantitative frequencies and probability to a FMEA or FTA block diagram to determine failure probabilities.

The APTA Manual for the Development of System Safety Program Plan, provides a framework for developing system safety plans for rail mass transit systems. The manual basically follows the process of MIL-STD 882C.

3.1.4 Comparison and Assessment

The reviewed documents cover three distinct subjects:

- Methods for system safety assessment, and of achieving safety goals which can be applied to any type of equipment.
- Specific system features appropriate to a high-speed maglev system operating over an elevated guideway.
- Examples of safety assessments applied to the German Transrapid maglev system.

3.1.4.1 System Safety Assessment and Design Techniques

The German and U.S. documents describe similar definitions and assessment techniques, and also discuss the same concepts for achieving high safety performance such as safe-life fail-safe, redundant and fault tolerant systems. In referencing such documents, the RW MSB indicates that structured safety assessments must be performed on a proposed maglev system to demonstrate that safety is adequate, and that appropriate methods have been used to achieve desired safety levels.

Such safety assessments are essential for any high-speed maglev system embodying new technology. The type of assessment is a function of the stage of system development. At conceptual and preliminary design stages, detailed design information will be lacking and emphasis should be on identifying and classifying potential hazards, such as in a PHA, and initiating action to resolve instances of unacceptable performance. When a more detailed design is available, more detail-oriented methods such as FMECA, FTA, and QRA are appropriate.

The question of system safety goals is considered in another study recently completed for the FRA related to collision avoidance and accident survivability. The safety goal as specified by the FRA for any new HSGGT system states that a level of safety equivalent to existing intercity public transportation systems must be provided. This safety study developed a quantitative measure of equivalent safety, expressed by two requirements:

- The rate of passenger fatalities in accidents should not exceed 0.2 per 10^9 passenger-km.
- The incidence of accidents at different severity levels shall not exceed the risk profile shown in Figure 3-1.

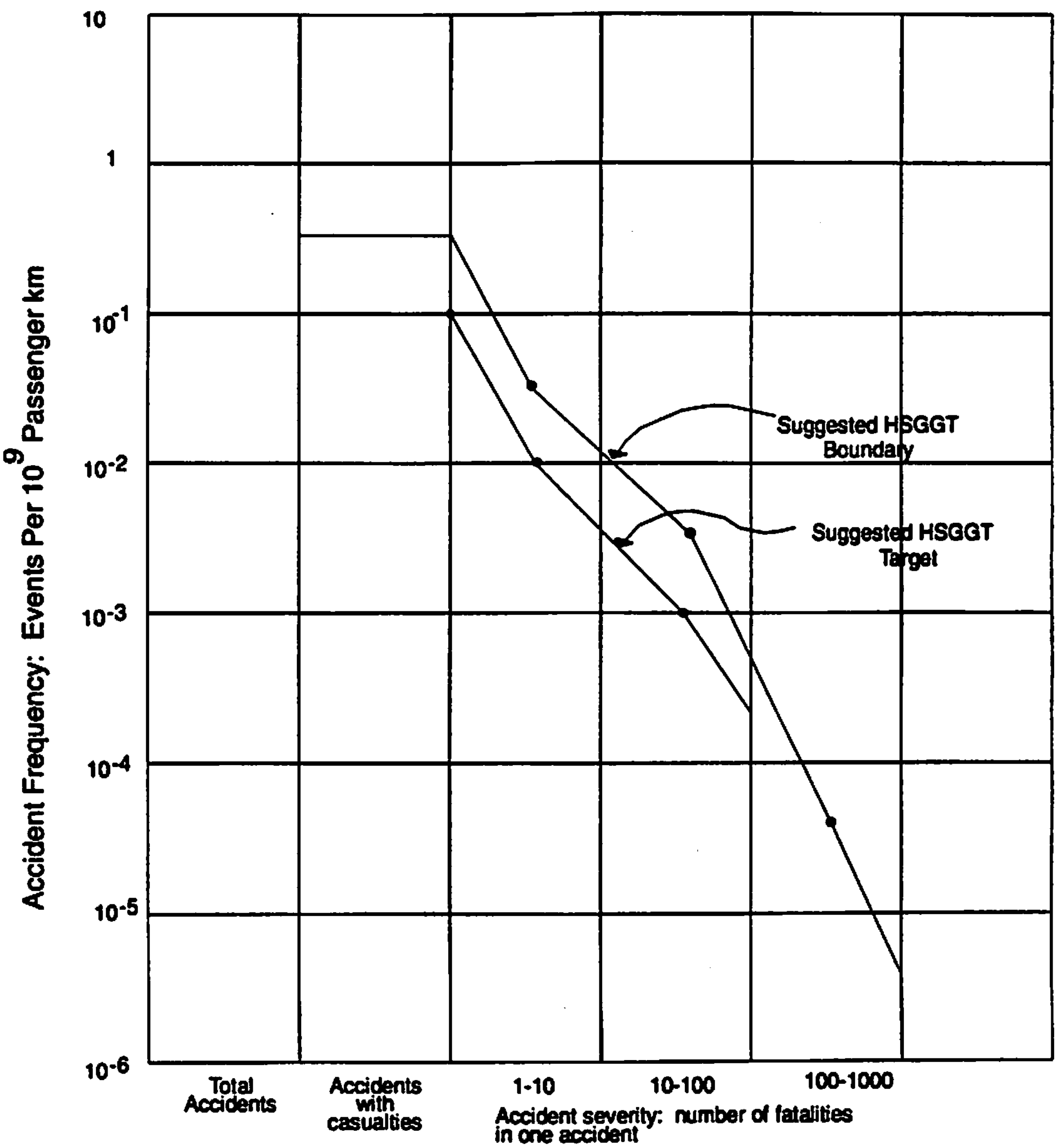


FIGURE 3.1 SUGGESTED RISK PROFILES FOR HIGH SPEED GUIDED GROUND TRANSPORTATION SYSTEMS

Source: Reference 9

Further details of the derivation and application of these requirements are given in the final report [9].

3.1.4.2 Maglev-Specific System Safety Requirements

The RW MSB and draft MBO contain requirements specific to high-speed maglev systems. These requirements, and their underlying premises, are as follows:

- Because the consequences of a high-speed collision would be catastrophic, the RW MSB requires full automation of vehicle control. The on-board operator monitors on-board systems and can initiate an emergency stop, but cannot operate the vehicle except possibly at very low speed - below 50 km/h (30 mph). The draft MBO permits manual operation at high speed, with two operators, and with full automatic supervision.

- Because a high-speed, uncontrolled set-down of the vehicle (loss of levitation) is considered unacceptable, the vehicle must be designed on the safe hover principle. This means that the levitation and guidance systems must be able to operate long enough to permit the braking of the vehicle to rest in the event of any anticipated vehicle or control system failure.

- Because it is judged not feasible to provide adequate emergency egress at all points along an elevated guideway, the concept of safe programmed braking has been specified. This concept requires that the vehicle speed and braking rate be controlled, and sufficient safe stopping places be provided so that the vehicle can always reach a safe stopping place in the event of any anticipated vehicle or control system failure.

All these requirements are system configuration choices, and alternative choices providing an adequate safety level may, in principle, be available. However, the requirement for automatic control or supervision of operations must be a precondition of high-speed maglev operations. There is no feasible way of providing protection to vehicle occupants in a high-speed collision, and any system lacking such controls would certainly be unable to meet overall system safety goals. The only question is the speed threshold below which manual operation may be permitted. The speed of 50 km/h (30 mph) specified by the draft MBO appears to be reasonable.

The second and third requirements, the safe hover and safe stopping place approaches, are specific safety-related system configuration choices mandated by the RW MSB and the draft MBO. Alternatives providing equivalent safety may be available, especially for emergency evacuation from the maglev vehicle.

Also, the systems providing safe hover and safe programmed braking to a designated stopping place are complex and need to be analyzed carefully to be sure that they are adequately safe. Therefore, it is not possible to confirm that these system configuration choices provide the required overall safety performance without detailed failure analyses.

3.1.4.3 Transrapid System Safety Analyses

The Basler and Hofmann safety assessment applies specifically to the Transrapid electromagnetic maglev system and provides partial assurance that the Transrapid system is able to meet overall safety goals. The assessment also provides useful material and guidance for performing equivalent studies for other maglev systems and route variants.

3.1.5 Findings

Both current FAA regulations and the RW MSB require structured system safety analyses. Furthermore, the U.S. Department of Transportation (DOT) statement of National Transportation Policy (NTP) says that safety is a top DOT priority and that safety in public transportation will be promoted by encouraging the development of industry safety standards and implementation of system safety plans. Under this policy, the FRA is carrying out comprehensive safety assessments of high speed rail and maglev systems proposed for installation in the United States. Furthermore, system safety analyses derived from the procedures described in MIL-STD 882C have been used in the U.S. for system safety analyses for different surface transportation systems, including previous studies of maglev system safety. Thus, comprehensive system safety analyses are becoming a widely used practice in transportation safety assurance, and are highly appropriate for transportation systems that embody new technology such as maglev.

For U.S. applications, consideration should be given to a requirement to perform structured system safety analyses on the maglev system as a whole and on safety-critical subsystems. A number of suitable, well-documented safety assessment procedures are available, including Preliminary Hazard Analysis (PHA), Fault Tree Analysis (FTA), Failure Modes and Effects Analysis (FMEA) and Quantitative Risk Analysis (QRA). The FAA requirements contained in 14 CFR, Part 25.1309 and AC 25.1309.1A also provide helpful guidance. A parallel study for the FRA [9] suggested some quantitative safety performance goals for high-speed ground transportation systems for use with QRA, and provides more detailed descriptions of system safety analysis techniques. The specific technique used is a function of the availability of engineering and safety performance data, the development status of the system or application being analyzed, and the exact purpose of the particular analysis.

The "safe hover" and "safe stopping place" approaches to achieving the desired system safety performance specified in the German requirements need to be carefully reviewed. A very low failure rate for several complex sub-systems is required to produce the desired performance. It is necessary to analyze the safety performance of the vehicle and guideway systems which provide the safe hover and safe stopping place capabilities in the same way as for other safety-critical systems. It is possible that alternative ways of achieving the desired safety goals are available.

3.1.6 Further Studies

A comprehensive understanding of system safety concepts and analysis techniques is critical to the safe development and operation of innovative maglev systems. It has only been possible to conduct a limited review of safety assessment techniques in this study. A more comprehensive review of this subject, together with the closely related subjects of reliability and availability, is highly recommended leading to detailed safety and reliability assessment guidelines for application to maglev and other HSGGT systems.

3.2 FUNCTIONAL AREA 102 - RELIABILITY AND AVAILABILITY

3.2.1 Description of Functional Area

In order to design a maglev system to meet the overall system safety requirements, it is necessary to carefully consider component and subsystem reliability, and to use suitable design philosophies to ensure that there is a very low probability of a safety-critical equipment becoming inoperative or unavailable in service. Design philosophies to achieve this goal include safe-life, fail-safe, redundancy and fault tolerance.

This functional area addresses the definition of these reliability and availability concepts, and the application of the different subsystem and component design philosophies to achieve desired safety goals.

This functional area is closely related to the following functional areas:

Functional Area 101, System Safety, addresses overall system safety goals and techniques for system safety assessment.

Functional Area 105, Computer Safety for Vehicle and Operation Control System, is a major area for the application of redundancy and fault tolerance in system design.

Functional Area 207, Brake Installation and Performance, where safety and reliability are critical concerns.

Functional Area 401, Operations Control System Design, a major area for the application of redundancy and fault tolerant design techniques.

In addition to the above, the different ways of achieving the required reliability and availability of safety-critical components and subsystems must be considered in virtually all vehicle, guideway and systems functional areas discussed in this report.

3.2.2 Safety Baseline

Meeting overall system safety goals (discussed in Functional Area 101) means that each safety-critical component and subsystem must be designed to meet certain individual reliability and availability goals. The goals can be defined as a minimum mean time between hazardous failures or a similar measure of safety performance. To meet the goals, each component or subsystem must be designed using an appropriate approach to achieving the desired safety performance. Whether fail-safe, safe-life, redundancy or fault tolerance approaches or combinations thereof are used, the design of a subsystem or component must be carried out with a proper understanding of the capabilities and limitations of each approach to safety performance, and properly reflect the reliability and service life performance of the components used.

3.2.3 Description of Existing Requirements

The requirements identified are listed in Table 3-3, and are described below by origin under three headings: German, United States, and other foreign and international.

3.2.3.1 German Requirements

Chapter 0 of the RW MSB provides formal definitions of safe-life, fail-safe, and redundancy, as listed below:

Reliability: Condition of a unit with regard to its suitability for meeting the reliability requirements during or after predetermined intervals under given service conditions (from DIN 40 041, Dec. 1990).

Availability (momentary): Probability of encountering a unit at a given time within the required service life in a functionally capable state (from 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 (from DIN 40 041, Dec. 1990).

Safe-life: During the anticipated service life, neither the product as whole, nor any of its critical subfunctions may fail (from VDI 2244, May 1988).

Redundancy: Presence of more functionally capable means in one unit than would be necessary to perform the required function (from DIN 40 041, December 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 (from VDI/VDE 3542, Chapter 1, Dec. 1988).

The RW MSB does not provide a definition of fault-tolerance as distinct from redundancy.

Chapter 1 of the RW MSB specifies the approach to be used to achieve required safety performance for different safety-critical subsystems.

In particular, redundancy is required in the on-board power supply systems, in magnetic levitation and guidance units, and in the safety braking system because the failure of individual units cannot be ruled out. Section 7.3 of Chapter 1 states that tests or analyses must be performed to prove that required performance has been achieved in the case of components designed on the fail-safe or safe-life principles.

Fail-safe and safe-life requirements for individual systems are discussed in this report under individual functional areas.

TABLE 3-3. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 102 - RELIABILITY AND AVAILABILITY

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 0 Chapter 1	Regulations for High-Speed Maglev Trains System Properties, Especially "Safe Hovering"	Maglev
DIN	40 041 Dependability Concepts	-		General
VDI/VDE	3542 Reliability, Redundancy and Fail-Safe Design of Safety-Critical Systems	-		General
VDI	2244 Design of Safe Equipment and Machinery	-		General
VDI	4005 Effect of Environmental Conditions on Reliability of Technical Products	-		General
FAA	14 CFR, Part 25 Airworthiness Standards for Transport Category Airplanes	Part 25.1309	Equipment, Systems and Installation	Commercial Aircraft
FAA	Advisory Circular 25.1309-1A System Design and Analysis			Commercial Aircraft

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 3-3. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 102 - RELIABILITY AND AVAILABILITY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
Department of Defense	MIL-STD 721 Definition for Reliability Engineering	-		Military/General
	MIL-STD 785B Requirements for Reliability Program (Systems and Equipment)	-		
	MIL-STD 756B Reliability Modelling and Prediction	-		
	MIL-STD 781D Reliability Testing	-		
	MIL-STD 1543A Reliability Program Requirements for Space and Missile Systems			
	MIL-HDBK 217F Reliability Predictions for Electronic Equipment			
APTA	Glossary of Reliability Availability and Maintainability Terminology for Rail Rapid Transit			Rail Mass Transit
	Guideline for Rail Rapid Transit Reliability Availability and Maintainability Specifications			

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

Several German requirements documents referenced in the RW MSB contain reliability, availability and related definitions, as well as guidance regarding reliability and availability analysis.

DIN 40.041, Dependability Concepts, contains only definitions of reliability terminology, including the definitions quoted above in Chapter 0 of the RW MSB.

VDI/VDE 3542, Safety Terms for Automation Systems Safety Requirements, contains similar definitions DIN 40.041, and also terms used for types of failure and for the statistical quantification of failure or defect rates. Part 3 contains a procedure for calculating failure rates and several examples of the calculation of failure rates for different components and systems. The effects of redundancy on failure behavior are described.

VDI 2244, Design of Safe Equipment and Machinery, is primarily concerned with safety assessment techniques, but includes descriptions of various ways of achieving desired safety performance. The definition of "safe-life" given in the RW MSB is derived from VDI 2244. Definitions are also provided for fail-safe and fault tolerance. Techniques for achieving safety described in qualitative terms include redundancy and diversity. Several examples of safety assessments are provided.

VDI 4005, Effect of Environmental Conditions on Reliability of Technical Products, specifies procedures for evaluating the effect of environmental factors on the reliability of technical products. The first step in the process is to identify environmental factors that will influence a piece of equipment, given its application, using a checklist provided. Potential environmental factors include:

- Mechanical shock and vibration
- Thermal and climatic effects (such as temperature, humidity, etc.)
- Chemical and biological effects
- Electromagnetic effects

Appropriate methods of quantifying the environment are specified, and corresponding test and analysis procedures are identified for each. Reference is made to other technical requirements documents for test and analysis procedures, including U.S. Military Standards (MIL-STD) in each area, especially MIL-STD 810, Environmental Test Methods. VDI 4005 is cited in RW MSB in the sections providing requirements for electrical and electronic equipment.

3.2.3.2 U.S. Requirements

The FAA requirements contained in 14 CFR, Part 25.1309 specify that airplane systems and associated components must be designed to ensure that they perform their functions under all foreseeable operating conditions, and that the occurrence of any condition that would prevent continued safe flight and landing is extremely improbable. Safety and reliability analyses must consider all possible modes of failure, including those due to external sources, and the probability of multiple failures and undetected failures.

The FAA Advisory Circular (AC) 25.1309-1A, System Design and Analysis, provides guidance regarding the interpretation of paragraph 25.1309, and includes a definition of the fail-safe design concept as follows:

- No single failure, regardless of probability, shall prevent the continued safe flight and landing of the airplane.

- Subsequent failures should also be assumed, whether detected or latent, unless their joint probability with the first failure is shown to be extremely improbable. "Extremely improbable" is defined by the FAA as a failure that is not anticipated to occur during the operational life of all airplanes of one type. Numerous techniques to achieve fail-safe design are listed, including redundancy, avoidance of common-mode failure situations, and adequate design safety margins to allow for unforeseen operational conditions and expected build-up of errors during manufacture. AC 25.1309-1A also provides guidelines for carrying out safety and reliability assessments. These are further described in Functional Area 101, System Safety.

MIL-STD 721, Definitions of Terms for Reliability and Maintainability, includes definitions for availability, reliability and redundancy, and many other terms used in reliability and maintainability engineering as listed below. No definitions are provided for fail-safe or safe-life.

Availability: A measure of the degree to which an item is in an operable and committable state at the start of a mission, when the mission is called for at an unknown (random) time.

Dependability: A measure of the degree to which an item is operable and capable of performing its required function at any (random) time during a specified mission profile, given item availability at the start of the mission.

Redundancy: The existence or more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical.

Redundancy, Active: That redundancy wherein all redundant items are operating simultaneously.

Redundancy, Standby: That redundancy wherein the alternative means of performing the function is not operating until it is activated upon failure of the primary means of performing the function.

Reliability: (1) The duration or probability of failure-free performance under stated conditions. (2) The probability that an item can perform its intended function for a specified interval under stated conditions. (For non-redundant items, this is equivalent to definition (1). For redundant items this is equivalent to definition of mission reliability.)

MIL-STD 785B, Reliability Program for Systems and Equipment Development and Production, provides detailed requirements for performing a series of tasks which together comprise a comprehensive reliability assessment program.

MIL-STD 756B, Reliability Modeling and Prediction, identifies and describes the different methods of predicting reliability when evaluating a design from concept to development. The document provides both the general requirements of reliability modelling and detailed descriptions of each task and method. Equations for modelling are presented for conventional reliability, Monte Carlo simulation and other methods.

MIL-STD 1543 (USAF), Reliability Program Requirements for Space and Missile Systems, is similar to MIL-STD 785, but prepared by the Air Force and tailored to the aerospace industries.

MIL-STD 781D, Reliability Testing for Engineering Development, Qualification and Production, provides specifications for reliability test programs, as a function of the type of equipment and where it is installed (e.g., on an aircraft or a ground vehicle). The programs include tests to quantify the operational environment, functional tests and environmental tests (vibration, temperature, etc.).

MIL-HDBK 217F, Reliability Predictions for Electronic Equipment, and Technical Reference TR TSY 00032 Issue 2, July 1988, Reliability Prediction Procedure for Electronic Equipment, both provide actual predictions for the reliability of electronic components as a function of component quality (commercial, aerospace, military) and of the operating environment.

The American Public Transit Association (APTA) Glossary of Reliability, Availability and Maintainability Terminology for Rapid Rail Transit defines these terms using language appropriate to rail transit engineering and operations. This document includes a definition of *fail-operational fail-safe* as follows:

Fail-Operational Fail-Safe: A system characteristic which permits continued operation on occurrence of a failure while remaining acceptably safe. A similar failure results in the system remaining safe, but non-operational.

The APTA Guidelines for Rail Rapid Transit Equipment Reliability, Availability and Maintainability (RAM) provides concise procedures and guidelines for quantifying, assessing, analyzing and managing RAM in the context of a rail rapid transit organization.

3.2.4 Comparison and Assessment

The reviewed documents cover three areas of reliability and availability:

- Definition of terms.
- Design philosophies or techniques for achieving desired reliability and availability levels, consistent with overall safety goals.
- Reliability and availability assessment techniques.

With regard to the definitions of terms, the documents are generally in agreement with each other, although there are some minor differences in some of the definitions. For example, in AC 13091A, the FAA defines fail-safe to include any failure which still leaves the airplane operational. In rail transit, fail-safe means the equipment fails at a safe but not necessarily operational state. Only the German documents provide a definition of the "safe-life" principle, although it is widely used in practice, in particular for structures. None of the documents provide a definition of "fault tolerant" as distinct from "redundant."

With regard to reliability engineering techniques, the German requirements VDI 2244, and VDI/VDE 3542, both provide short discussions of techniques to obtain a given level of reliability and availability. There is also a somewhat less structured discussion of the same subject in the FAA AC 25.1309-1A and some material in the APTA guidelines.

The third area, reliability and availability assessment, is very closely related to safety assessment as discussed in Functional Area 101. The techniques are very similar, and the discussion provided in Functional Area 101 applies equally to this functional area. One subject that may be of particular relevance is that of translating foreign reliability experience to the United States. The U.S. climatic environment may be more severe. There may be a larger temperature and humidity range, and possibly a more corrosive environment may exist due to proximity to salt water. Therefore, the extent to which reliability of individual components, and therefore, overall availability and safety performance, is influenced by these environmental factors needs to be quantified. The question of environmental influences on reliability is discussed in VDI 4005, and an assessment of these environmental effects is a required task in the military reliability programs, MIL-STD 785B and MIL-STD 781D.

Reliability data has been developed for components of the German Transrapid maglev system, and is used in the Basler and Hofmann safety study described under Functional Area 101, and in a Thyssen-Henschel study, [10]. More generally, extensive reliability data exists for electronic equipment, derived from military experience (MIL-HDBK 217F and TR TSY00032). Rail mass transit system operators are also active in assembling reliability data.

3.2.5 Findings

Current FRA regulations do not require any reliability and availability assessment to be carried out on a new railroad or maglev system. However, such assessments are specified in the German requirements, and are used selectively on existing railroad and mass transit systems. Use of such assessments is likely to increase, since they help improve the quality and efficiency of services, as well as improve safety management. Thus, reliability and availability assessments will be an important part of the overall safety assessment of a maglev system. For U.S. maglev system applications, consideration should be given to a requirement to carry out a structured reliability and availability analysis of the system as a whole, and on safety-critical subsystems.

The overall reliability assessment program should conform to a generally accepted technical requirement such as MIL-STD 785B. To the extent possible, the reliability data used in analysis should be derived from direct testing or operational experience in a comparable environment, or taken from a generally accepted reference source.

3.2.6 Further Studies

Further study of this subject is recommended, leading to reliability and availability guidelines for maglev and other HSGGT systems. Some of the reviewed documents are relatively inaccessible to U.S. readers as they are not available in English translation; others have not been prepared specifically for maglev or other HSGGT systems. The recommended guidelines should include definitions of terminology, descriptions of the different methods of obtaining adequate reliability and availability, guidance on how such methods should be applied to HSGGT systems, and guidance on reliability analysis. A compilation of reliability data for maglev system components would also be very useful.

3.3 FUNCTIONAL AREA 103 - QUALITY ASSURANCE

3.3.1 Description of Functional Area

In the most general sense, Quality Assurance (QA) is the activity which ensures that all systems, subsystems and components are conceived, designed, manufactured, and maintained so that their performance will fully meet all requirements of the vehicle operators, passengers, and government regulators, including those responsible for applicable safety requirements. Quality Assurance is a process and is independent of the specific technical requirements for a material, subsystem, or component. Quality Assurance processes are also applicable to ongoing maintenance and operational activities, and the QA process is likewise independent of the specific technical requirements for an activity.

The safety concern associated with QA is that a significant lack of quality in design, manufacture, construction, operation or maintenance could lead to a seriously substandard subsystem or component being installed in a maglev system, or incorrect maintenance or operational procedures being used, resulting in an accident.

QA concepts and procedures are applicable to all the functional areas discussed in this report.

3.3.2 Safety Baseline

Comprehensive Quality Assurance procedures are required in any project as complex as a high-speed maglev system to ensure that all subsystems, components and operations and maintenance activities conform to specified safety requirements. Since components and subsystems will be supplied by a broad spectrum of manufacturers in the United States, Europe and possibly elsewhere, it is preferable that the QA processes used are internationally known and accepted.

3.3.3 Description of Existing Requirements

The existing requirements are listed in Table 3-4, and are described below under three headings by origin: German, United States, and other foreign and international.

3.3.3.1 German Requirements

Chapter 7 of the RW MSB specifies a series of Euronorm (EN) requirements, 29000 to 29004 inclusive, for quality management and quality assurance. This series, collectively entitled Quality Management and Quality Assurance Standards - Guidelines for Selection and Use is identical to the German requirements in DIN 9000 to 9004.

EN 29000-29004 are only cited in the RW MSB in connection with vehicle manufacturing, although they can be applied, in principle, to any part of the maglev system.

TABLE 3-4. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 103 - QUALITY ASSURANCE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 7	Design Production and Quality Assurance of Mechanical Structures	Maglev
European Community	EN 29000 to EN 29004 inclusive Quality Management and Quality Assurance Standards	EN 29000 EN 29001 EN 29002 EN 29003 EN 29004	Guide to Selection and Use Model for QA in Design/Development, Production Installation and Servicing Model for QA in Production and Installation Model for QA in Final Inspection and Test Quality Management and Quality System Elements-Guidelines	General Industrial
International Standards Organization	9000-9004		Identical to EN 29000-29004 above	General Industrial
DIN	9000-9004		Identical to EN 29000-29004 above	General Industrial
ANSI/ASQC	Q90-Q94		Identical to EN 29000-29004 above	General Industrial
AAR	Manual of Standards and Recommended Practices	Section J MI003	Specification for Quality Assurance	Railroad
ASCE	Manual of Engineering Practice	No. 73	Quality in the Construction Project	Construction Industry

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The requirements embodied in EN 29000-29004 can be summarized as follows:

- EN 29000 provides an introduction to the quality management concepts, and to the other requirements EN 29001-EN 29004 inclusive.

- EN 29004 describes the quality control concepts embodied in the series of requirements 29000-29004. EN 29004 introduces a closed-loop control concept to quality management that ensures that any failure of a product or service to meet desired requirements is quickly identified and traced back to its cause, whether this is in design, manufacturing, testing or maintenance or any other process involved in delivering the product or service.

  To perform quality control as specified in EN 29004, an organization has to design procedures which must be embodied in a manual and implemented throughout the organization. These procedures should themselves be audited to ensure that they provide the expected benefits. It is customary in Europe for QA procedures to be audited by an authorized independent organization as being in compliance with EN 29000-EN 29004. The resulting certification is generally accepted in the engineering industries in Europe and is frequently required by purchasers of engineering products.

  EN 29004 then proceeds to describe the content of a quality management program for each stage in the conception, design, manufacture, distribution and maintenance of a product or a service. Section 8 on quality in specification and design is particularly applicable to high-speed maglev systems at their present stage of development, and includes recommendations to perform FMEA or similar safety and reliability analyses, carry out tests, validate computer systems and software, and to properly control design changes.

- EN 29001, EN 29002, and EN 29003 provide detailed specifications for quality management in a format that can be incorporated in contracts between a purchaser and a supplier of goods and services, following the principles described in EN 29004. The specific manufacturing activities covered in each document are:

  EN 29001: Design/development, production, installation and servicing
  EN 29002: Production and installation
  EN 29003: Final inspection and test

The requirements used depend on the nature of the activity to which the QA procedure is being applied.

3.3.3.2 U.S. Requirements

As well as ANSI/ASQC Q90-Q94 which are identical to EN 29000-EN 29004 described above, two U.S. Quality Assurance requirements have been identified.

The American Society of Civil Engineers (ASCE) published a guide to "Quality in the Construction Project" in 1990. This publication is a manual of good construction management practices for the whole project from conception to completion. There is only one short chapter (Chapter 19) devoted to the narrower subject of quality assurance. A traditional approach is taken to quality management, concerned with ensuring that appropriate inspections and tests are specified, firms and individuals are properly qualified, and that appropriate records are maintained and similar matters. Quality management concepts similar to those in EN 29000-29004 are not described or referenced.

The Association of American Railroads (AAR) developed a Specification for Quality Assurance (Section J of the Manual of Standards and Recommended Practices, also known as "M1003") in 1985 and issued a substantially revised version in 1991. The philosophy adopted by the AAR is similar to that of EN 29000-EN 29004 -- that a supplier of any equipment should design, document, and implement a set of QA procedures to be used throughout the organization. An independent audit certifies that a supplier's QA procedures are in compliance with the requirements. The AAR QA requirements provide administrative procedures for obtaining certification and for qualifying auditors, as well as the QA procedures themselves.

3.3.3.3 Other Foreign and International Requirements

The Quality Assurance and Quality Management Standards, EN 29000 to 29004 have been adopted by several individual countries and international standards-setting organizations, as well as by Germany and the U.S. as described above. In particular, the International Standards Organization (ISO) series ISO 9000-9004 and British Standard BS 5750 are identical to EN 29000-29004, ANSI/ASQC Q90-94 and DIN 9000-9004, apart from the language used.

3.3.4 Comparison and Assessment

The traditional way of ensuring quality in manufacturing, construction, maintenance and operations is through thorough post-manufacturing or construction measurements and tests, and close supervision and independent inspection of all activities. Such techniques are widely used throughout the guided ground transportation industry.

The major shortcoming of the traditional approach is that it identifies quality deficiencies relatively late in the manufacturing or other process, potentially causing severe delays and high costs to rectify errors. The traditional approach also typically fails to give employees a strong incentive for considering quality in their work. Often rate of production is the primary measure that is emphasized, and there is no self-correcting feedback mechanism to correct quality problems. To address these shortcomings, a set of new quality assurance processes have been developed, which go under the name of Total Quality Management or TQM. The procedures in EN 29000-29004 are a TQM process designed primarily for manufacturing industry, although they can be applied in principle to construction projects, and operating and maintenance services as well.

The TQM requirements of EN 29000-29004 have been widely accepted in Europe, and are a customary requirement in procurement contracts; for example, for railway and rail transit rolling stock. Supplier firms are certified by an independent organization as having implemented a QA process which complies with the requirements.

U.S. industry has lagged significantly behind Europe in the application of these QA processes, but EN 29000-29004 and similar processes (such as the AAR Manual, Section J) are now becoming more widely accepted and applied. Use of these processes are confined largely to manufacturing: the processes are not much used in construction, operations and maintenance activities. In the railroad industry, the AAR Manual Section J requirements have been adopted and are being further developed by the Railroad Industry Group of the National Association of Purchasing Management for application throughout the U.S. railroad supply industry. Since any maglev likely to be implemented in the United States in the next several years is likely to be a cooperative effort of U.S. and foreign firms, the use of internationally accepted QA requirements (such as EN 29000-EN 29004) is highly desirable. Suppliers of components and subsystems would have a common understanding of QA requirements and expectations regardless of their nationality.

TQM-like techniques can also be applied to safety management, specifically setting up a process by which all employees are empowered to consider safety in their day-to-day work. Feedback mechanisms are established to ensure that safety problems are observed and identified and fixed.

There are clearly good reasons for applying QA processes of the type embodied in EN 29000-29004 and their equivalents as widely as possible in the manufacture, construction, operation and maintenance of a maglev system. As well as reducing the risk of an accident due to errors in any activity, a properly structured QA program has the potential to reduce costs, delivery delays, and operational delays.

3.3.5 Findings

Present FRA safety requirements do not include quality assurance requirements of the type discussed under this functional area. Compliance with conventional railroad safety requirements is assured by specified tests and inspections, and requirements to maintain appropriate records of tests and test results.

The AAR and U.S. manufacturers are adopting ISO 9000 and similar quality assurance systems, and general application is likely over the next few years. Use of ISO 9000 and similar quality assurance processes is much less advanced in the civil engineering and construction industries, and in operations and maintenance activities, and experience that could be applied in these areas to a maglev system is lacking.

For U.S. maglev systems applications, consideration should be given to the application of a QA program based on ISO 9000-9004 or a similar requirement for all mechanical and electrical components and subsystems.

3.3.6 Further Studies

The extension of ISO 9000-9004 procedures to non-manufacturing maglev system activities is also potentially valuable. These activities include construction services, operating and maintenance activities, and safety management. However, there is limited experience with ISO 9000-9004 and similar procedures applied to these activities in the U.S. guided ground transportation industry. A study of how to apply these procedures to construction, operating and maintenance activities is desirable. This study could use the quality assurance requirements discussed in this functional area as a starting point.

3.4 FUNCTIONAL AREA 104 - CERTIFICATION

3.4.1 Description of Functional Area

Certification is the process or group of processes by which it is determined that a new or substantially modified maglev system is in compliance with all relevant safety requirements.

This functional area is closely related to other functional areas addressed in this chapter.

Functional Area 101, System Safety, discusses system safety analyses, which are an essential part of confirming that a maglev system is adequately safe.

Functional Area 102, Reliability and Availability, addresses the definition of reliability and availability, and the techniques used to achieve adequate reliability and availability of safety-critical systems. Careful testing and analysis of the reliability and availability techniques used will necessarily form part of a certification process.

Functional Area 103, Quality Assurance (QA), is also an integral part of any certification process. Adequate QA has to be in place to ensure that structures and systems built meet the specified safety requirements.

The remaining functional areas discuss requirements for individual subsystems of the maglev system, or operating and maintenance procedures. The certification process will have to encompass each one of these subsystems.

3.4.2 Safety Baseline

A comprehensive certification process is required to protect maglev system passengers and employees against adverse consequences arising from the use of substandard equipment or components.

Clear safety requirements must be specified for each safety-critical system, and appropriate inspections, testing or analyses should be carried out to confirm that safety-related requirements have been met. In addition, there must be a clear definition of responsibility for ensuring that the inspections, tests and analyses have been carried out properly. Depending on the circumstances, the responsibility could rest with a government agency, an independent testing laboratory, or the manufacturer of the system. In most cases, documentation of test results, quality standards, and safety-related analyses must be kept on file by the maglev system operator and be available for submission to or review by appropriate regulatory authorities.

3.4.3 Description of Existing Safety Requirements

The existing requirements reviewed in this functional area are listed in Table 3-5 and described below by origin under three headings: German, United States, and other foreign and international.

3.4.3.1 German Requirements

Chapter 1 of the RW MSB, Section 7, states that it is necessary to prove compliance with the safety requirements of the RW MSB. Proof of compliance must be shown by providing a full description of safety engineering features of the maglev system and accompanying operating practices. This description or specification is effectively a performance statement against which the actual system must be tested. At a minimum, the testing or certification must meet the following requirements:

- Manufacture or test certificates must be provided for all safety-relevant materials or components used in system construction.
- Passive systems must be documented by specifications, design and production records, and test results where needed.
- Active systems (such as control systems) must meet passive system requirements, plus tests and analyses to demonstrate adequate safety performance under the fail-safe or safe-life approaches to safety assurance.

The overall system safety description should be subject to an independent review for completeness and correctness.

Paragraph 1.4 of the draft MBO states that operating installations and vehicles may be put into operation only if they meet all applicable regulations, and have been demonstrably tested prior to initial use.

The justification and explanations attached to the draft MBO state that the required tests should comprise a complete examination of compliance with the regulations of the ordinance, as well as with all regulations and government requirements that can be attributed to it. The results of the tests must be documented.

The EBO, Paragraph 2, states that railroad installations and rolling stock must meet the regulations in the EBO and comply with the acknowledged rules of technology. The EBO also states (Paragraph 32) that new vehicles may not be placed into service until they have been accepted.

A technical report Safety/Reliability for Certification of TRANSRAPID Maglev Technology [10] provides a further description of safety certification in Germany. This report indicates that the phrase "acknowledged rules of technology" used in both the draft MBO and EBO means the body of applicable technical requirements issued by DIN, DIN/VDE and similar

TABLE 3-5. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 104 - CERTIFICATION

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
German Government	Draft MBO	Section 1.4	Basic Rules	Maglev
	EBO	Paragraph 32	Vehicle Acceptance and Inspection	Railroad
TÜV Rheinland	Florida Maglev High-Speed Transportation System Safety/Reliability for Certification of Transrapid Maglev Technology	-		Maglev
FRA	49 CFR, Transportation	Parts 209-236	Railroad Safety Requirements	Railroad
FAA	14 CFR, Aeronautics and Space	Part 21	Certification Procedures for Products and Parts	Aviation
Association of American Railroads	Manual of Standards and Recommended Practices	Section C Part 2 M1001	Specifications for the Design Fabrication and Construction of Freight Cars	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

organizations customarily used in specification of technological products and projects. Thus, these requirements are incorporated into the law by reference. The RW MSB, having been prepared by qualified experts, is regarded as being part of the "acknowledged rules of technology."

The report further states that the federal government of Germany has the authority to approve the operation of long distance railroads. For a conventional railroad, an independent expert organization will review the proposed operation and the relevant authority will give permission to operate based on the findings of the independent expert. Because of the novel nature of a maglev system, a variant on this independent expert process is used, called "Project Accompanying Safety Certification" (PASC). This consists of a series of staged reviews from concept development through detailed design, manufacture or construction, testing and initial operation, with the results being presented to the certifying authorities.

3.4.3.2 U.S. Requirements

49 CFR, Part 209 gives the FRA authority to enforce railroad safety regulations.

Certain devices or materials used on railroad systems are subject to type approval, most notably, end-of-train marking devices (49 CFR, Part 221) and impact-resistant glazing (49 CFR, Part 223). Otherwise, enforcement of regulations is governed by reporting and recordkeeping requirements, and spot inspections and reviews of records by FRA safety inspectors.

Under the Rail Safety Act of 1988, the FRA is responsible for safety oversight of all types of intercity guided ground transportation systems in the United States. Also, the U.S. DOT "Statement of National Transportation Policy" says that DOT agencies will promote safety in public transportation by encouraging the development of industry safety standards, and implementation of system safety plans. To comply with the Rail Safety Act and the DOT policy, the FRA is currently conducting on-going safety assessments of maglev and high-speed rail systems proposed for installation in the U.S. The end-product of the assessments will be a "Rule of Special Applicability" specifying safety requirements for an individual system.

The FAA requirements in 14 CFR, Part 21, specify the certification process used for aircraft and aircraft components. In summary, the regulations require the aircraft manufacturer to carry out the following actions:

- Submit full details of design specifications and materials used in construction of the aircraft.

- Demonstrate by analyses and tests, full compliance with all applicable airworthiness requirements.

- Carry out any additional ground or in-flight tests required by the FAA to demonstrate compliance with the applicable requirements.

In order to maintain a certification for a particular aircraft type in effect, the manufacturer must:

- Institute an approved inspection system to ensure that quality is maintained.

- Establish a process to ensure that only approved parts and materials are used in the aircraft.

- Set up a test procedure for newly completed aircraft.

Corresponding approval processes are used for aircraft materials, parts and manufacturing processes.

A number of certification processes are used by the Association of American Railroads (AAR) for equipment used in the conventional freight railroad industry. These processes particularly apply to vehicles which may operate on the lines of several different railroad systems. The process described in Section C, Part II of the Manual of Standards and Recommended Practices, for the approval of new freight car designs, is typical. Full details of the car design have to be submitted to the AAR, including design calculations, and a number of instrumented structural and track tests must be performed. The content of these tests depends on the degree of innovation in the car design. Following successful completion of these tests, not less than 20 cars of the new type must undergo a service test of not less than 25,000 miles each. Upon successful completion of this test, approval for normal operation is given, conditional on the satisfactory operation of the cars in normal service over a one-year period.

3.4.3.3 Other Foreign and International Requirements

No relevant requirements were identified.

3.4.4 Comparison and Assessment

Certification is the process by which assurance that the maglev system is in compliance with all applicable safety requirements is obtained. The content of the specific safety requirements is not relevant, except to the extent that different types of components or sub-systems may follow different certification processes.

In Germany, a major system safety study has been performed on the Transrapid system by the firm Basler and Hofmann [8]. This report is, in part, a response to a need for an independent assessment of maglev system safety. Component and subsystem specification and quality have been governed mainly by normal commercial specification and quality control practices, following recognized requirements such as the DINs.

In the United States, the FAA requires highly detailed data on new aircraft designs, which are thoroughly reviewed prior to certification. The FAA also witnesses the specified tests and can require additional tests to be performed. The FRA only has very limited certification requirements (for a few specific items), and otherwise relies on spot inspections to enforce safety regulations on conventional railroads. For novel HSGGT systems, the FRA is currently conducting ongoing safety assessments in cooperation with each system developer, to develop a "Rule of Special Applicability." This process is necessary because generally, applicable regulations appropriate for high-speed guided ground transportation systems do not otherwise exist. The AAR approval process for new freight car designs resembles the FAA process, in that a detailed review of design and test data is carried out by the approving organization, but is substantially less detailed.

Overall, the German process specified in the RW MSB, the FAA process, the evolving FRA process, and the AAR process are all similar in principle, but with differences of emphasis and the level of detail required in testing and documentation.

3.4.5 Findings

A more structured certification process is required for a maglev system than has traditionally been used for ground transportation systems, due to the degree of innovation in maglev systems, the higher speeds operated, and the corresponding severity of a high-speed accident, should one occur.

The objective of the certification process is to ensure that the travelling public is protected from the consequences of a deficiency in the design and construction of a maglev system.

This objective generally can be met by the current safety assurance process being applied by the FRA to novel high-speed maglev and wheel-on-rail systems. However, development of the FRA process is continuing, and the German requirements in Chapter 1 of the RW MSB provide useful guidance on the nature and completeness of certification. Therefore, consideration should be given to including the following certification requirements for maglev system applications as part of the FRA safety assurance process.

- Passive structures and systems such as vehicle body structures, guideway structures, etc., should be thoroughly documented with regard to material specifications, quality assurance process and tests, design calculations, production records and tests, and this data should be available for inspection and review by the certifying authority.

- Active systems and structures, including any mechanical moving parts such as vehicle suspensions and the guideway switch mechanism, should meet passive system requirements and, in addition, a proof-of-safety should be provided using appropriate analysis and tests to demonstrate an adequately low risk of critical failure.

- Overall system safety analyses as required in Functional Area 101 and safety analyses of safety-critical active systems should be subject to a review by a suitably qualified independent organization.

3.5 FUNCTIONAL AREA 105 - COMPUTER SAFETY FOR VEHICLE AND OPERATIONS CONTROL SYSTEMS

3.5.1 Description of Functional Area

A high-speed maglev system may include several computers that perform monitoring and control functions in safety-critical subsystems. Such computers may control the magnetic levitation and guidance systems, the safety braking system, and vehicle movements. This functional area covers general (as opposed to application-specific) requirements for computer systems which perform monitoring and/or controlling functions in safety-critical subsystems. Both hardware and software issues are included.

This functional area is closely related to the other general safety functional areas, and to functional areas which incorporate computer systems:

Functional Area 101, System Safety, discusses overall system safety issues. Computer controlled systems have a major role in achieving system-safety goals.

Functional Area 102, Reliability and Availability, discusses the different techniques for achieving the required safety performance. These techniques are applicable to computer controlled safety systems, as well as other vehicle and guideway systems.

Functional Area 206, Suspension Design and Installation, where computer systems may be used to control the magnet-to-guideway air gap of levitation and guidance magnets.

Functional Area 207, Brake Installation and Performance, where computer controls may be used for the vehicle-borne emergency or safety braking system.

Functional Area 401, Operations Control Systems Design, covering the system that monitors and controls guideway status and maglev vehicle movements, including interlocking systems.

3.5.2 Safety Baseline

Any computer system used to perform safety critical-functions, such as in vehicle suspension or braking systems, or in the control of high-speed vehicle movements, must exhibit an extremely low incidence of errors or failures that could lead to an accident. This means that suitable verification and validation techniques must be used to assure the correctness of any software used under all possible operating conditions. Computer hardware must have an appropriate level of redundancy or fault tolerance and fault indicating systems, so that the frequency of safety-threatening hardware failures is extremely low.

3.5.3 Description of Existing Safety Requirements

The existing requirements are listed in Table 3-6, and described below by origin under three headings: German, United States, and other foreign and international.

3.5.3.1 German Requirements

German requirements are contained in both the RW MSB maglev safety requirements, and in DIN, TüV and German Railways documents referenced in the RW MSB. The relevant parts of these documents are described below.

Chapter 4 of the RW MSB, On-Board Control System, provides requirements for the on-board safety computer that monitors vehicle location, speed, and status of the communication links to the operation control center. The safety computer is required to initiate and control safety braking to bring the vehicle to a stop at a safe stopping place in the event of a loss of communication, exceedance of permitted speed, or other safety-threatening failures. The computer is also required to monitor the functioning of other safety-critical systems such as the levitation and guidance magnets, and will initiate braking whenever required by the safety condition of these systems. Sections 2 and 3 of Chapter 4 state that both the safety computer and its software must meet the requirements for safety-critical computer systems given in MUe 8004. The validity and correctness of software must be confirmed through comprehensive checks and tests.

Chapter 9 of the RW MSB, Operational Control Equipment, specifies requirements for the Operations Control System. This system comprises all control system functions, including guideway status sensing, the interlocking system which ensures that vehicles are only permitted to move when the guideway is clear of obstructions, and the vehicle protection system that ensures that the vehicle obeys maximum and minimum speed limits, and does not run beyond the terminal point of the protected guideway. The RW MSB requires that all installations that record, process, or transmit safety-relevant information must be fail-safe as specified in DIN VDE 0831 (described below). Where it is not possible to assure fail-safe operation, per DIN VDE 0831 (as in a microprocessor system), two mutually independent functional units must be used. A breakdown must be reported without delay and safety-oriented action taken. If the system does not have a safe state, making such safety-oriented action impossible, then an appropriate two out of three voting, or fault-tolerant system must be used. Information processing systems must also meet the requirements of MUe 8004 and/or DIN VDE 0801, specifically:

- regular self tests or outside tests must be performed.
- monitoring installations (i.e., sensors) must directly check their proper function.

Computer software used in safety-relevant systems, must be prepared to the requirements of DIN VDE 0801. Specifically, programs must be carefully structured, fully documented, and thoroughly checked and tested. Section 4.2 of the RW MSB specifies testing requirements for software at various stages in software development from specification development, through draft software to finalized software.

TABLE 3-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 105 - COMPUTER SAFETY FOR VEHICLE AND OPERATIONS CONTROL SYSTEMS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Requirements	Chapter 4 Chapter 9	On-Board Control System Operations Control System	Maglev
German Government	Draft MBO EBO	Section 1.4 Paragraph 14-16	Basic Rules Signal Systems	Maglev Railroad
TÜV	Computers in Safety Technique (book)			General Industrial
DIN VDE	0801 Principles for Computers in Safety-Related Systems	-		General Industrial
DIN VDE	0831 Electrical Equipment for Railway Signalling			Railroad
TÜV	Minimum Standards for Safety-Related Computers in Railroad and Nuclear Engineering for Industrial Process Measurement and Control Equipment (equivalent to IEC 801)			Railroad, Nuclear
TÜV	SBT 90.01/00/E Guidelines for the Assessment of Safety-Relevant Computer Systems in Railroad Technology			Railroad
German Federal Railways	MUe 8004 Principles of Technical Approval in Signalling and Communication Engineering			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 3-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 105 - COMPUTER SAFETY FOR VEHICLE AND OPERATIONS CONTROL SYSTEMS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FRA	49 CFR, Transportation	Part 236	Instructions for the Installation, Inspection, Maintenance and Repair of Signal and Train Control Systems	Railroad
FAA	14 CFR, Aeronautics and Space Part 25, Airworthiness Standards, Transport Category Airplanes	Part 25.1309	Equipment, Systems, and Analysis	Aircraft
	Advisory Circular AC 1309.1A		System Design and Analysis	Aircraft
	RCTA/DO-178A Software Considerations in Airborne Systems and Equipment Certification			Aircraft
ANSI	STD 730-1984 IEEE Standard for Software Quality Assurance Plans			General Industrial
ANSI	STD 830-1984 IEEE Standard for Software Requirements Specifications			General Industrial
ANSI	STD 1008-1987 IEEE Standard for Software Unit Testing			General Industrial
ANSI	STD 1012-1986 IEEE Standard for Software Verification, Validation, and Test Plans			General Industrial
ANSI	STD 829-1983 IEEE Standard for Software Test Documentation			General Industrial

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 3-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 105 - COMPUTER SAFETY FOR VEHICLE AND OPERATIONS CONTROL SYSTEMS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
DOD	STD 2167A Defense System Software Development			General, Military
DOD	STD 2168 Defense System Software Quality Programs			General, Military
NASA	JSC 30244 Space Station Software Standards			Aerospace
FDA	Reviewer Guidance for Computer Controlled Medical Devices			Medical Equipment
UIC	738 Processing and Transmission of Safety Information			Railroad
Transport Canada	Report TD 10770E ATCS System Safety Validation Programs			Railroad
British Standards Institute	Draft Standard: Functional Safety of Programmable Electronic Systems			General Industrial
	Draft Standard: Software for Computers in the Application of Industrial Safety-Related Systems (Also called IEC/65A)			General Industrial
Institution of Railway Signal Engineers (U.K.)	Safety System Validation with Regard to Cross-Acceptance of Signalling Systems by the Railways			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The draft MBO requires that installations that provide for train safety must be fail-safe. There are no requirements that specifically address computer safety.

The EBO, Paragraphs 14, 15, and 16 specify general requirements for traditional block signalling systems. There are no requirements for computer safety.

DIN VDE 0831, Electrical Equipment for Railway Signalling, provides specifications for electrical components used in conventional railroad signalling systems and some features of signalling installations. Section 6.2 of DIN VDE 0831 specifies basic signal safety engineering requirements. A single fault shall not lead to an impermissible (i.e., unsafe) fault condition. Faults should be indicated at once and/or render inoperative any control function which would be affected by the fault, even if this interrupts railway operations. Alternatively, a regular inspection schedule may be used for fault detection and correction. DIN VDE 0831 also specifies numerous detailed design and installation requirements for cabling, relays, resistance and grounding requirements to minimize failure probability.

DIN VDE 0801, Principles for Computers in Safety-Related Systems, provides detailed guidelines for both the hardware and software of computers used for safety-critical applications. Recommendations are provided for the specification, design, manufacture, programming, installation, testing and servicing of safety-critical computer systems, mainly in the form of checklists and lists of the characteristics of different system types. Appropriate procedures with which to achieve an adequately safe system are selected from a "menu" of procedures according to the type of system and the safety requirements class needed. Examples of how to apply the procedures are provided.

A research report by TüV, Microcomputers in Safety Technique [12], provides a detailed discussion of both hardware and software safety issues, and presents procedures to ensure that both meet specified safety requirements. This report includes definitions of terminology used in safety-critical computing applications in Chapter 3, and some general "good practice" guidelines in Chapter 4 organized as "do's" and "don'ts." Chapter 5 defines safety categories by the number and type of "permissible" faults. Railway signalling systems are in the highest safety category in which no "dangerous" faults may occur. Chapter 6 provides detailed tabulations and checklists for procedures required to prevent systemic errors (i.e., error in software, or hardware design and assembly) and to properly protect against hardware failures. In Chapter 7, each procedure is described, and a reference provided for further reading.

Another TüV report, Guidelines for the Assessment of Safety-Relevant Computer Systems in Railroad Technology [13], provides a step-by-step specification for the specification, development, verification and validation of these systems. This report is in the form of a checklist of necessary steps and focuses particularly on software.

An additional TüV research report, Minimum Requirements for Safety-Related Computers in Railroad and Nuclear Engineering [14], focuses primarily on software diversity methods and the resulting benefits.

MUe 8004, Ground-Rules for the Technical Assessment of Signal and Telecommunications Engineering [15], is the German Federal Railway overall standard for both conventional and computer-based signal systems. Chapter 4 of the MUe 8004 provides very detailed requirements for computer software and hardware safety. These requirements emphasize the following:

- Proper recordkeeping of the results of all verifications and validation review tests and analyses performed during system specification design and developments.
- The use of carefully structured programming techniques for software preparation with the program broken down into simple modules to minimize the chance of errors, and to facilitate verification and validation.
- Use of a long checklist of potential failures to use in proving that the system is able to react in a safe way to all possible hardware failures. Both single and multiple failures are included.

Chapter 6 of MUe 8004 provides information on PASCAL programs for safety-critical applications, and guidelines for software and hardware testing.

3.5.3.2 U.S. Requirements

The FRA regulations contained in 49 CFR, Part 236, specify safety requirements for conventional railroad signal and train control systems. These specifications include the functional logic to be used in automatic block and centralized train control systems, as well as requirements for individual devices used in signal systems, but do not contain any requirements specifically addressing software-controlled computer systems in railroad signalling.

The FAA requirements contained in 14 CFR, Part 25.1309, prescribe the general requirement that the failure in commercial aircraft of any system that would prevent continued safe flight and landing must be shown to be extremely improbable, but there is no reference to software-controlled systems.

The FAA Advisory Circular (AC) 25.1309-1A, System Design and Analysis, provides further guidance on tests and analyses that can be used to demonstrate that an aircraft system complies with the requirements of 14 CFR, Part 25.1309. The tests and analysis described in AC 25.1309-1A are applicable to the hardware of computer systems; in Paragraph 7i states that the requirements of the Radio Technical Commission for Aeronautics Document RTCA/DO-178A shall be followed for safety-critical software. An error in critical-function software, as defined in RTCA/DO-178A, is equivalent to a catastrophic failure as defined in AC 1309-1A. Such failures must be shown to be "extremely improbable," equivalent to a failure probability of the order of 1×10^{-9} or less. The contents of AC 1309-1A are relevant to all maglev systems, not only computer-controlled functions, and further discussion is provided in Functional Area 101, System Safety.

The Radio Technical Commission for Aeronautics Document No. RTCA/DO-178A Software Considerations in Airborne Systems and Equipment Certification provides detailed guidelines for software development, verification, and validation. The principal subjects covered are as follows:

- The scope of the document is limited to software development and testing procedures. Other procedures that may be needed to reach safety and reliability targets in highly critical systems (e.g., aircraft fly-by-wire systems) such as independent software development teams, and use of diverse redundancy and monitoring are outside the scope of this document.

- A glossary of terms is provided including definitions of the commonly used terms of validation and verifications as follows:

  Validation - The process of establishing that the product, of which the software is a part, complies with equipment, system or aircraft level requirements.

  Verification - The process of establishing that the software satisfies its requirements.

- A step-by-step process is specified for software specification design, coding, verification, and testing with distinctions made for the degree of safety-criticality in the functions performed by the software. A disciplined software structure should be used such as modular design, with one module for each function. This approach facilitates testing, verification and maintenance of the software by people other than the originators.

- A discussion of configuration management and quality assurance is provided, particularly covering procedures to be followed in maintenance and modification of software after it has been put into use.

- A description is provided of documentation required to record and manage the software through its life-cycle from initiation of development through regular use in service.

A revision of RTCA/DO-178-B is currently in preparation, but is not yet available for review.

The AAR Manual of Recommended Practices for Signal Systems, Part 2.2.12, provides recommendations for microprocessor-based interlocking systems. General requirements in the Manual refer to meeting the requirements of the Federal Communications Commission (Part 15, Subpart J) regarding spurious emissions. Safety design standards are provided for software to give in safety assurance levels similar to that provided by vital relay systems. The manufacturer is recommended to do all executive and vital software programming, which should be installed in the system such that the unintentional changes by the user are prevented. System operation speed should be such that total communication and processing time to react to any vital field input shall not be less than one second, or alternatively, two seconds may be allowed. User-programmable vital software should be by means of a high-level language and should be stored in non-volatile memory.

Several other U.S. requirements provide guidance regarding the software development process to ensure adequately safe software. The majority of the U.S. requirements reflect the most recent application of engineering principles to the development and maintenance of software for commercial, military, and spaceflight applications and include:

- ANSI STD 730-1984: IEEE Standard for Software Quality Assurance Plans focuses on the development and maintenance of "critical" software, which could impact safety or cause large financial or social losses in the event of a failure.

- ANSI STD 830-1984: IEEE Standard for Software Requirements Specifications describes several approaches to good practice in the specification of software requirements.

- ANSI STD 1008-1987: IEEE Standard for Software Unit Testing defines an integrated approach to systematic and documented unit testing.

- ANSI STD 1012-1986: IEEE Standard for Software Verification, Validation and Test Plans defines specific minimum verification and validation (V&V) tasks and their required inputs and outputs.

- ANSI STD 829-1983: IEEE Standard for Software Test Documentation defines the content and format of eight documents that cover the entire testing process.

- FDA Reviewer Guidance for Computer Controlled Medical Devices focuses on the approach FDA reviewers should employ in reviewing computer-controlled medical devices.

- DOD-STD-2167A Defense System Software Development establishes requirements for software development that are applicable during the entire system life cycle.

- DOD-STD-2168: Defense System Software Quality Programs contains requirements for the development, documentation, and implementation of a software quality program.

- JSC 30244 NASA Space Station Software Standards provides an overview of the preferred technical and quality controls, identifies the preferred software development life cycle, and specifies documentation standards.

3.5.3.3 Other Foreign and International Requirements

UIC Code 738, Processing and Transmission of Safety Information, is the primary UIC requirement for computer systems applied to both railroad signalling and on-vehicle systems such as braking controls. Both hardware and software requirements are covered. The contents of UIC Code 738 can be summarized as follows:

- Section 3 of Code 738 specifies the kinds of equipment to which the requirements apply. These include signalling and train control systems, train location detection systems, wayside-vehicle communications, on-board train control systems, speed-, distance-, and position-measuring equipment, traction and braking controls, and door controls.

- Section 4 provides guidelines for the processing of safety information including specification, system design, validation and verification procedures, and documentation. The likely need for redundant hardware or self-checking systems to attain safety targets is mentioned, as well as the importance of availability and maintainability in an operating system. A system that is of safe design, but is unreliable, creates dangers due to frequent component replacement, and more frequent use of less safe "back-up" operating practices. The use of structured software is emphasized, as well as the uses and limitations of software diversity.

- Section 6 provides guidance on proving that the system meets safety requirements. An independent validator should review the specification, the system hardware and software design, and all modules of software for correct functioning. Hardware validation consists of applying a suitable failure analysis technique such as FMEA, and also tests to assure that the hardware function is not adversely affected by environmental conditions, such as temperature, humidity, and electromagnetic interference.

A technical report, ATCS System Safety Validation Programs [16], prepared by Transport Canada, concentrates on the development of a System Integration Simulator/Emulator/Tester (SISET) to test ATCS components in a simulated operating environment. The environment includes all conditions and actions normally encountered in a service application. SISET is proposed as a final validation of a piece of equipment after development by the manufacturer is complete.

In an appendix, the Canadian ATCS report attaches copies of two draft British and International Standards for "Programmable Electronic Systems" (PES) used in safety-critical applications. These are as follows:

- Draft British Standard on Functional Safety of Programmable Electronic Systems (PES) describes in general terms the "lifecycle" of a PES from conception through use in its designed function, and the actions required to obtain a desired level of safety at each stage in the lifecycle. Verification to confirm that goals have been achieved is emphasized at the end of each stage.

- Draft British Standard on Software for Computers in the Application of Industrial Safety-Related Systems consists of a concise specification for each stage in software development (specification development, verification, validation, documentation, etc.), plus longer "informative appendices" that provide background information and details of procedures to meet the requirements. This document is also known as IEC/65A of the International Electrotechnical Commission.

A technical report of the Institution of Railway Signal Engineers (UK), Safety System Validation with Regard to Cross Acceptance of Signalling Systems by the Railways [17], provides a comparative review of the safety requirements for signal systems developed by different European railways. Based on the review, a proposal is made for international requirements for signal systems, including software controlled systems. A table of development, validation and verification procedures recommended in different requirement documents is provided.

3.5.4 Comparison and Assessment

The essential characteristic of systems addressed in this functional area is that safe performance depends on the correct operation of both the hardware (the computer or microprocessor itself and any associated equipment such as sensors), and on the correctness of the program. Traditional railway signalling and related systems are distinctly different, in that they are made up of a relatively small number of individual devices (electrical, electronic, mechanical), which generally have known failure modes, and the operating logic is "hard-wired" rather than embodied in a program.

Two causes of failure of a programmable system to operate correctly can be identified:

- Random failures. These failures usually occur in hardware, but could also occur if the program or data were corrupted by a random event caused by, for example, an unusual electromagnetic event. Inability of the system to function consistently in the operating environment (temperature, humidity, mechanical vibration, electromagnetic) could be a significant cause of random failure.

- Systematic failures, where there is an error in the arrangement of hardware or in the program, introduced at the specification, design, development or installation stages. When a systematic fault is present, the system will always produce an incorrect output in particular operating circumstances.

The reviewed documents provide information on "good practice" in the design and development of software-controlled systems, and address methods of analyzing and controlling the consequences of both kinds of failure. The documents particularly emphasize methods for avoiding systematic failure through the development of error-free system architecture and software, and appropriate validation and verification procedures.

A brief comparison and assessment of good-practice information and methods of safety assessment for both random and systematic failures is provided below. However, it should be recognized that computer safety is a very broad subject, and it is not possible to fully address all the relevant issues within the scope of this review.

3.5.4.1 System Requirements

Several of the reviewed requirements documents provide guidance regarding good practice in the design of safety-critical programmable systems, as distinct from validation, verification and other safety assurance techniques.

One area which is common to the TüV publication [12], DIN-VDE 0801 and the U.S. Aeronautical software requirements (RTCA/DO-178A), is the classification of programmable systems by safety criticality. Since an unsafe failure of a maglev operation control system, or an on-board computer controlling emergency braking could lead to loss of life or severe property damage, all the referenced requirements assign such systems to the highest safety category.

The German documents, particularly the TüV publications, are research reports rather than formal requirements documents, and offer recommendations regarding good practice and appropriate system design features. Examples of recommendations for the highest safety class, taken from [12] are as follows:

- A high degree of diversity within the software design and/or software verification is necessary to ensure program correctness.
- A dual-channel diverse software system should be used in a system with a safe state.
- At least three diverse software channels should be used in a system without a safe state.
- Fault tolerance period should be larger than latency interval for dangerous faults.
- Structured programming should be used.
- Components should be used within their specification.
- Power supply should be monitored.
- Two independent time bases should be used.
- Two independent switch-off paths should be used.
- Programmable memories should be used within specification.
- Use dynamic memory only with hardware diversity or with added measures for the detection of information corruption and refresh faults.

The U.S. requirements, the UK Code 738, and the IRSE report from the UK [17] are procedural in nature, specifying procedures to be followed at each stage in the system design and development process, but not recommending particular technical solutions.

In contrast, the TüV recommendations, particularly those relating to software and hardware diversity are not the only ways of assuring a specified safety level. For example, the U.S. philosophy for microprocessor railroad interlockings uses a single microprocessor with self-checking rather than a redundant system. A related area mentioned in some documents, notably the IRSE report is the effect on overall safety performance of requiring "fault-tolerance," to avoid service interruption due to failures, and providing the capability of replacing defective components during maintenance without interrupting service. The IRSE report also mentions that the safety of any emergency operating procedure used when normal service is interrupted should be taken into account in overall system safety assessments. Such emergency operating procedures may be less safe than normal procedures, and the frequency with which they are required will affect overall safety performance.

3.5.4.2 Random Failures

The methods of system safety assessment described under Functional Area 101, <u>System Safety</u>, are generally applicable to random hardware failures in programmed systems. The methods include FMEA, Hazard Analysis, and quantitative failure analyses. Such analyses should cover both failures in the computer hardware itself, and failures of associated sensors, power supplies, communication systems and other equipment that provides an input to, or responds to an output from the computer system. The very extensive checklist of failure conditions provided in MUe 8004 is an aid to the analysis of hardware failure conditions. However, maglev-specific checklists will need to be developed, since the functions performed by safety critical computers, both on the vehicle and at wayside differ from those used in a conventional railway, and different sensors and computer systems are used.

3.5.4.3 System and Software Errors

System and software errors are systematic failures that are always present in a particular system. They will cause the system to behave incorrectly, possibly resulting in an unsafe condition, whenever a specific operating condition is encountered. Because systems and software errors are not random, precautions used to counter the risks of random failures, such as redundancy and fault tolerance, may be ineffective.

The approach recommended in all the requirements documents reviewed is to adopt a carefully structured process for system development with verification, validation, and full documentation at each stage. The usual stages are system specification, design and development, coding and testing. The reviewed documents agree in general terms on the level of verification and validation needed for a programmable system controlling a safety-critical process such as a maglev vehicle control or braking system. There is, however, an important limitation in using requirements that only address software development. In maglev applications, the software and hardware must operate together as a system, especially where hardware redundancy is critical to achieving the required safety performance. Therefore, validation of the system must include whether the software specification fully meets all system-level requirements, as well as whether the software itself complies with the software specification. Requirements that address software preparation only are therefore incomplete, and procedures embracing both the hardware and software systems are needed. The requirements and guidelines that best address hardware and software in combination are found in the TüV reports, and in ORE Code 738.

The IRSE report is a helpful comparison of different railway-specific requirements, and provides a very good checklist of safety assurance procedures, reproduced in Table 3-7.

3.5.5 Findings

Programmable computer control systems have only recently been applied to safety-critical functions in HSGGT systems. FRA research which will lead to the development of safety requirements is in progress.

A number of U.S. requirements provide good-practice guidelines for safety critical software, such as the IEEE requirements and the aviation requirements RTCA/DO-178-B. However, none of these documents combine hardware and software requirements, and none have been developed specifically for HSGGT systems.

Development of safety-critical computing requirements for transportation is more advanced in Germany and other foreign countries, providing guidance for system design, validation and verification. All these requirements are helpful in developing U.S. requirements, but all seem to require additions or amendments to be both suitable and complete.

Pending the results of ongoing research by the FRA, consideration should be given to the following general computer safety requirements for U.S. maglev system applications.

- A computer system controlling maglev vehicle operations, or an on-board safety computer controlling vehicle braking should be regarded as being in the highest safety category, as defined in DIN VDE 0801, the TüV reports and RTCA/DO-178A.

- Design and development of the overall system should follow recognized requirements developed for the same or an equivalent purpose. Relevant requirements identified include DIN-VDE 0801, MUe 8004, and UIC Code 738. Helpful guidance for system developers is also provided in the TüV and IRSE reports, although these are not formal requirements.

- Appropriate analysis should be carried out to demonstrate that the system is adequately safe with respect to random failures in the hardware of the computer and related equipment such as sensors and communication links. Specific types of analysis that may be used are PHA, FTA, FMEA, and QRA, as recommended in Functional Area 101, System Safety. Failure checklists equivalent to those given in MUe 8004 and referenced in ORE 738 are also useful, and should also be developed and applied.

TABLE 3-7. SAFETY ASSURANCE PROCESSES FOR RAILWAY SAFETY - CRITICAL COMPUTER SYSTEMS AND SOFTWARE

	Methods or Procedures for Hardware	M	HR	R
1	Failure mode, effect and criticality analysis	x		
2	Fault tree analysis		x	
3	Common mode failure analysis	x		
4	Different teams for design and verification	x		
5	Full testing	x		
6	Functional testing	x		
7	White box test		x	
8	Free testing - what if? method (a)	x	x	
9	Simulation			x
10	Static compliance with the specification	x		
11	Dynamic compliance with the specification		x	
12	MTBWSF calculation (Wrong Side Failure) (b)	x	x	
13	ORE catalog of failures (c)		x	
14	Tables for calculating residual risks (d)			x
15	Field trail before use for real/prototype		x	
16	Quality assurance requirements EN 29001	x		
17	Prescribed rules for documentation	x		

	Methods or Procedures for Software	M	HR	R
1	Software errors effect analysis	x		
2	Static software analysis		x	
3	Dynamic software analysis		x	
4	Code inspection by third party		x	
5	Formal specification with mathematical proof		x	
6	Validated compiler		x	
7	High level language		x	
8	Machine code tested on target hardware	x		
9	Different teams for design and verification	x		
10	Full testing through every branch of program	x		
11	White box test		x	
12	Functional testing	x		
13	Static compliance with the specification	x		
14	Dynamic compliance with the specification		x	
15	Defensive programming			x
16	Structured programming rules	x		
17	Field trial before use for real/prototype		x	
18	Quality assurance requirements EN 29001	x		
19	Prescribed rules for documentation	x		

TABLE 3-7. SAFETY ASSURANCE PROCESSES FOR RAILWAY SAFETY-CRITICAL COMPUTER SYSTEMS AND SOFTWARE (cont.)

	Methods or Procedures for Systems	M	HR	R
1	Hazard analysis review	x		
2	Fault tree analysis		x	
3	Different teams for design and verification	x		
4	Functional testing	x		
5	Simulation		x	
6	Static compliance with the specification	x		
7	MTBWSF calculation (Wrong side Failure)		x	
8	Field trial before use for real/prototype	x		
9	Quality assurance requirements EN 29001	x		
10	Prescribed rules for documentation	x		

(a) To be carried out with 5 if not mandatory
(b) Mandatory for evaluation purposes when required
(c) To be complemented by individual documents for components not listed
(d) To determine the overvalue used for safety circuits

M Mandatory
HR Highly Recommended
R Recommended

Source: Institution of Railway Signal Engineers; International Technical Committee Report No. 1, System Safety Validation with Regard to the Cross Acceptance of Signalling Systems by the Railways [12].

- System design and software preparation should follow a structured process as specified in recognized requirements documents. Particularly, these must include structured or modular programming, validation and verification at each stage in software preparation and full documentation. Relevant requirements documents providing useful guidance include the ANSI/IEEE Standards 730 and 1012, DIN VDE 0801, and RTCA/DO-178A.

3.5.6 Further Studies

Development of effective safety requirements for programmable computer control of safety-critical processes in maglev or other HSGGT systems is clearly a major concern. An initial review only of this large, rapidly developing subject has been possible in this study. Further research into computer safety is highly desirable, and is being pursued by the FRA. Two areas in particular have been noted in this review where further research into the state-of-the-art would be particularly useful:

- Design for maintenance. Although many of the reviewed documents mention maintenance and upgrading, more information is needed on how systems should be designed to ensure that maintenance and modifications can be carried out without risk of impacting safety performance, and without excessive post-maintenance validation and verification requirements.

- Effectiveness of verification, validation and testing. Most of the reviewed documents contain good-practice recommendations for the verification and validation of safety critical systems, but further information is desirable on the effectiveness of the different processes in avoiding errors. Such information would help determine whether a particular process is or is not appropriate for a particular application.

4. VEHICLE SAFETY REQUIREMENTS

4.1 FUNCTIONAL AREA 201 - VEHICLE AND CAB STRUCTURAL INTEGRITY

4.1.1 Description of Functional Area

This functional area is concerned with the overall safety performance of maglev vehicle structures, including the operator cab. There are two primary aspects to structural safety: safety performance in a collision, and the avoidance of catastrophic structural failure in normal service. Other performance demands on the vehicle structure, such as rigidity, meeting weight limitations, and provision of temperature and noise isolation, are not safety requirements in themselves, but meeting them may be critical to overall maglev system safety. For example, weight limitations must be observed to avoid imposing excessive loads on the guideway.

Other functional areas closely related to or having an interface with this functional area are:

Functional Area 101, System Safety, addresses the role of collision avoidance and survivability in achieving overall safety goals.

Functional Area 104, Quality Assurance, outlines procedures to ensure that high quality is maintained in manufacturing maglev vehicles and other equipment.

Functional Areas 202, Vehicle Operator and Crew Compartments, and 203, Passenger Compartment Interior Fittings and Components, both discuss strength requirements for interior fittings.

Functional Area 206, Suspension Design and Construction, discusses suspension loadings and the strength of vehicle suspension to body connections.

4.1.2 Safety Baseline

Vehicle occupants must be protected as far as is reasonably possible against the adverse consequences of collisions at low and moderate speed, and from dangers due to structural failures in normal service.

A significant risk of collision could exist with a maglev system at low and moderate speed. Movements at up to 50 km/h (30 mph) may be permitted under manual control in the event of failures in the operations control systems, leading to the possibility of human error-caused accident. Collisions at below 10 km/h (6 mph) would be minor, and those at speeds up to 50 km/h (30 mph) could be more serious.

In minor collisions such as those below 10 km/h (6 mph), the vehicle should be able to absorb the collision energy without suffering significant damage, and should do so in a way that does not produce high longitudinal decelerations in the vehicle that could cause standing passengers to fall down, or throw people against hard surfaces.

In more serious collisions (up to 50 km/h (30 mph)), the structure should be designed so as to protect occupied compartments against crushing, and to control deceleration rates to levels that minimize the risk of severe injuries inside the passenger or crew compartments due to people and loose objects such as baggage being thrown about the car. Discussion of vehicle interior safety is provided in Functional Areas 202 and 203.

Good crashworthiness design can provide some protection to vehicle occupants at higher speeds, but the energy dissipated in a high-speed collision is very large and it is not feasible to provide occupant protection using the vehicle structure. Safety at high speeds depends primarily on the performance of the operations control system, as discussed in Functional Area 401.

The other form of failure against which safety assurance is required is a catastrophic structural failure of the vehicle in normal service. Such a failure could occur if loads were not estimated properly, structures were not properly designed for the loadings, or that materials or workmanship were deficient. This risk may be higher for a maglev vehicle than for other guided transportation systems. The structure has to meet a large number of functional requirements, including meeting weight limitations, minimum stiffness requirements and overall dimensional limits. Use of innovative materials and construction techniques may be necessary to meet all these requirements. Therefore, safety requirements to ensure that vehicle structures are properly designed, manufactured and tested may be desirable.

4.1.3 Description of Existing Safety Requirements

The existing requirements are listed in Table 4-1 and described below by origin under three headings: German, United States, and other foreign and international.

The descriptions indicate whether the requirement is concerned with ensuring occupant protection in a collision or other form of accident, or with ensuring that structural loadings are properly estimated and the structure is adequately designed and built for these loads.

4.1.3.1 German Requirements

Chapters 5, 6, and 7 of the RW MSB contain requirements for vehicle structures.

Chapter 5, Load Assumptions, is primarily concerned with loads applied to the guideway. Section 5.4 specifies vehicle load cases that are to be used in guideway structural design. The load cases cover both vehicle-guideway forces in normal operation, and under emergency conditions such as the failure of individual levitation or guidance magnets. Paragraph 4.7 specifically excludes certain conditions from consideration as the risk of occurrence can be

TABLE 4-1. SAFETY REQUIREMENT FOR FUNCTIONAL AREA 201 - VEHICLE AND CAB STRUCTURAL INTEGRITY

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 5, Sections 3, 4	Load Assumptions	Maglev
		Chapter 6	Stability Analyses	Maglev
		Chapter 7, Section 2	Design, Quality Assurance of Mechanical Structures	Maglev
German Government	EBO	Section 3	Railroad Construction and Traffic Regulations	Railroad
German Government	Draft MBO	Chapter 3	Construction and Operating Code of Magnetic Levitation Rail System	Maglev
DIN	65118 Welding in Aerospace Applications	-		Aerospace
	29491 Testing of Welder for Aerospace Applications	-		Aerospace
German Federal Railways	DS 952 Welder Tests for Primary Components	-		Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 201 - VEHICLE AND CAB STRUCTURAL INTEGRITY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
German Welding Institute (DVS)	1603 Spot Welding of Steel in Railcars	-		Railroad
	1604 Spot Welding of Aluminum and Alloys in Railcars	-		Railroad
	1608 Welding Aluminum in Railcars	-		Railroad
	1609 Spot Welding of High Alloy Steel in Railcars	-		Railroad
	1610 Guidelines for Planning of Welded Structures in Railcars	-		Railroad
	1611 Radiographic Testing of Aluminum Welds in Railcars	-		Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 201 - VEHICLE AND CAB STRUCTURAL INTEGRITY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
VDI	2230 Systematic Calculation of High Duty Bolted Joints			General Industrial
ISO	286-2		System of Limits and Fits	General Industrial
FAA	14 CFR, Aeronautics and Space	Paragraphs 25.301 to 563	Definition of Loads and Proof of Structures	Aircraft
	Part 25, Airworthiness Standards, Transport Category Airplanes	Paragraph 25.575	Fatigue and Damage Tolerance Evaluation of Structures	Aircraft
FRA	49 CFR	Part 229.123 Part 229.141	Pilots, Snowplows and Endplates Structural Strength of M.U. Locomotives	Railroad
AAR	Manual of Standards and Recommended Practices	Section A, Part III	Passenger Car Requirements	Railroad
		Section C, Part II, M1001	Specifications for the Design Fabrication and Construction of Freight Cars	

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 201 - VEHICLE AND CAB STRUCTURAL INTEGRITY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
Canadian Government	Draft Passenger Car Design Safety Standards			Railroad
UIC	566 Coaches, Load Cases	-		Railroad
	651 Layout of Drivers' Cabs			Railroad
	515 Coaches, Running Gear			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

shown to be negligible, including actual impacts of guide or support magnets with guideway or a total loss of levitation at high-speed. The relevance of these load cases to vehicle design is that the vehicle/guideway interface loads are imposed on both the guideway and the vehicle.

Chapter 6 of the RW MSB, Stability Proofs (Guideway/Vehicle), provides detailed load cases to be used in the design of both the vehicle and guideway, together with how the loads should be combined and classified. Loads are classified as "primary" loads (p) which occur frequently in normal service, "secondary" loads (s) that are peak loads occurring infrequently in normal service, and "special" loads (sp) that occur as a result of an emergency situation or other type of unusual event. No specific strength requirements are identified with the load cases. A list of vehicle loads from Chapter 6 is provided in Table 4-2. Section 6.4 of Chapter 6 requires that structural safety factors be a function of the probability of occurrence of the load case, and the severity of consequences should the component fail. Specific safety factors are not given. Table 4-3 lists the load cases (load combinations) for which the vehicle structure should be designed, including a load case for a collision with an obstacle.

Section 3 of Chapter 7 of the RW MSB is primarily concerned with quality assurance in vehicle construction processes and materials. The requirements for welded construction discussed below are cited in this section. The welding requirements specify conventional railroad practice for aluminum and steel body structure construction, with corresponding allowable stresses for welded structures. Aviation welder qualification procedures are specified. Chapter 7 also specifies that only materials manufactured to a recognized technical requirement (such as DIN standards or Eurostandards) may be used for vehicle components, and only when the materials used are certified as being in compliance with the technical requirements by a recognized testing institution.

A number of German DINs and other requirements are referenced in Chapter 7 of the RW MSB. They generally provide technical requirements for welded and bolted joints and the qualification of welders. Individual requirements referenced are as follows:

- DIN 65 118 Aerospace: Welded Metallic Components provides details of weld geometries, and welding techniques for steel, aluminum and other metal alloys. The methods of indicating welding requirements on drawings are also specified, together with inspection and testing requirements.

- DIN 29 591 Aerospace: Examination of Welders specifies qualification tests for welders. The testing consists of making satisfactory welds in a number of geometric configurations and using different welding methods.

- VDI 2230 Systematic Calculation of High Duty Bolted Joints specifies in great detail the design principles and detailed calculations used in the design of high duty bolted joints. This requirement is applicable to the design of highly stressed joints such as those used in internal combustion engines, rotating couplings, gearboxes and similar applications.

TABLE 4-2. CLASSIFICATION OF MAGLEV LOADS

Type of Load	
Forces of Gravity	
- Dead weight of the vehicle, including equipment, supplies, passengers	P
- During beginning of hovering	P
- During hovering	P
- During regular startup, acceleration, and braking	P
- During emergency braking (safety braking system)	Sp
- During banking	P
- Due to discontinuity in the guideway geometry	P
- During regular setdown	P
- While lifting the vehicle with a crane	Sp
Aerodynamic Forces	
- On set-down vehicle	P
- Relative wind	P
- Crosswind v_s ($v_s \leq v_1$)	P
- Crosswind v_s ($v_1 < v_s \leq v_2$)	Se
- During entry in and exit from tunnel	P
- During tunnel passage	P
- Opposing traffic	Sp
- Passing structures near the track	Sp
Other Loads	
- From thermal effects	Se
- Impact from a bird	Sp
- Crashing into an obstacle	Sp
- Coupling forces	P
- Shutoff and failure of magnets and corresponding springs	Sp
- Failure of springs	Sp
- Faults in and failure of sensor equipment and of control circuits	Sp

Note: Where relevant, loads according to Chapter 5, Section 4.7 are to be classified as special loads

P = primary; S = secondary; Sp = special

Source: RW MSB, Chapter 6

TABLE 4-3. MAGLEV VEHICLE LOAD CASES

Load case P:	Primary loads in the most unfavorable configuration. If only one secondary load is present aside from the primary loads, then it should also be treated as a primary load.
Load case PSe:	Primary and secondary loads in the most unfavorable configuration.
Load case $PSeSp_1$:	Primary, secondary, and special loads during emergency braking.
Load case $PSeSp_2$:	Primary, secondary, and special loads during crashing into an obstacle.
Load case $PSeSp_3$:	Primary, secondary, and special loads during shutoff or failure of magnets, springs, sensors or control circuits.
Load case Sp_4:	Impact of a bird on the front windshield. The primary load "relative wind" should be included locally.
Load case Sp_5:	Lifting of the vehicle with a crane. Consideration must be given to the vehicle weight, including supplies and equipment and excluding passengers, crew, and luggage.

Source: RW MSB, Chapter 6

- A series of requirements published by the Deutscher Verband für Schweisstechnik (DVS)(German Welding Institute) for welding in the construction of rail rolling stock. These requirements are primarily concerned with spot welding techniques for vehicle body-shell construction as follows:

  - DVS 1603 Spot Welding of Steel in Railroad Rolling Stock Construction specifies details such as the length and spacing of the spots, and material overlap dimensions as a function of weld configuration, strength requirements and material thickness. Requirements for welding equipment are also provided.

  - DVS 1604 Spot Welding of Aluminum and its Alloys in Railroad Rolling Stock Construction is exactly similar as DVS 1603, but is for aluminum instead of steel.

  - DVS 1605 Welding of Aluminum in Railroad Rolling Stock Construction provides information for design and execution of continuous welds in aluminum alloys. Fatigue design stress curves are provided for specified alloys as a function of maximum to minimum stress ratios and alloy specification. Electrode materials and other details of the welding process itself also are specified.

  - DVS 1609 Spot Welding of Alloy Steel in Rail Rolling Stock Construction is exactly similar to DVS 1603, but is for alloy steel instead of carbon steel.

  - DVS 1610 General Guidelines for Planning Welded Structures in Railroad Rolling Stock Construction provides a checklist (about two pages long) of factors that have to be specified or considered in the design and construction of welded rail vehicle structures.

  - DVS 1611 Radiographic Testing of Aluminum and Aluminum Alloy Welded Joints in Railroad Rolling Stock Construction specifies weld quality requirements (maximum incident of porosity, intrusions, cracks, etc.) as a function of material thickness, and details of testing procedures.

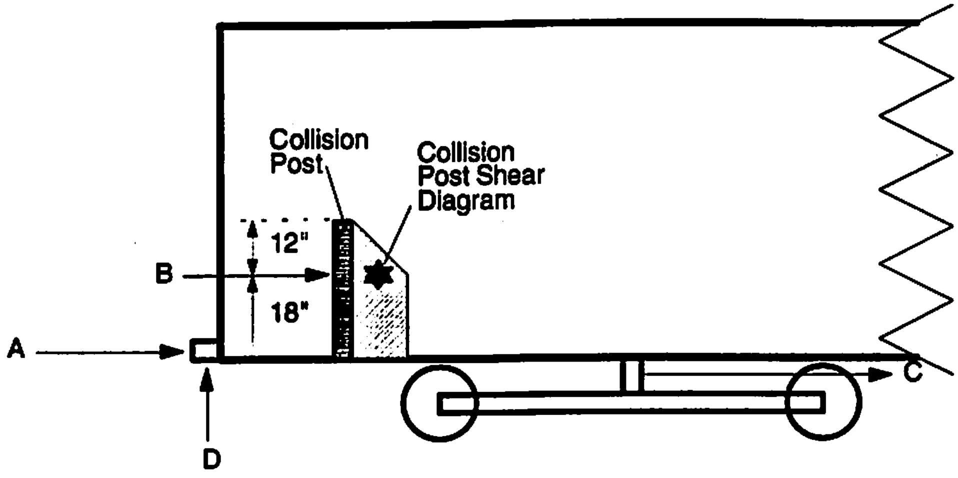
- DS 952 Welder Tests for Primary Components is a German Federal Railways requirement for welder skills qualification tests, covering all commonly-used weld geometries.

4.1.3.2 U.S. Requirements

The FRA regulations for locomotives (49 CFR, Part 229.141) provide requirements for the structures of multiple-unit (MU) locomotives. The requirements for trains exceeding 273 tonnes (600,000 lb) empty weight, are given in Figure 4-1 and Table 4-4, together with the corresponding UIC requirements discussed below. Trains of empty weight less than 273 tonnes may be designed to reduced structural strength requirements as listed in Table 4-4.

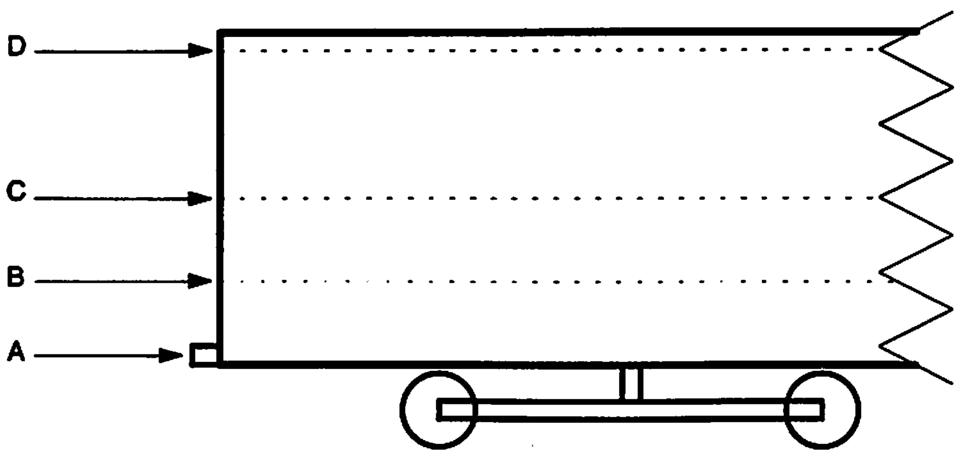
Part 229.123 of the FRA regulation requires that all lead locomotives and cab cars be equipped with an adequate pilot, end plate, or snowplow.

North America Requirements (AAR/FRA): trains exceeding 600,000 lb. empty weight



A	Buff	800,000 lb.
B	Collision Post (each of two)	300,000 lb.
C	Truck/Body	250,000 lb.
D	Coupler, etc.	100,000 lb.

European (UIC Code 566)



A	Buff	2000 kN (448,000 lb.)
B	350 mm (14") Above A	400 kN (90,000 lb.)
C	Center Rail Level	300 kN (67,000 lb.)
D	Cant Rail Level	300 kN (67,000 lb.)

In addition there is a diagonal load of 500 kN (112,000 lb.) at buffer level.

FIGURE 4.1. COMPARISON OF NORTH AMERICAN AND EUROPEAN CAR BODY STRENGTH REQUIREMENTS

TABLE 4-4. NORTH AMERICAN AND UIC VEHICLE BODY STRUCTURAL STRENGTH REQUIREMENTS

North American Requirements

Load (see Figure 4-1)	Train Empty Weight			
	Above 2670 kN (600,000 lb)		Below 2670 kN (600,000 lb)	
	Metric kN	English lb	Metric kN	English lb
A Buff	3560	800,000	1780	400,000
B Collision Post (each of 2)	1334	300,000	890	200,000
C Truck Body	1112	250,000	1112	250,000
D Coupler Vertical	445	100,000	334	75,000

UIC Code 566 Requirements

Load (see Figure 4-1)	Metric kN	English lb
A Buff (compression)	2000	449,000
Buff (tension)	1500	337,000
Buff (diagonal)	500	112,000
B Compression at 350 mm (14 in) above buff	500	112,000
C Compression, center rail	300	67,000
D Compression, cant rail	300	67,000

Section A, Part III of the AAR Manual of Standards and Recommended Practices specifies the same structural loads as the FRA, and makes a number of recommendations regarding the construction of passenger car structures in plain carbon steel, covering materials, manufacturing processes, and general quality requirements.

Section C, Part II of the AAR manual provides a specification for the design, fabrication and construction of freight cars. This freight car requirement is of interest because of the methodology used, rather than the applicability of specific requirements to maglev vehicles. The specification includes the following requirements.

- A list of acceptable materials for freight car construction, primarily by reference to national standards published by ASTM and similar organizations.

- Static load cases for design of different car types, including the loadings from the commodity carried.

- Allowable stresses for static loads as a fraction of the yield or ultimate strength of the material, including allowable stresses for welds.

- Workmanship or quality requirements to be applied in construction, including requirements for welded, bolted and riveted joints.

- A detailed fatigue design procedure for structural components subject to fatigue loads, based on a measured structural load spectrum in service. Cars in high-mileage service are to be designed for a service life of 3,000,000 miles and others for 1,000,000 miles. Material fatigue properties are also specified.

The FAA in 14 CFR, Part 25 provides detailed requirements regarding the loads for which airplanes must be designed, and corresponding design and construction practices. The principal requirements are as follows:

- Design load cases are specified in Parts 25.301 to 25.563. The loads are generally the maximum loads expected in service. Loads included are in-flight, and landing loads in all operating conditions for which the aircraft is designed, and correspond to aircraft performance requirements specified elsewhere in Part 25.

- Part 25.571 specifies that a fatigue life evaluation is required for all structural components subject to alternating loads and where failure would be catastrophic. Analyses, supported by test evidence, must be carried out to show that either the safe fatigue life exceeds the service life of the component, or that the expected damage would not result in catastrophic failure, and is detectable in inspection.

- Structures must survive an emergency landing load case as specified in Parts 25.561 and 562, specified in terms of static acceleration levels as listed in Table 4-5.

TABLE 4-5. AIRPLANE EMERGENCY LANDING LOAD CASE

Loading		Static Acceleration
Longitudinal	forward	9.0 g
	rearward	1.5 g
Vertical	upward	3.0 g
	downward	6.0 g
Lateral	(airframe)	3.0 g

- Part 25.303 specifies that a safety factor of 1.5 shall be used for static structural calculations, relative to the ultimate strength of the material. Part 25.305 states that any deformation must not interface with safe operation.

- Part 25.307 requires that validated structural analyses or tests must be carried out to prove that the structure meets the requirements for each load case. Tests must be carried out on any questionable component or design detail (Part 25.601). The FAA may require ultimate strength tests during the certification process.

- Parts 25.603 and 25.605 require that materials and construction processes conform to approved industry or military specifications, taking into account environmental conditions such as temperature and humidity expected in service.

There are a great number of U.S. industrial and military standards and specifications for materials and processes that might be used in the construction of maglev vehicle structures, including the following:

U.S. Military Standards (MIL STD)
U.S. Military Handbooks (MIL-HDBK)
American National Standards Institute (ANSI)
America Society for the Testing of Materials (ASTM)
American Iron and Steel Institute (AISI)
Aluminum Association (AA)
American Welding Institute (AWI)
Society of Automotive Engineers (SAE)

A detailed review of these requirements is beyond the scope of this study. However, each of these requirements will typically define requirements for a material or process to meet a specification; and the performance that can be expected of the resulting material or structure.

4.1.3.3 Other Foreign and International Requirements

The primary UIC document concerned with the strength of passenger vehicles is Code 566, Load Cases which specifies that a rail vehicle must be capable of sustaining the loads listed in Table 4-3 and illustrated in Figure 4-1 without permanent deformation. The vehicle body must also meet the following requirements.

- The coach body must sustain an evenly distributed vertical load of 1.3 times the total vehicle weight plus a 200 percent passenger load, at 80 kg (176 lb) per passenger, in combination with a 2000 kN compressive load without deformation.

- The body assembly should form a tubular beam. The end walls of the body shall be strengthened by anti-collision pillars that join the underframe to the vehicle walls and roof to distribute collision loads through the structure.

- Body natural frequencies in all load conditions should be sufficiently separated from bogie hunting and pitching frequencies to avoid resonance.

UIC Code 651, Layout of Driver Cabs, specifies that locomotives and cab vehicles must meet the longitudinal strength requirements specified in Code 566. In addition, the operator's compartment should be surrounded by structure that is stronger than the structure ahead of and behind the cab, to reduce the risk of crushing of the occupied space in a collision.

UIC Code 515, Coach Running Gear, Paragraph 2.6.2 specifies that the bogie (truck) to body connection must be able to sustain the following forces:

- Vertical force equal to 1.3 x maximum static vertical load on the bogie from the body.

- Lateral force equal to 0.3 x maximum static vertical load on the bogie from the body.

- Longitudinal force equal to that produced when the bogie is subjected to a 5g acceleration (for example, in an impact).

Normally, the maximum static load on the bogie is that produced when the body is fully laden with passengers and baggage. The longitudinal force requirement is intended to ensure the integrity of the body-to-body connection in a longitudinal impact. For a typical bogie of five tonnes (5.5 tons) mass, the requirement means that the bogie-to-body connection must sustain a load of 250 kN (56000lb).

The draft Canadian Passenger Car Design Safety Standards reiterate the FRA and AAR carbody strength requirements as given in Figure 4-1 and Table 4-3. The Canadian requirements also require that corner posts be provided, and that the whole end of the car structure - collision posts, corner posts, underframe, body bolster and draft gear housing be designed as an integrated welded structure capable of carrying the specified loads in structural members and connections.

A specification for vehicle structures prepared by French National Railways (SNCF) requires compliance with UIC Codes 566 and 651 as described above, and also specifies collision energy absorption requirements and other miscellaneous requirements as follows:

- An obstacle guard must be provided on leading vehicles, able to resist an impact force of 30 tonnes at any position.

- Crushable structure must be provided ahead of the cab and below cab window levels, with an energy absorption capability of 2×10^6 Joules (1.480×10^6 ft-lbf).

- Buffers for minor low speed impacts are required, with an energy absorption capability of 5×10^4 Joules (3.69×10^4 ft-lbf).

- Aluminum must not be used for the structure of the first or last vehicles of a trainset.

- Vehicles must be designed so that unoccupied end spaces are less strong than occupied spaces, and that all capability of energy absorption in vehicle ends is used before crushing of occupied spaces can occur.

- An anti-climbing device must be provided, effective with all other vehicles that may be encountered in normal service, and with a minimum vertical strength of half the mass of the vehicle.

British Rail specifies that a pilot or cowcatcher be fitted to all lead vehicles that travel at speeds exceeding 97 km/h (60 mph). The pilot must be able to sustain a 610 kN (330,000 lb) impact. Lead vehicles must have an axleload exceeding 120 kN (27,000 lb). This requirement is particularly aimed at unpowered cab vehicles, and the cab vehicles of MU trains.

A general industrial international requirement ISO 286-2, System of Limits and Fits, specifies dimensional accuracy limits for holes and shafts as a function of the purpose and the kind of fit required. Kinds of fit can include one guaranteed to give a clearance for use where the parts are expected to move relative to one another, or an interference fit where a force must be sustained without relative movement. The dimensions in this requirement can be used for slots and keyways as well as round holes and shafts. This requirement is referenced in the RW MSB, Chapter 7, Section 3.1.1.2 with respect to mechanical structures.

4.1.4 Comparison and Assessment

There are four issues that require discussion with regard to vehicle structures.

- The specification of normal service load cases.

- Design and manufacture of the vehicle structure to ensure that the structure can sustain the expected loads without catastrophic or premature failure.

- The specification of structural performance requirements in collisions.

- Proof of performance

4.1.4.1 Normal Service Load Cases

A series of normal service load cases are specified in several existing requirements documents. Chapter 6 of the RW MSB provides load cases for maglev for different load categories. The FAA commercial airplane regulations specify load cases for all flight and landing situations. The AAR requirements specify both static load cases and highly detailed fatigue load cases for conventional railroad freight cars. All these requirements follow a common philosophy of deriving appropriate structural design load cases for all normal operating conditions. The RW MSB requirements appear to be comprehensive in identifying load cases and load case combinations, but in comparison with the AAR and commercial aircraft requirements, lack specificity with regard to the identification of fatigue vs static load cases, and required component fatigue life in operating hours, distance travelled or load cycles.

The actual loadings specified for conventional rail vehicles of different types are not applicable to maglev vehicles, because of differing vehicle and train weights and load-paths.

4.1.4.2 Design and Manufacture of Structures

Structures must be designed and manufactured so that they will provide the expected service life without structural damage or premature structural failure under normal operating loads. This performance is achieved by following established and appropriate design, material and manufacturing requirements. The different requirement documents reviewed emphasize different parts of the design and manufacturing process. The DIN and other requirements referenced in the RW MSB include the series of DVS requirements concerned with welding procedures, and design requirements in VDI 2230 concerned with basic mechanics of bolted joints. The content of VDI 2230 is similar to that which would be found in a text book or engineering handbook. Materials to be used in the structure are not specified, except to state that they have to conform to a recognized technical requirement such as a DIN standard.

Among U.S. requirements, the AAR manual covers design, materials and manufacturing procedures for freight cars. The FAA regulations for commercial aircraft specify allowable safety factors, and sources for material performance data, but do not cover manufacturing techniques. The FRA regulations only specify load cases for collision performance, and do not contain any requirements covering design, materials or manufacturing methods for rail vehicle structures of any type. The contents of the FRA regulation reflect the fact that accidents due to catastrophic structural failure of a rail vehicle body are extremely rare. The AAR requirements are principally intended to ensure vehicle durability in service rather than having a strictly safety-oriented purpose. In contrast, catastrophic structural failure has been a historic cause of aircraft accidents; the FAA regulations address such risks through detailed structural design manufacturing and testing procedures.

A maglev vehicle is considered to be between a conventional rail vehicle and an aircraft with respect to structural failure risks. Apart from suspension components (discussed separately in Functional Area 206), there is less likelihood of an undetected structural failure having catastrophic consequences comparable to those that could follow from the failure of an aircraft structure. The vehicle is close to the ground, and support and guidance functions are performed by a suspension system built to separate requirements. However, low weight is more critical in maglev vehicle design than for conventional rail vehicles in order to minimize the weight and energy consumption of the magnetic levitation system and the weight of guideway structures. Therefore, maglev vehicle structures may have a lower maximum strength and shorter fatigue life than a typical rail vehicle structure. Also, greater use may be made of light alloys that require more careful consideration of strength and fatigue properties in design than the steels customarily used in North American rail vehicles. Overall, maglev vehicle structures are likely to be stressed more highly, and require more detailed and thorough structural analysis and quality control in manufacture than a conventional rail vehicle structure.

4.1.4.3 Collision Performance

The traditional approach to specifying collision performance in conventional rail vehicles such as in the FRA, AAR and UIC requirements, is to specify minimum buff strength, collision post strength, and other design loadings. These requirements have evolved out of long experience of the behavior of conventional rail vehicles in accidents. There is no equivalent experience for maglev vehicles; because of differing control system capabilities and vehicle weights, this approach is inappropriate.

The overall question of collision performance requirements for HSGGT vehicles of all types (wheel-on-rail and maglev) and the relationship with operations control system performance has been examined in another FRA study on collision safety [9]. The principal conclusions of this study are:

- A systems approach should be used to develop collision safety requirements for an HSGGT system, consistent with an overall system safety requirement specified in terms of a risk profile (accident frequency vs severity graph). The proposed risk profile has been shown in Figure 3-1.

- However, within the systems approach, all HSGGT vehicles should have a minimum collision performance to ensure that extremely flimsy vehicles are not put in service.

- Above this minimum, the required collision performance is a function of the hazards to which the vehicle is exposed, which depends on the performance of collision avoidance systems.

- The most suitable way of specifying collision performance is to define the minimum level of protection that the structure must provide to vehicle occupants in defined vehicle collision scenarios. The scenarios of relevance to the overall vehicle structure are a collision with another similar maglev vehicle, collision with debris and other smaller objects on the guideway, and a bullet impact scenario.

4.1.4.4 Proof of Performance

Proof of performance requirements address ways of demonstrating that the maglev vehicle structure, as built, will perform as intended in the specified load environment. The FAA commercial aircraft requirements state that structural performance must be demonstrated either by validated engineering analysis, or by direct structural tests on components. The FAA may require tests to be performed on selected components if there is any question regarding their performance. Fatigue tests are required on critical components.

The railroad requirements specify instrumented tests of performance under the maximum buff load, but otherwise normal structural engineering analyses are accepted without testing. For maglev vehicles, the measurement of actual loads generated in operation is highly desirable to validate for the assumed load cases in the absence of established data on maglev vehicle service loads and stresses. Once structural load estimates have been validated, it is reasonable to expect normal structural analyses to be sufficient to ensure structures are adequate to support the specified loads.

4.1.5 Findings

Well-formulated requirements for maglev vehicle structures are essential to ensure adequate accident survivability in collisions, and to prevent serious structural failures in service under normal operating loads.

Present railroad-derived structural requirements such as those of the FRA, AAR and UIC are not appropriate for maglev vehicles. Maglev vehicles and trains will likely be lighter than conventional rail vehicles or trains, and will be provided with better collision avoidance systems. However, design procedures (as opposed to specific strength requirements) developed for conventional rail vehicles may provide some guidance regarding appropriate structural design approaches for maglev vehicles. Use of the very strict structural design manufacture and testing requirements applicable to commercial aircraft does not appear to be appropriate for maglev vehicles. Accidents resulting from catastrophic failure of a vehicle body structure are not a significant accident cause in conventional rail systems and should be similarly unlikely on a maglev system.

Of the requirements reviewed, those provided by RW MSB appear to be the most appropriate for the specification of load cases and requirements for the design and manufacture of maglev vehicle structures. The RW MSB does not discuss accident survivability performance except to specify an undefined accident survivability load case. Given the inapplicability of existing railroad requirements, a new requirement for the accident survivability performance of maglev vehicle structures is needed. In addition, the RW MSB does not address proof-of-performance and a new requirement is needed, particularly to apply to the first use of a new maglev system.

For U.S. maglev system applications, consideration should be given to maglev vehicle structure safety requirements in four distinct areas as described below.

4.1.5.1 Specification of Normal Service Load Cases

Vehicle structure load cases equivalent to those given in Chapter 6 of the RW MSB should be developed for maglev vehicle structure design. Static and fatigue load cases should be clearly distinguished, and fatigue load cases should specify load spectrum and fatigue life requirements. The load cases should reflect all phases of vehicle operation (acceleration, maximum speed operation, braking, etc.) and include expected system malfunctions, for example, operating with a failed suspension or propulsion unit.

4.1.5.2 Design and Manufacture of Structures

Design analyses, allowable stresses and safety factors, materials and manufacturing processes should all conform to established engineering practices as specified by a recognized requirements-setting organization (such as DIN, ASTM, or ANSI) for the same or a similar purpose. In more detail, requirements in this area should include the following:

- All materials must be manufactured to specifications issued by recognized requirements-setting organizations, for which relevant performance data are available.

- Working stresses, fatigue life, and safety factors used in design should be comparable to those used for the same materials for an equivalent purpose. In particular, structural safety factors should reflect the severity of consequence of failure of each position of the structure.

- Manufacturing processes such as welding, should be carried out to recognized specifications developed for an equivalent purpose, including the qualification of welders and similar skilled labor used in vehicle manufacture.

4.1.5.3 Collision Performance

The study of collision safety for the FRA [9] has developed a collision performance requirement in which performance is defined as a maximum acceptable vehicle damage and acceleration levels in a specified collision. In this way, the collision performance specification can protect vehicle occupants from injury due to excessive vehicle crushing or high deceleration, without being specific to maglev vehicles or trains of a particular weight and design. Two "specified collisions" are identified in Reference 9, a very low-speed collision - 10 km/h (6 mph) which the maglev vehicle should survive without significant structural damage, and a higher speed 50 km/h (30 mph) collision in which crushing of the vehicle body should be confined to unoccupied areas.

4.1.5.4 Proof of Performance

Instrumented tests should be carried out on substantially new maglev systems to validate the load cases used in design. The tests shall be performed in all expected operational conditions, including with failed components (such as a suspension magnet) where applicable.

Structural performance should be confirmed using generally accepted structural analysis methods. Tests of individual components should be performed where there is a significant question as to the validity of available analysis techniques for the particular application, either in the ability of analysis techniques to estimate applied loads, or in the behavior of the structure under load.

4.1.6 Further Studies

Since an in-depth study of maglev structural performance in collisions is lacking, further study is needed to better define the collision performance requirements for maglev vehicles. Such studies might include:

- Definition of the collision risk based on the performance of the operations control system and other collision avoidance safety measures.

- Analysis of structural performance needed in defined collision scenarios needed to ensure survivable space in the vehicle, and to keep deceleration values to within tolerable limits.

4.2 FUNCTIONAL AREA 202 - ON-BOARD OPERATOR AND CREW COMPARTMENTS

4.2.1 Description of Functional Area

This functional area addresses all safety issues relating to the safety and working environment inside an operator compartment, including the impact performance of forward facing or side facing windows, where fitted. The functional area also covers on-board crew compartments other than in the conventional head-end operator's position, such as an engineer's compartment where the functioning of on-board systems may be controlled or monitored.

Other functional areas which have an interface with or are closely related to this functional area are:

Functional Area 101, System Safety, which discusses the integration of the duties of on-board operators into overall system safety considerations.

Functional Area 201, Vehicle and Cab Structural Integrity, which covers the overall vehicle structural performance in a collision or in normal operation, other than the impact performance of windows.

Functional Area 203, Passenger Compartment Interior Fittings and Components, which addresses safety issues associated with parts of the maglev vehicle occupied by passengers. In particular, the performance of windows raises similar concerns for the operator, crew members and passenger compartments.

Functional Area 602, Emergency Features and Equipment, including Access and Egress, which discusses maglev vehicle design requirements to protect occupants and permit rescue and escape in an emergency.

4.2.2 Safety Baseline

Occupants of on-board vehicle operator or crew compartments must be provided with an environment in which they can perform their duties effectively, and one that is free of hazards that could lead to accidental injury. Specific safety concerns that might be addressed by safety requirements include:

- Protection against the penetration of the compartment windows by objects flying above the guideway, or propelled or shot at the vehicle.

- Protection against injuries caused by a crew member slipping or falling, or being thrown against interior equipment or surfaces in the event of sudden lateral or longitudinal acceleration or deceleration.

- Protection against injuries caused by interior equipment becoming detached from its mountings due to unusual loads, such as those imposed by sudden acceleration or deceleration of the vehicle.

- Protection against hazardous equipment in the compartment such as high voltage electrical equipment, hot surfaces or moving machinery.

- Provisions for emergency egress and access.

- Provisions for an adequate working environment to minimize risks of human error. Requirements can include human factors design of controls and instruments, good visibility of the guideway through forward-facing windows where applicable, and avoidance of excessive heat, cold, and vibration.

4.2.3 Description of Existing Safety Requirements

The existing safety requirements are listed in Table 4-6 and described below by origin under three headings: German, United States, and other foreign and international.

4.2.3.1 German Requirements

The RW MSB identifies an impact with an object flying above the guideway as a "load case" (Chapter 5, Paragraph 3.6), and references UIC Code 651, Layout of Drivers' Cabs in Locomotive Railcars, Multiple Unit Trains and Driving Trailers (described below), for glazing requirements for forward-facing windows.

Other than for forward-facing windows, there are no requirements cited in the EBO or draft MBO, or in the RW MSB for windows or glazing.

The RW MSB requirements (Chapter 4) also state that all relevant information on the status of vehicle systems (such as levitation, systems and doors) must be properly displayed to the operator, and that the operator control console design should follow the provisions of six DIN standards 33.400 to 403, 413 and 414.

The specific content of these DIN standards is as follows:

- DIN 33.400 Ergonomic Principles defines terms used in operator ergonomics for all kinds of work environments, and identifies guiding principles to be taken into account in designing a workstation. These include such matters as reach, sitting vs. standing issues, body posture and movement, strength requirements and similar matters.

- DIN 33.401 Manual Controls - Design Principles provides recommendations for the design of control elements (levers, knobs, foot pedals, etc.) so that they can conveniently be manipulated by the human operator. Recommended limits are provided for forces, movements and linear and angular movements for different control elements.

TABLE 4-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 202 - ON-BOARD OPERATOR AND CREW COMPARTMENTS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 7 Paragraph 2.1.2 Chapter 4, Paragraph 4 Chapter 5 Paragraph 3.6	Design Production and Quality Assurance of Mechanical Structures - protection of persons in vehicles On-Board Control System - operators console Load Assumptions: Loads from Disruptions Caused by the Environment (e.g., Bird-Strike)	 Maglev Maglev Maglev
German Government	Draft MBO	Paragraph 3.7	Drivers Booth	Maglev
UIC	651 Layout of Drivers' Cabs	Section 2.2.2, 2.2.3 Section 2.2.4 Section 2.7, Appendix 3 Section 2.8 Section 2.9 Section 3, Appendix 5 Section 4 Section 5	Interior Cab Fittings and Emergency Exit Windows In-Cab Lighting Heating, Ventilation and Air Conditioning Visibility from Cab Layout of Controls Seats	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 202 - ON-BOARD OPERATOR AND CREW COMPARTMENTS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
DIN	33.400 - Ergonomic Principals 33.401 - Manual Controls - Design Principles 33.402 - Human Body Dimensions 33.403 - Climate at Workplace 33.413 - Ergonomic Aspects of Indicating Devices 33.414 - Ergonomic Design of Control Rooms			General Industrial
FRA	49 CFR, Part 229 Railroad Locomotive Safety Standards	Part 229.47 Part 229.117 Part 229.119 Part 229.127 Part 223	Emergency Brake Valve Speedometer Cabs, Floors and Passage Ways Cab Lights Safety Glazing Standards	Railroad
FAA	14 CFR, Part 25 Airworthiness Standards, Transport Category Airplanes	Part 25.771 Part 25.773 Part 25.775 Part 25.777	Cockpit Size Visibility through Windshield Windshields and Windows Positioning of Controls	Commercial Aircraft
AAR	Manual of Standards and Recommended Practices	Section F RP500 S504 S521 S528 S532 RP542	Locomotives and Electrical Equipment Glazing Requirements Locomotive Cab Seats Floors Cab Interior Layout of Controls Cab Heating System	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

- DIN 33.402 Human Body Dimensions provides standard human body dimensions for workstation dimensional design.

- DIN 33.403 Climate at Workplace provides recommendations for standardized measurements of temperature, humidity and ventilation.

- DIN 33.413 Ergonomic Aspects of Indicating Devices provides recommendations for instrument design for control panels. The recommendations relate the purpose of the instrument to its size and form (analog dial, digital readout, etc), and focus on the individual instrument. Computer screen displays that are increasingly being used to replace conventional "one purpose" instruments, for example in aircraft cockpits, are not covered.

- DIN 33.414 Ergonomic Design of Control Rooms provides recommendations for the design of control rooms and consoles, focussing on the interface between the console and the operator, and covering manual reach, comfortable field of view and dimensioning.

The draft MBO (paragraph 3.7) requires that the drivers be equipped with instruments indicating the status of all safety-critical systems. Means of communication to the control center must also be provided.

With regard to measures to minimize injury risk to operators and crewmembers, the RW MSB states in Chapter 7, Paragraph 2.1.23, Protection of Persons in the Vehicles, that persons must not be endangered by objects that become detached or are loosely mounted. No further detail is provided other than good engineering principles should be applied to interior vehicle design. There is no discussion of emergency egress, separate from that for all vehicle occupants.

4.2.3.2 U.S. Requirements

The FRA requirements contained in CFR Title 49, Part 223 specifies the glazing requirement for locomotives and passenger cars operating on U.S. railroads. Locomotives and cars must be fitted with certified glazing having the following performance:

Type I - Forward-facing locations (e.g., driving cabs) must be able to sustain impacts from a 10.9 kg (24 lb) object with dimensions of 8" x 8" x 16" at 13.4 m/sec (44 ft/sec) and a 0.22 caliber rifle bullet of 40 grains weight at 293 m/sec (960 ft/sec) without penetration. Part 229.119 also requires that the windows provide an undistorted view of the right-of-way from the normal driving position, but does not impose quantitative field-of-review requirements.

Type II - Side-facing windows must be able to sustain impacts from a 10.9 kg (24 lb) object with dimensions of 203 x 203 x 406 mm (8" x 8" x 16") at 3.7 m/sec (12 ft/sec), and a 0.22 caliber rifle bullet of 40 grains weight at 293 m/sec (960 ft/sec.)

A type-test using a specified test procedure is required to obtain certification for a specific glazing product.

The FAA requirements for commercial aircraft windshields (14 CFR, Part 25.775) specifies that window panels shall withstand an impact from a 1.82 kg (4 lb) bird at sea-level design cruising speed without penetration. The window system must also be designed to ensure that there is a low probability of injury from windshield fragments as a result of bird impacts.

The FRA requirements for locomotive cabs contained in 49 CFR, Part 229, specify adequate illumination of in-cab instruments, the provision of a reading light, and adequate heating and ventilation. There are no regulations regarding application of good "human factors" design principles to cab design. However, there is a growing interest in the "comfort cab" in the U.S. railroad industry. The design of these cabs emphasizes the use of an ergonomically designed control console, plus improved temperature control and noise and vibration insulation. The comfort cab follows design principles similar to those described in the DIN standards discussed above. Noise requirements are further discussed in Functional Area 210.

Specific FRA requirements of relevance to the operator and crew member environment in 49 CFR, Part 229 are:

- Part 229.47 requires the provision and prominent marking of an emergency brake valve, in a position accessible to the operator.

- Part 229.117 requires the provision of an accurate (+/- 5 mph) speed indication.

- Part 229.119 requires that the cab floors and passageways be kept tidy and clear of obstructions or debris that may create a hazard. This paragraph also requires proper ventilation and heating to a minimum of 10°C (50°F).

- Part 229.127 requires illumination of control instruments in a way that does not interfere with night vision of the track, and a switchable reading light.

The FRA requirements in 49 CFR, Part 229 regarding measures to minimize injuries in case of a slipping or falling incident or sudden acceleration are as follows:

- Part 229.41 requires that hazardous equipment such as moving machinery, hot surfaces and high tension electrical apparatus be in non-hazardous locations or equipped with suitable guards to prevent personal injury in the event of slipping, falling, or sudden acceleration or deceleration.

- Part 229.43 requires that sources of harmful gases such as engine exhaust and battery packs be suitably vented or positioned such that gases cannot enter the cab.

- Part 229.119 requires that cab floors and passageways be kept clear of obstruction or debris, to minimize the risk of injury.

FAA requirements in 14 CFR, Part 25, applicable to commercial airplane cockpits occupied by the pilot and flight crew are:

- Part 25.771 requires that the compartment must be of adequate size for the legal minimum crew, and that an adequate working environment be provided with respect to noise, vibration, heating, cooling and ventilation. Quantitative requirements are not provided.

- Part 25.772 requires an emergency exit from the cockpit if it is separated from the rest of the aircraft by a lockable door.

- Part 25.773 requires that windshields must provide adequate external visibility for normal operations.

- Part 25.777 requires that standard positioning and movement directions for major flight controls must be used.

The AAR Manual of Standards and Recommended Practices, Section F Locomotive and Electrical Equipment includes a number of requirements for cabs and controls, reflecting U.S. diesel-electric locomotive practice. Requirements of potential interest are:

- S 504 Locomotive Cab Seats requires that the seat structure pedestal and attachment to the locomotive structure be able to withstand the following loads:

  - Vertical force of 182 kg (400 lb) applied to the cushion or armrests without damage other than a maximum of 13 mm (0.5 in) permanent deformation of the armrests.

  - A horizontal impact of 1.5 g from a 114 kg (250 lb) weight applied to the backrest 0.36 m (14 in) above the seat cushion with no damage or permanent deformation.

  - A horizontal impact of 3.0 g from a 114 kg (250 lb) weight applied to the backrest 0.36 m (14 in) above the cushion with a maximum of 50 mm (2 in) permanent deformation of the backrest, but no other damage. The flooring standard S 521 mentioned above also helps reduce the incidence of slipping and falling incidents.

- S 528 Cab Interior requires that all exposed corners shall be rounded to minimize injury risk.

- S 532 Layout of Controls specifies layout of controls and instruments for the standard locomotive control-stand.

- RP 500 Glazing Requirements extends the FRA requirements to include fire resistance, light transmittal and distortion and abrasion resistance. Requirements are also provided for electrically heated windows.

- RP 542 Cab Heating System adds design details, to the performance requirements in the FRA regulation 49 CFR 229.119 cited above.

- S 521 Floors specifies the strength and surface finish of non-slip cab floor material.

4.2.3.3 Other Foreign and International Requirements

This section is devoted exclusively to UIC Code 651: Layout of Drivers' Cabs in Locomotives, Railcars, Multiple Unit Trains and Driving Trailers.

Section 2.7 and Appendix 3 of Code 651 provide glazing requirements for forward-facing windows. The primary requirement is that the window shall sustain an impact from a 1 kg standard projectile at a speed of 160 km/h, plus the maximum speed of the vehicle in which the windows are installed. The test may be conducted with either the window pane at right angles to the direction of the projectile, or with the window at the angle it is installed in the vehicle. This requirement is intended to protect against an object thrown or becoming detached from a train traveling in the opposite direction.

Safety glass must be used for side windows and any internal glazing (for example in internal doors or mirrors) exceeding 250 cm^2 (40 in^2) (Paragraph 2.7.3). Safety glass is defined as a type of glass that, when broken, does not produce sharp-edged fragments capable of causing injury. Alternative materials to glass may be used that provide equivalent protection from the risk of injury in the event of breakage. All windows must bear a permanent marking certifying the performance standard to which they have been manufactured.

A number of paragraphs in Code 651 address the in-cab environment as summarized below.

- Appendix 5 and Section 3 provide requirements that define a field-of-view from the normal operator's position and related requirements to ensure an adequate view of the track ahead. Window materials and positioning must be such that the external view is not impaired in any way by visual distortion, (especially of color) or reflections from internal light sources. There is also a requirement for an openable side window to enable the operator to see back along the train.

- Section 2.9 recommends heating, cooling and ventilation requirements to maintain a comfortable working environment in the cab. Temperature should be maintained in the range 18-23°C (64-73°F) (Section 2.9).

- Section 2.8 requires that suitable lights must be provided for instruments, for reading timetables and operating instructions, and for general lighting in the cab. Such lighting must not impair the operators external visibility.

Detailed recommendations based on good ergonomic principles are provided for the positioning of the operators seat and the layout of controls. These are similar to but less detailed than the requirements in the DIN 334xx series discussed above under German requirements. Recommendations are also provided regarding consistency in the relationship between movement directions of switches, and control devices and the resulting effects. For example, clockwise rotation of a master controller should result in additional power.

UIC Code 651 has several requirements that are intended to minimize accidental injury and provide for emergency egress in an accident. These are as follows:

- Paragraph 2.2.2 requires that sharp edges, protruding objects, etc., must be avoided so as to reduce the risk of injury in a collision or sudden acceleration or deceleration.

- Paragraph 2.2.3 requires proper protection from miscellaneous hazards in the cab such as hot surfaces, live electrical equipment, and toxic substances.

- Paragraph 2.2.4 requires an escape route from the cab to the opposite end of the vehicle. This paragraph also recommends that all the attachments between internal equipment and vehicle structure must withstand a minimum of 3g, and ideally 5g in longitudinal acceleration.

- Paragraph 2.7.2 requires that side windows be big enough to serve as emergency exits.

4.2.4 <u>Comparison and Assessment</u>

Three subject areas are addressed in this discussion: glazing requirements, human factors requirements, and injury avoidance.

4.2.4.1 Glazing Requirements

The maglev system will be exposed to the same or similar hazards with regard to impacts on forward-facing windows as other transportation vehicles operating on or near the ground, including bird impact, gunfire, and other flying objects.

Flying objects could include those that have a source external to the maglev system (such as objects picked up by a strong wind), objects that have been thrown at the guideway by vandals, or objects that have become detached from the vehicle or guideway, or another vehicle travelling on an adjacent guideway.

The gunfire hazard of greater concern in the United States than elsewhere, but the other hazards are similar in all countries. The frequency of occurrence of potentially hazardous impacts is a function of the guideway configuration and the nature of the guideway's immediate surroundings including:

- Height of guideway above surrounding land, where an elevated guideway is used.

- Presence of structures or trees of a height greater than the guideway within a close distance (say 100 m or 328 ft).

- Presence of passes accessible by the public. Passes might be avoided in high-speed areas, but could be more difficult to avoid in low-speed areas near terminals.

- Presence of an adjacent guideway, which creates a potential hazard from objects detached from or thrown up by a vehicle traveling in the opposite direction.

Although measures to protect the right-of-way against intrusions are discussed in Functional Area 304, Right-of-Way Security, full protection against these hazards cannot be guaranteed. Therefore, impact requirements are essential for both forward-facing and side-facing windows. Forward-facing window requirements should include gunfire protection as in the present FRA regulations as well as an appropriate "large object" impact test.

The FRA bullet impact requirement was designed to protect against gunfire and appears to be suitable for all guided ground transportation vehicle windows, independent of speed of operation or window orientation.

A large-object impact performance requirement is needed for forward-facing windows. The three large object impact tests identified (aviation bird strike, UIC projectile, and FRA cinderblock) involve objects having very different weights and impact behavior. The tests are not directly comparable, and it is not clear which is the most demanding, either from the point-of-view of glazing fracture, or of retention of the glazing in its mounting.

The comparison between these large object impact tests is summarized in Table 4-7:

TABLE 4-7. LARGE OBJECT IMPACT TEST REQUIREMENTS FOR FORWARD FACING TRANSPORTATION WINDSHIELDS

Originating Authority	FRA 49 CFR 223	FAA 4 CFR 25.775	UIC Code 651
Object Description	Cinderblock	Chicken	Aluminum/Steel Missile
Weight (kg) (lb)	10.9 24	1.82 4	11 2.2
Test Velocity (m/sec) (ft/sec)	13.4 44	max at low altitude, level flight	max + 160 km/h
Test velocity for m/sec 350 km/h vehicle* ft/sec	13.4 44	97 319	142 465
Kinetic Energy kN-m of object ft.lb	0.98 1443	8.56 12641	10.08 14773

*Chosen as a representative example.

The table shows that both the bird strike and the UIC projectile tests involve much higher energies than the FRA cinderblock test, and the UIC projectile is as hard or harder than the cinderblock. This suggests that the UIC test may be the most severe for glazing penetration; however, the UIC and the FAA bird strike tests are both similar for retention of the glazing in its mounting. The FRA impact requirement may not be suitable for high-speed maglev vehicles because the relatively low energy is not representative of high-speed impacts to which maglev vehicles may be exposed.

Whether the UIC or FAA tests are appropriate for a maglev vehicle operating in the U.S. will depend on a judgement regarding the likelihood of encountering the corresponding hazards—impact with a large bird, or impact with a hard object. However, given the similarity of energies, and the fact that the UIC missile test will likely produce higher localized impact forces, it is likely that a glazing system that will pass the UIC test will also pass the FAA test. Thus, adoption of the UIC requirement will be the conservative choice.

With regard to side windows, only the FRA requires a large object impact test. The UIC code requires the use of safety glass or an equivalent, but does not have an impact requirement. Glancing impacts of large objects on side windows appear to be possible, and a side window impact requirement, such as the FRA Type II specification may be appropriate.

4.2.4.2 Human Factors Requirements

Operating environment requirements cover ergonomics or human factor issues associated with the layout of controls and instruments, seating, interior and exterior visibility and related matters, and interior temperature ventilation and humidity.

The human factors requirements reviewed differ in details, but have the same general intent. Any of the requirements described either alone or in combination appear to be suitable for application to maglev systems in the U.S. The 33400 series DINs cited in the RW MSB provide useful ergonomic guidelines for crew compartments and control consoles. The only significant omission in the DINs is a "visibility" and "field-of-view" requirement through operator compartment windows. UIC 651 field-of-view requirements are comprehensive, but dimensioned specifically for conventional railroad operations. Maglev requirements will depend on the nature of operator duties which require an external view, and will likely be maglev-system specific. A forward view for manual operation, or providing the ability to make a visual check along the length of the vehicle or train may be appropriate requirements. None of the requirements reviewed address computer screen displays which are increasingly being used in place of conventional instruments. If used, computer screen delays should meet recognized requirements for clarity and ease of use.

The UIC 651 requirements for temperature control (maintaining temperature between 18-24°C (64-73°F) are more restrictive than the FRA/AAR requirement of a minimum temperature of 10°C (50°F).

4.2.4.3 Injury Avoidance

With regard to measures to minimize injury and provide for emergency egress in an accident, there is generally no conflict between the different requirements, only variations in emphasis. Chapter 7 of the RW MSB, Paragraph 2.1.2 requires that potentially injurious situations should be avoided, but does not refer to any of the detailed requirements identified and discussed under this heading.

The principal requirements mentioned in one or more of the referenced documents which could be applicable to a U.S. maglev system are as follows:

- Sharp corners, protruding objects, etc., should be avoided to minimize injury risk in the case of sudden acceleration or deceleration. Protection against interior impacts in the case of sudden acceleration or deceleration has been studied in a parallel Volpe Center project on collision safety, leading to recommendations for impact protection requirements.

- Adequate protection against accidental contact with hazardous equipment and surfaces is required.

- Non-slip flooring is required to minimize the risk of slipping and falling incidents.

- A minimum strength of attachment of seats and other equipment to the structure is required, normally expressed in terms of lateral and longitudinal accelerations to which the seat is subject. Application of the same requirements to equipment in operators and crew compartments as are suggested for passenger compartments would be appropriate, as was discussed in Functional Area 203.

- Provision for emergency access and egress from the compartment is required through a door or passageway to an adjacent passenger compartment, or through a door or window in the crew compartment to the exterior, if there is a lockable door between the compartment and the rest of the vehicle.

4.2.5 Findings

Present FRA requirements for the resistance of all windows to bullet impacts and requirements for large object impacts on side windows are applicable to maglev vehicle operator compartments. The existing FRA large object impact requirement is not adequate for forward-facing windows of HSGGT vehicles such as maglev. A more demanding requirement is needed.

Present FRA requirements for locomotive cab interiors contained in 49 CFR, Part 229 concerned with minimizing the risk of accidental injuries to cab occupants are also applicable to maglev systems. Other technical requirements, such as those of the AAR and UIC, recommend a number of additional measures to reduce injury risks that could also be applicable to maglev vehicle operator and crew compartments. There are no FRA requirements for the human factors design of cabs or crew compartments. However, application of recognized human factor design requirements is desirable to operator controls and instruments, where safety-related functions are being performed.

For U.S. maglev system application, consideration should be given to the following requirements for vehicle operator and crew compartments.

- As well as to the existing FRA bullet impact and side window large object impact requirement, consideration should also be given to new and more demanding impact requirements for forward-facing windows. The FAA 1.8 kg (4 lb) bird strike or the UIC 1 kg (2.2 lb) missile requirements may be suitable alternatives.

- The application of recognized human factors principles to operator cab design is desirable. The DIN-standards in the 33.400 series cited in the RW MSB provide comprehensive requirements that could be applicable, and further guidance is provided in UIC Code 615.

- Other appropriate requirements are to provide adequate external visibility from the operator compartment consistent with the operator's duties, requirements for the provision of interior lighting for key instruments and controls, and climate control requirements.

- Requirements for protection against accidental injuries in the compartment are desirable, including the avoidance of sharp corners and protrusions, provision of non-slip flooring, and the adequate attachment of seats and other equipment to the vehicle structure.

- Provision for emergency egress, either to an adjacent passenger compartment, or directly to outside the vehicle via an emergency exit in the crew compartment, as required for aircraft by 14 CFR, Part 25.772.

4.2.6 Further Studies

Further studies in two areas are suggested relating to the safety of maglev vehicle operator compartment or other compartments exclusively occupied by vehicle crew.

- Selection of an appropriate large object impact test for forward-facing windows. Information is lacking with which to make a logical choice between the UIC 1 kg (2.2 lb) projectile, the FAA 1.8 kg (4 lb) bird, or another test to provide adequate protection.

- Definition of appropriate design principles for computer screen displays that are increasingly being used in place of conventional instruments. This subject is not mentioned in the reviewed documents, although it is likely that pertinent information exists.

4.3 FUNCTIONAL AREA 203 - PASSENGER COMPARTMENT INTERIOR FITTINGS AND COMPONENTS

4.3.1 Description of Functional Area

This functional area addresses safety requirements for seats and other interior equipment, baggage storage, exterior and interior windows and mirrors, and the treatment of interior surfaces and fittings to minimize impact injuries. The other functional areas which address related safety requirements are:

Functional Area 201, Vehicle and Cab Structural Integrity, which covers all aspects of the overall vehicle structural performance, both in collisions and in normal operation, except the impact performance of windows.

Functional Area 202, On-Board Operator and Crew Compartments, which covers similar requirements for operator cab interior fittings and components.

Functional Area 204, Passenger Vehicle Doors and Entryways, which discusses the specific requirements for passenger doors and adjacent areas in the vehicle.

Functional Area 602, Emergency Features and Equipment, which addresses emergency access and egress, as well as requirements for emergency features and equipment.

4.3.2 Safety Baseline

Occupants of the passenger compartment of a maglev vehicle must be provided with a hazard-free environment as far as possible, and one that is equipped to minimize injury severity if the vehicle is involved in an accident. Specific safety concerns that should be addressed include:

- Protection against the penetration of external side windows by flying objects.
- Protection against injuries resulting from accidental breakage of interior glass, such as glass partitions, interior door windows and mirrors.
- Strength of seats and other interior fittings and equipment, including attachments to the vehicle structure to withstand normal service and emergency loadings. Loadings can be due to sudden acceleration, or loads applied by a slipping or falling person.
- Measures to minimize injuries due to impacts between compartment occupants and interior surfaces and equipment. Such impacts can occur as a result of sudden deceleration in a vehicle accident, or a slipping or falling incident unrelated to a train or vehicle accident.
- Proper containment of baggage so that it cannot become a missile in the event of a sudden deceleration, or accidentally fall out of overhead racks or bins.

4.3.3 Description of Existing Safety Requirements

The existing requirements are listed in Table 4-8, and described below by origin under three headings: German, United States and other foreign and international.

4.3.3.1 German Requirements

Chapter 7 of the RW MSB, Paragraph 2.1.2 states that the maglev vehicle must be structurally designed such that persons in the vehicle are not endangered, where possible, by objects that have become detached or are loosely mounted. Chapter 6, Paragraph 3.1 identifies load combinations for which the vehicle must be designed including a "collision" load case, but does not provide numerical values. The specified load cases would logically apply to vehicle interior fittings and equipment as well as the overall structure. The EBO and draft MBO require that tempered or laminated safety glass should be used in side windows and for any interior glass. Safety glass is defined in UIC Code 651 to be different types of glass, comparable materials, or combinations of these two materials which ensure a reduction in the risk of injury in the event of breakage.

4.3.3.2 U.S. Requirements

Current Amtrak specifications require that all interior fittings attached to the car structure, including seats, partitions, and baggage racks and storage, should be designed to withstand the following acceleration levels:

Longitudinal	6g
Lateral and vertical	3g

The safety factors to be used in structural design are not specified.

The FAA regulations contained in 14 CFR, Part 25 prescribe several requirements for commercial aircraft interior fittings and attachments. Part 25.561 defines an emergency landing design case which produces the following acceleration levels:

Longitudinal	9.0g forward, 1.5g rearward
Lateral	4.0g
Vertical	3.0g upward, 6.0g downward

All interior fittings, including seats and their attachments to the structure, must withstand these acceleration loads without deformations that would impede in any way rapid evacuation of occupants. The forces are assumed to act separately. Seats are further subject to dynamic shock load tests as specified in Part 25.562, when occupied by a 77 kg (170 lb) anthropomorphic dummy, with seat belts fastened and properly adjusted.

TABLE 4-8. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 203 - PASSENGER COMPARTMENT INTERIOR FITTINGS AND COMPONENTS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Requirements	Chapter 7 Paragraph 212	Design Production and Quality Assurance of Mechanical Structures Protection of Persons in Vehicle	Maglev
German Government	EBO	Chapter 29	Railroad Car Equipment	Railroad
	Draft MBO	Section 3.4	Vehicle Compartments	Maglev
UIC	566 OR Load Cases 560 OR Doors, Entrance Platforms, Windows, etc. 651 Layout of Drivers' Cabs in Locomotives, Railcars, Multiple Unit Trains, and Driving Trailers	- -		Railroad Railroad
FAA	14 CFR Airworthiness Standards, Transport Category Airplanes	Part 25.561/2 Part 25.625, 25.775 Part 25.785 Part 25.787 Part 25.789	Emergency Landing Static and Dynamic Conditions Safety Factors in Structural Design Windshields and Windows Seats, Berths, Safety Belts and Safety Harnesses Stowage Compartments, Retention of Items of Mass	Commercial Aircraft

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-8 SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 203 - PASSENGER COMPARTMENT INTERIOR FITTINGS AND COMPONENTS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FRA	49 CFR	Part 223	Glazing Standards	Railroad
Amtrak	495 Specification for Coach Seats	-		Railroad
Canadian Government	Draft Railroad Passenger Car Safety Standards	-		Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The specification of the dynamic loads is as follows:

- Change in downward vertical velocity of not less than 10.66 m/sec (35 ft/sec), reaching a peak of 14g in less than 0.08 sec.

- Change in forward longitudinal velocity of not less than 13.4 m/sec (44 ft/sec), reaching a peak of 16g in less than 0.09 sec.

Specified force or impact levels for the head, compression of spine, and legs, as measured by the dummy, must not be exceeded. Seats and their attachments must not deform in any way that would impede emergency evacuation of occupants.

Part 25.785 specifies that seats, safety belts and harnesses shall be designed so that occupants will not suffer serious injury as a result of being subject to the inertia forces prescribed in Parts 25.561 and 25.562. Seats must be designed assuming a 77 kg (170 lb) occupant. A safety factor of 1.15 shall be used in design (Part 25.625) except for seat-to-structure attachments, and seat belt or harness-to-seat or structure, where a factor of 1.33 shall be used. The safety factors apply whenever the seat strength has not been proven by a direct test.

Part 25.789 requires that all items of mass in passenger and crew compartments and galleys shall be restrained from becoming a hazard under the acceleration levels specified in Part 25.561, as cited above.

With regard to side windows, the FRA regulations contained in 49 CFR, Part 223 require that certified glazing meeting the Type II performance requirements shall be used for all side windows. The requirements are detailed in the discussion of operator cabs and crew compartments in Functional Area 202.

The FAA regulations do not specify impact loads for side windows, but 14 CFR, Part 25.775 states that all windows must be designed to withstand the pressure and temperature differentials applying to high altitude flight of pressurized airplanes. Windows must also be designed to withstand the pressure differentials associated with a cabin pressure altitude of 15,000 ft after any single failure of the installation or associated systems.

With regard to baggage storage, Amtrak requires that the acceleration levels cited above (6g longitudinal and 3g lateral and vertical) be applied to baggage racks and storage, as well as other interior fittings.

In 14 CFR, Part 25.787, the FAA requires that stowage compartments must be designed for the maximum placarded load, with the most unfavorable load distribution for all applicable load cases, including the emergency landing load case specified in 14 CFR, Part 25 561. Compartments ahead of or below the passenger compartment, however, need not be designed for the emergency landing load case. Enclosed overhead bins must be used on aircraft having 10 or more seats.

Part 25.785 provides requirements concerned with protecting commercial aircraft occupants from impacts with interior surfaces and fittings. The seated occupant must be protected against injury during the emergency landing scenario by a lap-type safety belt and one or more of the following precautions:

- A shoulder harness to prevent the head striking any injurious object.
- Elimination of injurious objects within striking range of the head.
- An energy-absorbing rest that will support arms, shoulders, head and spine.

In addition, each projecting object that would injure persons seated or moving about the airplane in normal flight must be padded.

4.3.3.3 Other Foreign and International Requirements

Two other requirements in this functional area have been identified, the UIC code primarily used by European railway systems, and draft Canadian railroad passenger car requirements.

With regard to the strength of interior equipment and attachments, the UIC Code 566, Load Cases, requires all internal fixtures, including seats and their attachments, to sustain the following acceleration levels *simultaneously*.

Longitudinal	5g
Lateral	1g
Vertical	3g

For seat structural design, the weight of a passenger is assumed to be 100 kg (220 lb).

UIC Code 560 requires that tempered or laminated safety glass shall be used for both side windows and interior glazing and mirrors. Safety glass is defined in UIC Code 651 as a glazing material that ensures a reduction in the event of breakage, as indicated in Section 4.3.3.1 above.

With regard to baggage storage, UIC requires that the general dynamic load case as specified in Code 566 above should apply. In addition, there is a separate load case for baggage racks:

> 1000 N (224 lb) per meter of length
> plus, 850 N (191 lb) at any point on the front edge.

The rationale for the 850 N load is that a passenger may hold onto the baggage rack for support. There is no requirement for enclosed overhead racks, which are viewed as undesirable because of concern over terrorist bomb attacks.

The draft Canadian regulations require that seats, interior fixtures and baggage storage compartments sustain 5g longitudinal and 3g vertical and lateral acceleration. Closed aircraft-style overhead baggage bins must be used.

4.3.4 Comparison and Assessment

Four subject areas are reviewed in this discussion: interior and exterior glazing, the strength of interior equipment and attachments to the vehicle structure, measures to mitigate injuries due to impacts with exterior surfaces and equipment, and baggage storage.

4.3.4.1 Windows

Only the FRA specifies impact tests for side windows. The FAA requirements are concerned with pressure and temperature differentials in high altitude flight but do not include an impact requirement. The UIC requirements specify the use of safety glass to protect against injuries following accidental breakage, but do not specify strength. A maglev vehicle operating in the United States may be exposed to gunfire; therefore, the FRA bullet impact requirement in 49 CFR, Part 223 should apply. Since there is also the risk of a glancing impact on a side window from flying objects, the FRA large object impact test in 49 CFR, Part 223 appears to be suitable. The high speed of the maglev vehicle does not increase impact velocity, as it cannot change the component of velocity of a flying object perpendicular to the direction of travel. One hazard that is not addressed in existing railroad requirements is resistance to air pressure shocks. These shocks are potentially severe when two vehicles pass at speed on adjacent tracks, or when a vehicle enters a tunnel. Some research to quantify the severity of such shocks and the potential need for glazing strength requirements to resist such shocks would be desirable.

Only the UIC Code provides a requirement for interior glass and mirrors, which is that safety glass should be used. This requirement is a reasonable precaution against injuries from accidental breakage of such glass, however caused.

4.3.4.2 Equipment and Attachment Strength

The FAA, Amtrak, Canada and UIC all specify steady-state acceleration levels that must be withstood by occupied seats and other interior fittings, including attachments to the primary vehicle structure. In addition, the FAA requirements include a short-duration impulse load with higher acceleration levels. The specified acceleration levels are summarized in Table 4-9.

TABLE 4-9. VEHICLE FITTINGS AND ATTACHMENTS: ACCELERATION LOAD CASES

Requirement Source	Applicability	Acceleration			Seat Occupant Weight (kg)
		Vertical	Lateral	Longitudinal	
14 CFR 25.561	Aircraft, Static	3g upward 6g downward	4g	9g forward 1.5g rearward	77
14 CFR 25.562	Aircraft, Dynamic	14g downward	–	16g forward	77
Amtrak	Intercity Rail	3g	3g	6g	84
UIC 566	Passenger Rail	3g	1g	5g	100
Canada	Passenger Rail	3g	3g	5g	83.8

As for conventional railroad passenger cars, the situations which could produce high accelerations in a maglev vehicle are likely to be a collision or a loss of support or guidance (e.g., suspension system failure). In contrast to a conventional railroad passenger car, maglev system configurations currently under development are unlikely to derail completely, but could suffer a malfunction of the lateral guidance system that could lead to high lateral acceleration. Therefore, the Amtrak requirements for lateral and vertical acceleration appear to be reasonable for maglev vehicles. The high vertical acceleration in the FAA requirements address vertical impact in a heavy landing which has no equivalent in maglev operations, which are located relatively close to the guideway and ground level.

Longitudinal accelerations can result from a collision with an obstruction or another vehicle. The magnitude and duration of such accelerations are a function of mass and structural characteristics of both the maglev vehicle and the obstruction. Maglev vehicles may differ from conventional trains in weight to crush-strength ratios. Also, vehicles may be more firmly constrained to the guideway, and thus be less likely to jackknife in a severe collision than conventional trains. Given these differences, direct application of a railroad-derived longitudinal requirement may be inappropriate, and it may be desirable to use a maglev system-specific load case derived from a "survivable collision" scenario. This subject has been studied in more detail in a recent FRA study of collision safety [9].

4.3.4.3 Surface Impact Mitigation

None of the railroad-related requirements address measures to reduce the severity of impacts between occupants and interior surfaces and equipment. The FAA regulations for aircraft require that interiors be padded and that the seated, belted-in occupant shall survive the acceleration cases specified in 14 CFR, Parts 25.561 and 25.562 without exceeding specified injury criteria. A similar approach is attractive for maglev, but considerable analysis and testing is required to demonstrate compliance with injury criteria requirements. The collision safety provides further information on this issue.

4.3.4.4 Baggage Storage

All the requirements reviewed specify that baggage storage has to withstand static accelerations as listed in Table 4-9. In addition, the aircraft and the Canadian railroad regulations specify that only fully-enclosed bins may be used for overhead storage. Amtrak and UIC permit open overhead racks. The UIC provides specific strength requirements for racks, including addressing use as a supporting handhold.

4.3.5 Findings

In most serious guided transportation system collisions and "sudden stop" accidents, a large number of injuries are caused by impacts between people and hard interior surfaces as well as internal equipment and baggage becoming detached from the structure. Therefore, safety requirements for passenger compartment interior fittings and components are necessary.

The FRA regulation for "Type II" side window glazing contained in 49 CFR, Part 223 is applicable to maglev vehicles. No other FRA regulations exist for passenger compartment interiors.

FAA commercial aircraft regulations contained in 14 CFR, Part 25, and requirements developed for conventional rail passenger vehicles by UIC, Amtrak and the Canadian government provide useful guidance regarding appropriate passenger interior safety requirements for maglev vehicles.

For U.S. maglev system applications, consideration should be given to the following safety requirements, in addition to the existing FRA side window glazing requirement:

- Safety glass should be used for interior glazing and mirrors, as required in UIC Code 560, to reduce the risk of injury from accidental breakage.

- The strength of seats, and the attachments of seats and other interior fittings to the vehicle structure should be designed to withstand acceleration of 6g longitudinally and 3g laterally and vertically. This requirement is based on present Amtrak practice. Alternatively, the safety assessment process described in the recent collision safety study [9] may be used to derive longitudinal strength requirements for seats and fittings.

- Hard surfaces and objects throughout the passenger compartment should be padded as required in 14 CFR, Part 25.785 to provide protection against injuries due to occupant-interior impacts. Alternative requirements may be developed using the process developed in the collision safety study [9].

- The application of aviation practice regarding baggage storage is recommended. Baggage should be placed in enclosed overhead bins, up to a maximum placarded weight, (14 CFR, Part 25.787) or in purpose-designed baggage compartments. Fully loaded compartments should be able to contain baggage under the acceleration loads specified above.

4.3.6 Further Studies

Further studies of passenger compartment interior safety are suggested in the following areas:

- To follow up on the Collision Safety report [9], further study is desirable to determine the strength of the interior fitting attachment to the vehicle structure, and of ways of mitigating the injury-causing potential of impacts between vehicle occupants and interior surfaces and objects in a collision.

- Study is also desirable to determine the window and window-mounting strength needed to resist the aerodynamic shock loads imposed on windows when two vehicles pass at high speed, or a vehicle enters a tunnel.

4.4 FUNCTIONAL AREA 204 - PASSENGER COMPARTMENT DOORS AND ENTRYWAYS

4.4.1 Description of Functional Area

This functional area addresses safety issues relating to the functioning of passenger vehicle doors and other vehicle equipment in areas directly adjacent to and associated with doors, such as steps, entryways and vestibules. These issues also include the relationship between the door and platforms at stations, and all aspects of operating manual or automatic doors. The principal related functional area is 601, Emergency Features and Equipment Including Access and Egress, which includes the use of regular doors in an emergency.

4.4.2 Safety Baseline

Doors must not present a hazard to travellers using the maglev system, either when entering or leaving the vehicle, or while the maglev vehicle is moving. Specific concerns that should be addressed are:

- Ensuring that doors remain closed while the maglev vehicle is in motion.
- Prevention of entrapment, for example, of a person or clothing in a door.
- Provision of emergency means of opening a door if the automatic mechanism has failed.
- Prevention of slipping or falling incidents when entering or leaving the vehicle.

It is assumed that maglev vehicles will have automatic doors.

4.4.3 Description of Existing Safety Requirements

The existing requirements identified in this functional area are listed in Table 4-10, and described below by origin under three headings: German, United States, and other foreign and international.

4.4.3.1 German Requirements

Chapter 4 of the RW MSB, requires that door status be monitored and displayed on the operator control panel, and that an interlock must be provided which prevents vehicle movement unless all doors are properly closed and locked.

The draft MBO requires that vehicle floors adjacent to doors must be level with the platform so that passengers can enter or leave the vehicle without danger. Interlocking devices must be provided so that all doors must be closed and locked before the vehicle can move in normal operation, but unlocked when speed falls below 5 km/h (3 mph). A monitoring

TABLE 4-10. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 204 - PASSENGER COMPARTMENT DOORS AND ENTRYWAYS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 4	On-Board Control System	Maglev
German Government	Draft MBO	Section 3.4	Vehicle Compartments	Maglev
	EBO	Chapter 29	Railroad Car Equipment	Railroad
UIC	560 Doors, Entrance Platforms, Steps, Handles, Handrails of Coaches and Luggage Vans	Section 3 Section 3 Section 4	Entrance Door Door Locking Device Entrance Platform, Handrails and Step	Railroad
FRA	49 CFR	Part 231	Railroad Safety Appliance Standards	Railroad
FAA	14 CFR, Part 25 Airworthiness Standards, Transport Category Aircraft	25.783	Doors	Commercial Aircraft
AAR	Manual of Standards and Recommended Practices	Part A S.034-69	Passenger Car Specifications	Railroad
Canadian Transport Commission	Passenger Car Safety Standards - Draft	Section 42	Automatic Doors	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

system for door status must be provided for the use of the on-board operator. Finally, persons must not be endangered when doors are being closed.

The EBO requires that remotely controlled powered doors must not cause hazards to people, and specifically, that protection against trapping fingers in doors must be provided.

4.4.3.2 U.S. Requirements

The FRA regulation contained in 49 CFR, Part 231.14 provides requirements for the size and location of steps and handrails at passenger car doors. These requirements are primarily to ensure the safety of railroad staff during switching activities.

The FAA regulation contained in 14 CFR, Part 25.783 requires that each separate cabin must have an external door. Means must be provided to lock and safeguard the doors against opening in flight, due to inadvertent operation or the failure of any single structural element. Provision for reliable direct visual determination of locking status must be provided. Doors must be openable from both outside and inside, even when the persons are crowded against the inside. The opening means must be simple, obvious and clearly marked.

The regulations implementing the Americans with Disabilities Act specify door width and the use of high platforms to address needs of mobility-impaired persons.

The AAR Manual of Standards and Recommended Practices, Section A, Standard S-034-69, Section 23 specifies that only sliding doors may be used on railroad cars. Neither inwardly or outwardly opening doors are permitted.

4.4.3.3 Other Foreign and International Requirements

UIC Code 560 contains detailed requirements for both powered and manual doors, and for entry platforms and steps of conventional rail vehicles. Since all maglev vehicle doors are expected to be power operated, only the powered door and entryway requirements of UIC 560 are relevant, as listed below.

- Doors must be locked automatically at speeds exceeding 5 km/h (3 mph). The locking system must be such that two separate defects must occur before the doors can open accidently when the train is in motion.

- Emergency manual means must be provided to unlock and open the doors from both inside and outside the vehicle. Usually an unlocking lever handle situated behind a breakable glass panel is provided. Instructions for use must be displayed.

- Sliding doors must be equipped with a pressure-sensitive edge or equivalent to detect obstacles and door controls must respond to detection by stopping or re-opening.

- Non-skid floor covering must be used inside the vehicle adjacent to doors.

Several paragraphs in UIC 560 specify the dimensions and spacing of entry steps and handrails for use when the platform height is not level with the vehicle floor. External steps and handrails to facilitate conventional railroad switching activities are also specified.

The draft Canadian Railway Passenger Safety Design Standards issued by the Canadian Transport commission (CTC), Section 42 are identical to the UIC requirements, with the additional requirements that audible warning of door operation be given, and that visual indication of door status be provided locally inside and outside the car and in the control cab.

4.4.4 Comparison and Assessment

It is expected that a maglev vehicle operating in the United States will be equipped with power doors, and stations will have platforms at the same height as the vehicle floor adjacent to doors. Safety requirement should be appropriate for such a system. Safety requirements for power-operated doors are lacking in the United States. The most comprehensive requirements reviewed are those contained in UIC 560 and the very similar Canadian requirements, and both are consistent with the less detailed German requirements. Furthermore, the UIC and Canadian provisions appear to address all safety baseline requirements and are similar to practice on mass transit systems in the United States equipped with automatic doors.

4.4.5 Findings

Present FRA regulations concerning steps and handholds at passenger car doors are not applicable to maglev vehicles, since platforms will be at the same height as vehicle floors. Conventional railroad-style switching activities requiring end-of-vehicle handholds and steps are not a feature of maglev operations.

For U.S. maglev system applications, consideration should be given to the following safety requirements primarily based on the requirements of UIC Code 560:

- The automatic doors should be under the control of and monitored by the on-board operator of the maglev vehicle. The operator should also have a means of visually checking door status prior to departure.

- The door locking mechanism should be highly reliable, to prevent unintended door opening while the maglev vehicle is moving, and an interlocking mechanism with the vehicle propulsion system should be provided to prevent vehicle movement unless the doors are locked.

- Emergency means should be provided to manually release the door locking mechanism and to open the door from both inside and outside the vehicle. The location of the emergency release should be indicated by appropriate signs together with operating instructions.

- To ensure safety during closing, the door closing mechanism should be provided with means to detect entrapment of any object by the door, and to open automatically to release any trapped object. Maximum closing force should not exceed a value that could injure a person trapped by a closing door. An automatic audible warning should be given before operating the door.

- To ensure safety of passenger movements through the entryway, vehicle floors adjacent to the door shall have non-slip flooring, and the door area should be well lighted.

4.4.6 Further Studies

Although various existing requirements in the UIC Code and U.S. rail mass transit practice appear to address most door safety concerns, some further study of the applicability of requirements to maglev is desirable to ensure that all concerns have been properly addressed.

4.5 FUNCTIONAL AREA 205 - FIRE SAFETY

4.5.1 Description of Functional Area

This functional area addresses all safety issues associated with minimizing the occurrence of fire on board a maglev vehicle and protecting the occupants of the vehicle from the consequences of a fire, should one occur.

Other functional areas which address safety requirements relevant to fire emergencies are:

Functional Area 404, Electrical Safety, which discusses the requirements for electric cabling and other equipment. Electrical malfunctions can initiate a fire, and proper selection and design of electrical components and systems are important in minimizing this risk.

Functional Area 602, which discusses Emergency Features and Equipment Including Access and Egress in all types of emergencies, including fires, together with other safety-related emergency features and equipment.

4.5.2 Safety Baseline

Occupants of a maglev vehicle must be provided with fire protection at least equivalent to that provided in other public transportation systems. Fire safety issues include:

- Vehicle design practices to minimize fire risk,
- Requirements for the fire safety of materials used in a maglev vehicle,
- Fire walls/barriers, to retard or prevent the passage of a fire from compartment to compartment in the vehicle, and
- Fire detection and suppression systems to control a fire.

These requirements must be consistent with the configuration of the maglev system, especially for access to a stranded vehicle and the ease with which an emergency evacuation can be carried out. Generally, more stringent fire safety requirements are applicable in situations where accessibility and means for emergency evacuation are limited.

4.5.3 Description of Existing Safety Requirements

The existing requirements are listed in Table 4-11 and described below under three headings: German, United States, and other foreign and international.

TABLE 4-11. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 205 - FIRE SAFETY - MATERIALS AND DEVICES

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 11	Fire Protection	Maglev
German Government	Draft MBO	Section 3.4	Vehicle Compartments	Maglev
	Bostrab: Streetcar Construction and Operation Directions	Section 33	Vehicles	Light Rail Vehicles
BRAND-RL	Preliminary Vehicle Fire Protection Guidelines	-	-	Light Rail Vehicles
DIN	50060 Testing of Burning Behavior of Materials and Products, Terms and Definitions	-	-	General Industrial
	5510 Preventative Fire Protection in Railway Vehicles	Part 1 Part 4 Part 5 Part 6	Levels of Protection, Preventative Measures, Certification Structural Design of the Vehicle Electrical Operating Means Emergency Brake, Fire Alarms, and Fire Fighting Equipment	Railroad
	4102 Fire Behavior of Building Materials and Building Components	Part 2 Part 4 Part 5 Part 6	- Definitions, Requirements and Tests - Summary and Use of Classified Building Materials - Fire Barriers in Liftwells and Glazings - Ventilation Ducts, Definitions, Requirements and Tests	Buildings
German Railways	DS 899/35 Code of Practice for Testing the Burning Behavior of Solids	-	-	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-11. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 205 - FIRE SAFETY - MATERIALS AND DEVICES (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
VDMA	24169 Explosion Protection in Fans Transporting Combustible Gases, etc.	-	-	General Industrial
FRA/Federal Register	Volume 54 No. 10 January 17, 1989	-	Rail Passenger Equipment: Reissuance of Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics	Intercity and Commuter Rail
FTA/Federal Register	Volume 49 No. 158 August 14, 1984	-	Recommended Fire Safety Practices for Rail Transit Materials Selection	Rail Mass Transit
FAA	14 CFR, Part 25 Airworthiness Standards, Transport Category Airplanes	Part 25.865 Part 25.851 Part 25.853 Part 25.855 Part 25.858 Appendix F	Fire Protection of Flight Controls, etc. Fire Extinguishers Compartment Interiors Cargo and Baggage Compartments Cargo Compartment Fire Detection Test Criteria and Procedures	Commercial Aircraft
NFPA	130 Fixed Guideway Transit Systems	Chapter 4 Appendix D	Vehicles Fire Risk Assessment	Rail Mass Transit
Amtrak	352 Specification for Flammability, Smoke Emissions and Toxicity	-	-	Railroad
Amtrak	307 Smoke Alarm System for Passenger Cars	-	-	Railroad
AAR	Manual of Standards and Recommended Practices	Section E RP539	Fire Protection for Diesel-Electric Locomotives	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-11. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 205 - FIRE SAFETY - MATERIALS AND DEVICES (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
UIC	564-2 Fire Protection and Fire-Fighting Measures in Railway Passenger Vehicles	Section 3 Section 4 Section 5	Behavior of Materials and Components in the Event of Fire. Special Directives (for Vehicle Design Details). Fire-Fighting Methods.	Railroad
British Standards Institution	BS 6853 Fire Precautions for Railway Passenger Rolling Stock	-	-	Railroad
Airbus Industrie	ATS 1000.001 Fire-Smoke-Toxicity (FST) Test Specifications	Section 4.2	Toxicity Requirements	Commercial Aircraft

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The requirements reviewed cover the following areas of fire safety:

- The classification of the fire threat as a function of the operating environment. More stringent requirements may apply to situations where the means of escape are more restricted.
- Miscellaneous vehicle design requirements to reduce fire risks.
- Requirements for the flammability, smoke emission and toxicity of materials incorporated into the vehicle.
- Requirements for fire barriers between equipment compartments and compartments occupied by passengers and crew, and between passenger compartments.
- Requirements for fire detection and suppression equipment.

4.5.3.1 German Requirements

Chapter 11 of the RW MSB is exclusively concerned with fire protection, and refers to several DINs and other requirements addressing different aspects of fire safety, including UIC 564-2, FAA 14 CFR, Part 25.883 and Airbus Industrie ATS 1000.001. German requirements documents referenced are as follows:

DIN 5510, Part 1, Preventative Fire Protection in Railway Vehicles specifies four levels of fire protection commensurate with the risk and escape possibilities in the case of a fire. The agency responsible for technical supervision determines which fire protection level is applicable to a vehicle.

Chapter 11 of the RW MSB, Fire Protection, specifies that the highest level requirements of DIN 5510 shall apply to high-speed maglev vehicles, defined by DIN 5510 as where "The risk to the passenger vehicle is markedly determined by use on lines without a safety space."

The DIN 5510 series also specifies a number of vehicle design requirements to reduce the risk of fire.

Part 4 of DIN 5510 specifies precautions for minimizing the risk of fire starting in a rail vehicle, including proper containment of combustible gases and liquids, ease of cleaning, provision of insulation around hot items such as heating ducts, and measures to minimize the risk of a litter-bin fire. Other requirements in Part 4 address the design of heating and ventilating systems. The requirements include limiting temperatures to 200°C in the neighborhood of heating devices, arranging hot air outlets so that they cannot be completely blocked, arranging ducting, etc., so that the effectiveness of fire barriers is not compromised, and providing the means to switch off or block ventilation fans if a fire occurs.

Part 5 of DIN 5510 provides requirements for electrical systems to reduce fire risk, including cable standards, junction boxes and light fittings. Notably, cables for communication and public address systems, and control lines for traction power, brakes and doors must be separated from other high voltage cables (over 500 volts) by enclosure in separate ducts.

Requirements for ventilation fans for flammable and explosive gases and vapors are provided in VDMA 24 169. This requirement is cited in RW MSB in connection with ventilation fans for battery compartments. The requirement specifies measures to prevent sparks, and to keep operating temperatures low with such fans to avoid the risk of igniting gas given off by the batteries.

The RW MSB refers to several German requirements which specify the flammability and smoke emission performance of materials installed in the maglev vehicle, as follows:

- DIN 50060 provides multilingual (English, French, German) definitions of terminology used in testing of the burning behavior of materials. Terminology for flammability, fire loading, performance of fire barriers, and related matters is included, but not toxicity.

- DIN 4102 contains requirements for the fire behavior of non-combustible building materials, such as steel, concrete, gypsum wallboard, and wood. These requirements are incorporated into German building codes, and are cited by RW MSB for non-combustible materials incorporated into the maglev vehicle. DIN 4102 contains several parts as follows:

  - Part 2 contains requirements for testing building components specifically for determining the performance of walls and floors as fire barriers. Performance is assessed by applying a specified flame to one side of the barrier and measuring temperature on the other side. Temperature must not exceed an average of 140°C over the test area and 180°C at any single point during the test period. Materials are classified by fire resistance time in minutes. F30 must pass a 30-minute test, F60 a 60-minute test, and so on. F180 is the highest classification.

  - Part 4 is an extensive volume defining construction requirements for meeting different fire resistance classifications with different materials.

  - Part 5 defines specific requirements for fire doors and glazing to meet different barrier performance levels, including test procedures.

  - Part 6 defines specific requirements for ventilation ducts, including fire dampers used to shut-off ducts in case of fire.

- DS 899/35 is a requirement issued by German Federal Railways (DB) for testing the fire performance of combustible materials incorporated into vehicle structures. Test requirements for smoke-emission, flammability and the capacity to form drops, and forms for reporting results are included.

Other requirements for combustible material fire performance cited in the RW MSB were from U.S. and other sources and will be described in the relevant sections below.

RW MSB requires that by using suitable materials and design, fire walls must be provided to ensure that fire transmission can be excluded for a period of time at least as long as that needed to evacuate the passengers and crew (Chapter 11, Section 4.3). A fire door and barrier meeting this requirement must be provided between vehicle sections.

Part 6 of DIN 5510 provides requirements for fire detection and suppression systems for rail vehicles operating in the most severe environment. Such vehicles must be equipped with one fire extinguisher in each passenger or crew compartment, and automatic fire detection equipment that will provide a warning to the vehicle operator or another continuously manned crew location together with an indication of the location of the fire.

The German Directive for the Construction and Operation of Streetcars (Bostrab) was not referenced in the RW MSB, but also contains fire safety requirements. Section 33 of the Bostrab document contains the general requirement that passenger area construction materials and vehicle design should employ state-of-the-art approaches to fire protection. Specific information explaining the Bostrab requirements is contained in a companion vehicle fire protection guideline (BRAND-RL) document. BRAND-RL provides detailed requirements and information for vehicle design, materials selection and fire suppression. Most of the test procedures and performance requirements for flammability and smoke generation are taken from the German Federal Railways requirements contained in DS 899/35, DIN 4102 or UIC Code 564-2. The requirements primarily apply to vehicles that operate through tunnels, and more stringent requirements apply to vehicles that operate through tunnels that lack a "safety space" for occupant evacuation. There is no mention of DIN 5510, which appears to have been prepared after publication of BRAND-RL.

4.5.3.2 U.S. Requirements

With regard to vehicle design requirements, NFPA 130, Section 4.3, specifies a number of electrical system design requirements, including overload protection systems. Provision to de-activate all ventilation systems automatically or remotely must be provided. The FAA requirement contained in 14 CFR, Part 25.865 requires that essential flight controls, engine mounts and other flight structures located in designated fire zones must be constructed of fire-proof materials, or shielded so that they are capable of withstanding the effects of a fire.

Requirements for the flame spread and smoke emission of materials used in transportation vehicles have been developed in the U.S. by the FRA, FTA, FAA, Amtrak, and NFPA, these requirements can be summarized as follows:

- The FRA requirements for passenger train cars are contained in Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics (Federal Register, January 17, 1989).

  Test procedures and performance requirements are specified for flammability and smoke emission for all commonly used materials, as indicated in Table 4-12 reproduced from the FRA guidelines. Sources of guidance in the selection of electrical cable insulation are also provided. Electrical insulation is not otherwise provided for in the guidelines.

TABLE 4-12. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSIONS CHARACTERISTIC FOR COMMUTER AND INTERCITY RAIL VEHICLE MATERIALS

Category	Function of Material	Test Procedure	Performance Criteria
Passenger seats, sleeping and dining car components	Cushions, Mattresses[1,2,5,9*]	ASTM D-3675	$I_s \leq 25$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤175
	Seat and/or Mattress Frame[1,5,8]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤200
	Seat and Toilet Shroud, Food Trays[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤200
	Seat Upholstery, Mattress Ticking and Covers, Curtains[1,2,3,5]	FAR 25.853 (Vertical)	Flame Time ≤ 10 sec.; Burn Length ≤ 6 inch
		ASTM E-662	D_s (4.0) ≤ 250 coated; D_s (4.0) ≤ 100 uncoated;
Panels	Wall[1,5,10]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
	Ceiling[1,5,10]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
	Partition, Tables and Shelves[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
	Windscreen[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
	HVAC Ducting[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (4.0) ≤ 100
	Window[4,5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
	Light Diffuser[5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤200
Flooring	Structural[6]	ASTM E-119	Pass
	Covering[7,10]	ASTM E-648	C.R.F. ≥ 0.5 w/cm^2
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
Insulation	Thermal[1,2,5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	D_s (4.0) ≤ 100
	Accoustic[1,2,5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	D_s (4.0) ≤ 100
Elastomers	Window Gaskets, Door Nosing, Diaphragms, Roof Mat.[1]	ASTM C-542	Pass
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200
Exterior Plastic Components	End Cap, Roof Housings[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0)≤ 200
Component Box Covers	Interior, Exterior Boxes[1,3,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	D_s (1.5) ≤100; D_s (4.0) ≤ 200

Source: Federal Register, Vol. 54, No. 10, January 17, 1989

TABLE 4-12. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSIONS CHARACTERISTIC FOR COMMUTER AND INTERCITY RAIL VEHICLE MATERIALS (cont.)

Notes

1. Materials tested for surface flammability should not exhibit any flaming running or flaming dripping.

2. The surface flammability and smoke emission characteristics should be demonstrated to be permanent by washing, if appropriate, according to FED-STD-191A Textile Test Method 5830.

3. The surface flammability and smoke emission characteristics should be demonstrated to be permanent by dry-cleaning, if appropriate, according to ASTM D-2724. Materials that cannot be washed or dry cleaned should be so labeled and should meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

4. For double window glazing, only the interior glazing should meet the materials requirements specified herein, the exterior need not meet those requirements.

5. ASTM E-662 maximum test limits for smoke emission (specified optical density) should be measured in either the flaming and non-flaming mode, depending on which mode generates the most smoke.

6. Structural flooring assemblies should meet the performance criteria during a nominal test period determined by the transit property. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal test period should not be less than 15 minutes. Only one specimen need be tested. A proportional reduction may be made in the dimensions of the specimen provided that it represents a true test of its ability to perform as a barrier against under car fires. Penetrations (ducts, etc.) should be designed against acting as passageway for fire and smoke.

7. Floor covering should be tested in accordance with ASTM E-648 with its padding, if the padding is used in actual installation.

8. Arm rests, if formed plastic, are tested as cushions, if hard material, are tested as a seat back shroud.

9. Testing is performed without upholstery.

10. Carpeting on walls and ceilings are to be considered wall and ceiling panel materials, respectively.

- The FAA, in 14 CFR, Part 25.853, requires that all materials used in passenger or crew compartments of commercial aircraft must meet specified test criteria. The test procedures to be used are specified in detail in Appendix F to Part 25. Part 25.855 contains similar requirements for baggage and cargo compartments, which vary according to accessibility during flight and whether or not fire detectors are fitted. Part 25.858 provides requirements for cargo compartment fire detectors.

- The requirements for rail transit vehicle flame spread and smoke emission, as contained in Recommended Fire Safety Practices for Rail Transit Materials Selection (Federal Register, August 14, 1984), are very similar to the FRA requirements.

- The flammability and smoke emission requirements in Amtrak Specification Number 352, Flammability, Smoke Emission and Toxicity, are very similar to the FRA Guidelines. A toxicity test is also required, NBSIR 82-2532, Further Development of a Test Method for the Assessment of the Acute Inhalation Toxicity of Combustion Products. Data on the concentration of CO, CO_2, O_2 and HCN are required to be reported but no acceptability criteria are given.

- Chapter 4 of NFPA 130, Vehicles repeats the FTA requirements for material flammability and smoke emission performance and also recommends that a "Hazard Load Analysis" be performed. In this analysis, the concentration and characteristics of flammable material in a compartment of the vehicle are calculated, leading to an estimate of heat output. The heat output should be below 80 BTU per cubic foot to keep fire propagation risk to acceptable levels. The FTA, NFPA, and Amtrak barrier requirements are similar.

With regard to barrier requirements to contain a fire, the FRA guidelines recommend that floors should resist penetration by an undercar fire for twice the period needed to bring the train to rest and evacuate the car. In any case, this should not be less than 15 minutes. Penetrations (ducts, etc.) should be designed against them acting as a passageway for fire and smoke. The FTA, NFPA, and Amtrak barrier requirements are similar.

Amtrak Specification 307, Smoke Alarm System for Passenger Rail Cars, contains requirements for a smoke alarm system that will detect dangerous smoke levels and shut down air dampers and blower fans in the car ventilation system.

With regard to fire detection and suppression equipment, Chapter 4 of NFPA 130, requires that each vehicle or operators cab be equipped with approved portable fire extinguishers except where sufficient wayside extinguishers, standpipe systems or other fire-fighting equipment are available.

FAA requirements (14 CFR, Part 25.851) specify a minimum of one fire extinguisher for approximately every 30 seats in the passenger cabin and in each cargo compartment accessible in flight. Smoke detectors are required in lavatories and most cargo compartments.

The AAR Manual of Standards and Recommended Practices, Section E Locomotive and Electrical Equipment requires one fire extinguisher having a minimum capacity of 9 kg (20 lb) in the operator's cab and two 14 kg (30 lb) or three 9 kg (20 lb) extinguishers in the engine room (Recommended Practice RP 539). The AAR requirement also emphasizes that cleanliness and good housekeeping in the locomotive is effective in reducing fire risk, especially by avoiding a build-up of dirt and debris at high risk locations in the cab and equipment compartments.

4.5.3.3 Other Foreign and International Requirements

Two important requirements for rail vehicle fire safety have been identified, British Standards Institution BS 6853, Fire Precautions in the Design and Construction of Railway Passenger Rolling Stock, and UIC Code 564-2, Regulations Relating to Fire Protection and Fire-Fighting Measures in Passenger-Carrying Railway Vehicles.

BS 6853 divides rail vehicles into two classes:

Category I - vehicles which require a higher resistance to fire than other trains, such as trains that operate in confined situations (tunnels or elevated structures), sleeping cars and unmanned cars.

Category II - all other vehicles.

BS 6853 recommends that the total amount of combustible material in the vehicle be limited as far as possible. The fire hazard implications of the proximity of different materials to each other and to ignition sources, and the effects of ventilation should be taken into account in vehicle interior design. Heaters in passenger and crew areas should be designed or protected so that air flow around them cannot be accidentally obstructed. Ventilation fans should be designed so that they will not recirculate combustion products in the event of fire.

Standardized tests are specified for the flammability and smoke emission performance of each principal type of material. The tests are specified in other British Standards Institution publications. More stringent performance requirements are specified for "Category I" vehicles as defined by BS 6853 -- those from which emergency escape is expected to be difficult. No toxicity requirements are provided on the grounds that no broadly accepted test or evaluation procedure is available.

Transverse fire barriers are required by BS 6853 at the ends of coaches or within their length to prevent or limit the spread of fire. Transverse fire barriers should provide protection for a minimum of 20 min on category I vehicles.

Finally, BS 6853 requires that one fire extinguisher shall be carried in each car, and that automatic smoke detectors should be installed in sleeping car compartments and food service galleys.

The principal requirements in UIC Code 564-2 are as follows:

- Non-metallic material fire performance has to meet one of a number of alternate acceptable requirements, including German Railways DS 899/35.

- Car design features are recommended to delay the spread of a fire.
  - As far as possible, electrical cables should be enclosed in metal conduit.
  - Transverse fireproof bulkheads should be installed a maximum of 11 meters (37 ft.) apart. This means that a typical rail passenger car should be divided into at least two compartments.
- Each car shall be equipped with at least one portable extinguisher of not less than 6 kg (13 lb.) capacity. Sleeping and restaurant cars shall have two extinguishers. Extinguishers using environmentally damaging substances, such as halon are not permitted.

The RW MSB cites Airbus Industrie Specification ATS 1000.001 for toxicity requirements. This specification provides flammability/smoke and toxicity minimum criteria for nonmetallic materials installed in the interior of commercial aircraft manufactured by Airbus Industrie. Flammability and smoke emission requirements are identical to FAA requirements in 14 CFR, Part 25.853. Toxicity requirements are expressed in terms of maximum permitted concentrations of toxic gases in at least three samples tested under flaming and non-flaming conditions:

	c (ppm) within 4 minutes
Hydrogen Fluoride HF	100
Hydrogen Chloride HCL	150
Hydrogen Cyanide (HCN)	150
Sulphur Dioxide SO2 + H2S	100
Carbon Monoxide CO	1000
Nitrous Gases NO + NO2	100

These results have to be accomplished at each test run.

Toxic combustion products, other than those listed in this specification which are expected or come up during testing, have to be indicated on the test report (for example HBr).

4.5.4 Comparison and Assessment

The fire hazard in high-speed maglev vehicles in the United States is similar to that in conventional self-propelled or locomotive-hauled passenger railroad cars. If the maglev vehicle operates on an elevated guideway, the ability to escape from the vehicle in a fire emergency may be more restricted than from a conventional rail vehicle; but similar to that from an underground heavy rail mass transit train.

Safety requirements are appropriate for general vehicle design practices which may affect fire risk, for the flammability, smoke emission and toxicity of materials, for fire barriers, and for fire detection systems and extinguishers. The requirements are discussed below.

4.5.4.1 Vehicle Design Practices

Good vehicle design practices are addressed in DIN 5510, Part 4, BS 6853, UIC 564-2, and NFPA 130. There is generally no conflict between these requirements where they address the same subject, but the subjects addressed varies between the requirements documents. All appear to be generally suitable for application to maglev vehicles in the United States. The principal requirements covered in the documents reviewed which are suitable for application to maglev vehicles are as follows:

- Use good practice with regard to electrical equipment and cabling (NFPA 130, DIN 5510 Part 5), as discussed in more detail in Functional Area 404, Electrical Safety.

- Provide for vehicle ventilation systems to be shut off either automatically or remotely (NFPA 130, DIN 5510 Part 4).

- Ensure that vehicle heating system outlets cannot be blocked and overheat, and that dirt, litter or other debris cannot accumulate and become a fire hazard (DIN 5510 Part 4, BS 6853, UIC 564-2).

- Ensure that safety-critical control lines are non-combustible, or are contained so that they can continue to function in the event of fire (14 CFR, Part 25.865).

4.5.4.2 Flammability, Smoke Emission and Toxicity

With regard to the flammability and smoke emission requirements for vehicle materials FRA, FTA, Amtrak, and NFPA are all virtually identical, with Amtrak and FRA being slightly more comprehensive. Amtrak or FRA requirements would appear to be suitable for application to maglev vehicles.

Toxicity requirements are specified in Airbus Industrie ATS 1000.001 and in Amtrak Specification 352, which references NBSIR 82-2532. Both the Amtrak and the Airbus Industrie toxicity tests require materials to be tested under both flaming and non-flaming conditions. The Amtrak specification requires animal tests to determine the toxicity of combustion products. LC 50 is the concentration needed to produce death in 50 percent of laboratory animals exposed to the combustion products. The Airbus test states maximum allowable concentrations of toxic substances produced in the test, but not LC 50 values.

NFPA 130, Amtrak 352 and BS 6553 all indicate that test data for individual materials should not be interpreted in isolation. Other factors to be taken into consideration in vehicle design for fire risk reduction include the total quantity of flammable material, combinations of materials in a particular part of the vehicle and their orientation, and the proximity to an ignition source. Analysis of total fire loading, and occasionally full scale tests are warranted to ensure that fire risks are properly understood and controlled.

4.5.4.3 Fire Barriers

The referenced documents contain a variety of different requirements for barrier location and performance. Amtrak, FRA, NFPA 130, and FTA all require floors to pass the ASTM E119 fire barrier test for a period equal to at least twice the time taken to come to a complete rest, plus the time needed to evacuate all people from the vehicle. Amtrak and FRA also specify the flammability of equipment box covers, which may serve to contain a fire.

Requirements for vertical transverse fire barriers are found in RW MSB, BS 6853 and UIC Code 564-2. BS 6853 requires transverse barriers providing 20 minutes protection at the ends of vehicles. UIC 564-2 states that barriers are required less than 11 m (37 ft) apart, and RW MSB requires barriers at the ends of each vehicle section. Neither UIC or RW MSB specifies quantitative protection time, but RW MSB has language similar to that in the FRA requirements for protection for at least the time needed to stop and evacuate the vehicle.

Both floor and transverse vertical barriers would be desirable in a high-speed maglev vehicle. Floor barriers would delay fires initiated in underfloor equipment compartments from spreading into passenger compartments, and fire resistant transverse bulkheads would prevent growth of a fire along the train. Fire resistant bulkheads separating passenger compartments from above-floor equipment compartments would also be desirable.

For all types of barriers, it will be important to ensure that effectiveness is not impaired by ducts, etc., penetrating the barrier.

4.5.4.4 Fire Detection and Suppression

Provision of at least one manual fire extinguisher in each passenger compartment is required by NFPA 130, the FAA, DIN 5510, UIC 504-2 and BS 6830. AAR requires extinguishers in the cab and engine room of a diesel-electric locomotive. Provision of a fire extinguisher is clearly a desirable precaution. There is a concern, however, in the U.S. environment of unauthorized use by vandals. Mass transit practice in the U.S. is to place extinguishers in each operator cab where they are only accessible to crew members, rather than in the passenger compartment. Alternatively, some kind of breakable seal might be used on the extinguisher mounting to discourage inappropriate use.

Requirements vary regarding fire and smoke detectors. DIN 5510 requires detectors in each vehicle with a remote display to the vehicle operator. The FAA and BS 6853 require detectors in spaces, such as lavatories or sleeping car compartments, where a fire may develop undetected, but not in main passenger compartments. Provided the vehicle is equipped with manual alarms in passenger compartments, automatic detectors in passenger seating compartments would seem to be superfluous. Detectors in lavatories and enclosed equipment or cargo spaces may be desirable.

4.5.5 Findings

Fire safety requirements for maglev vehicles operating in the United States will be essential. Past experience indicates that a significant risk of on-board fire exists in all types of passenger transportation vehicles. As a result, detailed and widely similar fire safety requirements have been developed for application to transportation vehicles in both U.S. and Europe.

Existing FRA fire safety guidelines addressing material flammability and smoke emission, and fire barriers are appropriate for maglev vehicles. In addition, consideration should be given to the following fire safety requirements for U.S. maglev applications:

- A calculation of the total fire hazard load, such as required by NFPA 130, should be performed.
- Good vehicle design practice to minimize fire risk should be followed, as described in Section 4.5.4.1 above, with regard to electrical systems, ventilation shut-down capability, and heating systems.
- Suitable fire extinguishers should be provided in the operator cab and each passenger compartment.
- Smoke and/or heat detectors should be installed in unoccupied spaces, such as lavatories and equipment compartments, where a fire risk may exist.

4.5.6 Further Studies

It has not been possible to carry out a detailed comparison of the different flammability, smoke emission, toxicity and barrier performance tests specified in the reviewed documents in this study. Although the intent of all the test procedures is similar, significant differences might exist in how different materials perform in the different tests relative to acceptability criteria. The differences may have implications for the acceptability of different material for use in a maglev vehicle, and the applicability of the different test procedures. Therefore, a more detailed comparison of test procedures, acceptability criteria and material performance is desirable.

Another issue deserving further study is how the performance of materials in the individual flammability and smoke emission tests relates to the performance in a typical vehicle installation. Factors which may influence performance are the quantity of material, orientation, and proximity to other flammable materials. Tests and analyses of a portion of a typical vehicle passenger compartment, using representative fire scenarios (such as a paper litter fire) would be valuable.

The FRA is sponsoring a study by the National Institute of Standards and Technology to further investigate the different U.S. and foreign approaches to passenger train fire safety.

4.6 FUNCTIONAL AREA 206 - SUSPENSION DESIGN AND CONSTRUCTION

4.6.1 Description of Functional Area

The suspension system of an electromagnetic maglev vehicle comprises support and guidance electromagnets, a mechanical or pneumatic suspension system between the magnets and the vehicle structure, and a microprocessor-based control system to maintain the air gap between the magnets and the guideway within specified limits.

This functional area addresses the overall design of the suspension system which supports and guides the maglev vehicle as it travels along the guideway, and the mechanical design, manufacture and assembly of the mechanical elements of the suspension system. The hardware and software of the microprocessor system which controls the air gap of each magnet is addressed in Functional Area 105, Computer Safety for Vehicle and Operations Control Systems, together with other safety-critical computer systems.

Other functional areas which have an interface with or are closely related to this functional area are as follows:

Functional Area 101, System Safety, in which the overall safety performance requirements of the magnetic levitation support and guidance systems are discussed. This particularly includes the concept of "safe hover" - ensuring that adequate magnetic suspension performance can be maintained in any anticipated failure condition for the time taken to reach a safe stopping place.

Functional Area 102, Reliability and Availability, which addresses the concepts used in safety-critical subsystems of the maglev system.

Functional Area 201, Vehicle and Cab Structural Integrity, which includes requirements for the strength of attachments between the suspension units and vehicle body structure.

Functional Area 208, Vehicle-Guideway Interaction, which is concerned with defining safe interaction conditions with regard to forces, deflections and the magnet air gap, and ensuring that such safe conditions are maintained at all times.

4.6.2 Safety Baseline

Because of the restricted air gap between the levitation magnets and the guideway, maglev vehicle suspension components and subsystems may be subject to a high vibration environment as the vehicle moves over guideway alignment and profile irregularities. The suspension also transmits vehicle support and guidance forces from the support and guidance magnets to the vehicle body structure. A magnet failure, any structural failure of a suspension component, or a failure to provide the designed performance (stiffness and damping at each suspension unit) is potentially hazardous. The vehicle could experience a partial loss of support or guidance, leading to an impact between part of the vehicle and the guideway, mechanical damage to vehicle or guideway and/or an unplanned sudden stop.

Suspension units are also potentially vulnerable to impacts from debris and foreign objects on the guideway which are small enough to pass under any deflector or pilot fixed to the vehicle body.

Suspension systems and components must be designed so that adequate structural integrity and functional reliability is maintained under the worst design case loading. Such loads, whether single events or cyclic repeated loads, must not cause a structural failure, or the loss of a critical function such as maintaining the minimum acceptable air gap between the suspension and guidance magnets and the guideway. The same performance integrity should be maintained under any anticipated "survivable" component failure, such as the failure of an individual suspension magnet or secondary suspension unit. In particular, the failed suspension unit must be supported or contained so that it does not endanger other vehicle components or systems. Some degradation or ride quality is normally tolerable under such failure conditions, but this should not be so severe as to cause danger to vehicle occupants.

4.6.3 Description of Existing Safety Requirements

Existing safety requirements are listed in Table 4-13 and described below under three headings: German, United States, and other foreign and international.

4.6.3.1 German Requirements

Section 3.1.1 in Chapter 1, System Properties, of the RW MSB requires that the suspension systems for vehicle support and guidance consist of multiple independent units, so that adequate functionality is maintained even when the maximum conceivable number of units fail during a mission.

Chapter 5, Load Assumptions, of the RW MSB characterizes the types of mechanical loads for which the vehicle must be designed. These include loads on the suspension systems, as well as other elements of the vehicle structure. Interface loads between the levitation and guidance magnets and the guideway are the most significant loads for the suspension system, and comprise the following categories:

- External loads on the vehicle due to wind.
- Response of suspension components and the vehicle to guideway geometry variations, whether these are due to initial construction tolerances, vehicle static and dynamic loading, or external factors such as the settling of guideway support foundations.
- Electromagnetic loads from the propulsion, guidance and support systems.
- Loads associated with different phases of vehicle operation such as acceleration, braking and negotiation of curves, as well as operations under emergency conditions or with partial failures of the suspension system.

TABLE 4-13. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 206 - SUSPENSION DESIGN

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1	System Properties, Including Safe Hovering	Maglev
		Chapter 5	Load Assumptions	
		Chapter 6	Stability Analyses (Guideway/Vehicle)	
		Chapter 7	Design, Production and Quality Assurance of Mechanical Structures	
German Government	Draft MBO	Paragraph 3.4	Vehicle Bodies	Maglev
		Paragraph 3.5	Vehicles - Carrying and Guidance System	
	EBO	Section 3, Paragraphs 19-21	Vehicles	Railroad
UIC	515, Coaches: Running Gear	-		Railroad
FRA	49 CFR	Part 213	Freight Car Safety Standards	Railroad
		Part 229	Railroad Locomotive Safety Standards	
AAR	Manual of Standards and Recommended Practices	Section C	Specifications for the Design, Fabrication and Construction of Freight Cars	Railroad
		Section D	Trucks and Truck Details	
		Section G	Wheels and Axles	
Canadian Government	Draft Passenger Car Design Safety Standards	Paragraph 25	Fail-Safe Design of Circuits and Systems	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

Chapter 6 of the RW MSB, Stability Analyses (Guideway/Vehicle), develops mechanical load cases (specified load combinations) for which the vehicle and guideway, including the suspension system, must be designed. Loads are classified as primary, secondary, and special loads. Primary loads are those associated with normal operations for which a large number of load cycles may be expected. Secondary loads are also associated with normal operations, but have a low frequency of occurrence. Maglev system components should withstand primary and secondary loads without damage or loss of operating performance.

Special loads are those occurring in some type of emergency or partial failure condition. Examples include emergency braking or operation with a failed suspension unit. The vehicle must be able to operate safely under such conditions, but not necessarily without minor damage (such as caused by occasional minor magnet-guideway impacts) or loss of performance. Safety factors used in structural design should reflect the severity of consequences of a failure.

Chapter 7 of the RW MSB, Design, Production, and Quality Assurance of Mechanical Structures, provides information on the design of mechanical structures to withstand the load cases identified in Chapter 6. Chapter 7 also discusses manufacturing requirements. Quality management techniques described in EN (European Standards) 29000-29004 must be used. These are fully described under Functional Area 103, Quality Assurance. Requirements for welded and bolted connections are also specified. These requirements have been described under Functional Area 201, Vehicle and Cab Structural Integrity, but apply equally to mechanical suspension components.

Section 3.4 of the draft MBO contains the general requirement that vehicles must be designed in such a manner that they withstand all loads incurred by their proper use. Section 3.5 of the draft MBO provides requirements for the carrying and guidance system. In summary these are:

- Reliable guidance and support must be assured under all expected operating conditions.

- The support and guidance systems must be able to absorb the highest conceivable loads.

The supporting notes to the draft MBO mention that there are occasions when there may be contact between the magnets and the guideway. These include the normal process of setting the vehicle down on its skids at low speed, and occasional short duration contact between the guideway and support or guidance magnets.

Section 3 of the EBO, Paragraphs 19-21 and Appendix 6 contain requirements that affect suspension systems for conventional railroads. These requirements include maximum permitted vehicle weights and axleloads, the minimum curve radius that the vehicle must be able to operate over, and dimensional limits for wheels and axles.

4.6.4.2 U.S. Requirements

All existing requirements apply to conventional railroad vehicles of different types. The relevance to maglev vehicles relates to the intent rather than in the details of the requirements. Several FRA railroad safety regulations contained in 49 CFR, Parts 213 and 229 include safety requirements for the suspension systems of conventional railroad vehicles.

- Parts 213.103 to 213.117, specify minimum dimensional and other car condition requirements including for wheelsets, axles and truck components. These requirements are primarily wear and deterioration limits (discussed more fully in Functional Area 209, Inspection and Maintenance), but apply also to newly constructed cars.

- Parts 229.63-229.75 specify requirements for the suspension systems of locomotives. As with freight cars, these requirements primarily specify wear and deterioration limits (discussed more fully in Functional Area 209, Inspection and Maintenance), but apply also to newly constructed locomotives.

The AAR Manual of Standards and Recommended Practices contains a number of suspension requirements in Section D, Trucks and Truck Details for Freight Car Trucks. Specific items of interest are:

- Standard S-010 states that field tests may be required by the AAR to qualify a truck or suspension systems for regular service.

- Standard S-300-84, Basic Freight Car Truck Data, contains basic design data for trucks, including dimensional limits, and load maxima by bearing size. Individual standards are referenced for each component.

- Standard S-202-83, Specification for Truck Bolsters, contains requirements for materials to be used to manufacture bolsters, and for static and dynamic load tests. Static loads must be sustained without sustaining permanent defections in excess of those specified. The dynamic test involves applying a specified number of load cycles to the bolster, representative of a severe service environment. The bolster must be free of damage and be able to pass the static load test after completing the dynamic test.

- Standard M-203-83, Specifications for Truck Side Frames, Cast Steel, contains static and dynamic test requirements for side frames in a similar format to the bolster requirements in S-202-83.

Section D also contains numerous dimensional and material requirements for truck components, including post-manufacture inspection and test requirements to ensure that quality is maintained.

The AAR Manual, Section C, Part II (M1001), Specifications for Design, Fabrication and Construction of Freight Cars, contains some general requirements that pertain to suspension systems. Specific items of interest are:

- Section 1.2 of Chapter 1 specifies procedures for qualifying cars of a new and untried type for service. Such cars must undergo a design review by AAR, various static tests, and closely monitored field service trials.

- Chapter 10 provides requirements for cars equipped with single-axle trucks, including maximum movements of the vehicle in its suspension, and maximum acceleration levels in the body, when tested over a perturbed track with specified deliberately constructed irregularities.

- Chapter 11 specifies service-worthiness analyses and tests for new freight cars, including comprehensive dynamic and perturbed track tests of suspension performance. These requirements are discussed under Functional Area 208, Vehicle-Guideway Interaction, but also define requirements to be met in suspension design.

4.6.3.3 Other Foreign and International Requirements

UIC Code 515, Coaches: Running Gear, specifies requirements for rail passenger car suspension systems. Requirements of interest for high-speed bogies (trucks) for operation at over 160 km/h (100 mph) are as follows:

- Paragraph 2.6.1 states that the bogie-body connection should be designed to avoid the transmission of vibration.

- Paragraph 2.6.2 specifies the minimum strength required for bogie-to-body connections based on anticipated load cases. Bogie components and connections should sustain the specified load combinations without exceeding the yield limit for the materials used.

- Paragraph 3.5.1.3 recommends that axle boxes be electrically insulated from the bogie frame, and a grounding connection between the axle and bogie frame be provided. The grounding connection is needed to avoid electric shock risks, and the risk of rolling bearing damage due to transmission of electric current through the bearing.

- Paragraph 3.1.9 requires that shackle stops must be provided to ensure that the wheelset and bogie frame can be lifted in safety.

- Paragraph 3.2.1 requires that unsprung parts must be as light as possible.

- Paragraph 3.2.4 recommends that every effort must be made to separate the natural body frequencies and the suspension frequencies.

- Paragraph 3.2.5 requires that safety must be guaranteed by safety slings or stops in case of a spring fracture.

- Paragraph 3.3.2 requires that bogies with pneumatic suspension shall be capable of safely operating in a damaged state at full speed.

- Paragraph 3.3.5.3 recommends that arresting devices must be provided in case of any operating anomaly of the levelling valves.

- Paragraph 3.4 requires that new bogie frame designs must be subject to a program of fatigue tests specified in Appendix 4 of the code. This appendix specifies static tests on an instrumented (strain-gauged) structure, and a dynamic load test of up to 10 x 10^6 load cycles, at various load levels. Test loads are specified as a function of vehicle and bogie mass.

Paragraph 25, of the draft Canadian Passenger Car Design Safety Standards, requires that in the event of a failure of any electrical or mechanical system vital to the safety of passenger car occupants, or of the car itself, the car shall remain in a safe operating condition. If the car is equipped with a body banking system, this shall have a fail-safe provision to return the banking system to center throughout the train and indicate a speed limitation when applicable.

4.6.4 Comparison and Assessment

The subjects addressed in the reviewed requirements documents can be compared and discussed under three headings: Structural integrity, redundancy and failure tolerance, and tolerance of the operating environment. A related subject, performance as a suspension system to limit vehicle-guideway loads and vibration to acceptable levels is discussed under Functional Area 208, Vehicle-Guideway Interaction.

4.6.4.1 Structural Integrity

The normal air gap between guideway and the levitation or guidance magnets of an electromagnetic (attractive) maglev system is approximately 10 mm (0.4 in). Because of this small air gap, the magnets have to closely follow the corresponding guideway reaction surfaces. A suspension system is needed between the magnets and the vehicle body to isolate the body from guideway irregularities and provide an acceptable ride quality. Support and guidance magnets and components of the suspension system must be designed to withstand the resulting high vibration environment and cyclic loading. Trucks and truck components of a conventional wheel-on-rail vehicle are similarly subject to a high vibration and cyclic loading environment.

Chapter 6 of the RW MSB specifies load cases to be used in the design of vehicle structures, including suspension components, but does not specify design analyses to be used, or criteria for structural testing. The safety requirements for conventional railroad vehicles in UIC Code 515 and the AAR Manual of Recommended Practices require estimates of the loading environment of suspension components, and static and dynamic (fatigue) tests to demonstrate that the structures are adequate for the environment. Such testing is highly desirable on a maglev suspension system, and should include representative high vibration environment tests of the magnet to ensure that magnet windings and other construction features are structurally adequate. Instrumented track tests are customarily performed with new design trucks over perturbed track to confirm that service loadings are as expected, and similar tests would be appropriate for maglev vehicles.

4.6.4.2 Redundancy and Failure Tolerance

A maglev vehicle suspension system consists of multiple support and guidance units. Each unit has sensors to measure the air gap, a control system to maintain the magnet air gap, the levitation and guidance magnets and a suspension system consisting of spring and damper elements between the magnets and the vehicle body. Chapter 1 of the RW MSB states that the vehicle must be capable of operating safely even when the maximum number of individual suspension units have failed. Such failures could be due to an electrical failure in the magnet, in the magnet power supply, in the gap sensor, or in the control system. In such an event, the RW MSB requirement means that remaining operating suspension units can adequately support and guide the vehicle, and that the failed unit is supported or retracted so that it cannot contact the guideway, or otherwise interfere with safe operation.

In conventional wheel-on-rail systems, the equivalent of a magnet failure is a wheel, axle or bearing failure. This is a catastrophic failure, since no redundancy is available. Safety requirements for wheels, axles and bearings specify that only high quality materials can be used, and regular inspections are performed to ensure that serious defects are detected and corrected before failure.

However, both U.S. and foreign conventional railroad safety requirements and practices do recognize that certain suspension components such as springs and dampers can fail. Where air springs are used, UIC Code 515 requires that rail vehicles must be able to operate at maximum speed with the springs deflated. Accidental over-inflation, due to a malfunction of a leveling valve could also occur. Failures are also possible with coil springs and hydraulic spring units. Because of the possibility of failure, conventional practice is to provide rail vehicle suspensions with stops to limit the magnitude of vehicle movements on its suspension. It is also customary to provide safety hangers and stops to contain damaged components in case of a structural failure.

4.6.4.3 Operating Environment

Support and guidance magnets and other suspension components, including magnetic gap sensors, may be exposed under the vehicle. As such, they are exposed to ambient climate conditions (temperature, ice and snow, water), and may also be exposed to impacts with small foreign objects lying on the guideway which are small enough to pass under any guard fitted to the front of the vehicle. None of the reviewed documents discuss the operating environment. However, it is essential that under-vehicle suspension components are able to operate satisfactorily over the full range of ambient conditions likely to be encountered, and be adequately protected against impacts with debris on the guideway. Impact protection will be especially important for potentially fragile items such as gap sensors.

4.6.5 Findings

Suspension components are subject to a potentially high stress environment, and a mechanical failure could lead to a partial loss of maglev vehicle support or guidance. Furthermore, suspension behavior is complex, and loadings are difficult to predict accurately. Thus, pre-service testing of new designs is highly desirable to validate design analyses. Safety requirements are required to ensure that failure risks are adequately controlled.

Existing FRA requirements for conventional rail vehicle suspension systems primarily specify limits on wear and deterioration, and do not provide any guidance for maglev vehicles.

Both the AAR Manual and the UIC code contain suspension design and testing requirements that are applicable in principle to maglev suspension systems, and particularly emphasize design and testing procedures, and component failure precautions.

Chapter 6 of the RW MSB provides the most comprehensive information of maglev-specific load cases for which suspension systems should be designed, and refers to requirements for welded and bolted joints. The RW MSB does not provide detailed guidance regarding suspension testing, or on how to ensure that the vehicle can operate safety with a failed support or guidance suspension unit.

Comprehensive maglev vehicle suspension design and installation safety requirements should include elements from both the RW MSB design load cases, and from the conventional railroad requirements for testing and failed component precautions. Therefore, consideration should be given to the following safety requirements for U.S. maglev system applications.

4.6.5.1 Suspension Component Structural Integrity

- All suspension structural components should be designed using fatigue in the load cases derived from Chapter 6 of RW MSB, and appropriate fatigue design techniques.

- Loadings and stresses in suspension components of a new design should be measured during pre-service instrumented tests to confirm design analyses.

- Structurally critical and complex components of a new design should be subject to laboratory static and fatigue strength tests.

- Complex assemblies, such as levitation or guidance magnets, which operate in a high-vibration environment should be subject to vibration durability tests using representative vibration frequencies and amplitudes.

4.6.5.2 Redundancy and Failure Tolerance

The vehicle should be able to operate safely at all speeds up to maximum speed with any reasonably foreseeable failure of the suspension system, including failure of an individual levitation or guidance magnet. Specific requirements are:

- In the event of any failure of a levitation or guidance magnet or its associated sensor or control system, the magnet must be supported or retracted so that it cannot contact the guideway or otherwise interfere with safe vehicle movement.
- If air springs are used in the suspension system, the vehicle must be able to operate safely at all speeds with any possible combination of deflated air springs.
- The suspension system must be fitted with stops, safety hangers, and other appropriate means to limit maximum movements and to minimize the risk of a suspension component becoming detached from the vehicle or dragging on the guideway in case of a structural failure.

4.6.5.3 External Environmental Tolerance

The maglev suspension system should be able to function satisfactorily in ambient temperatures and other weather conditions appropriate to the region in which the vehicle is expected to operate. The suspension systems should also operate satisfactorily and not be subject to unusually rapid degradation in any special conditions applicable in the operating region, such as in the presence of sand or salt. External parts of the system must be able to sustain impacts of debris or small objects on the guideway passing under the vehicle.

4.6.6 Further Studies

Experience of maglev vehicle suspension performance tests and analyses is lacking in the United States. Instrumented tests, accompanied by corresponding analyses are desirable to better understand suspension behavior and to identify potentially hazardous situations. A review of suspension performance with a defective suspension magnet or air spring is particularly critical.

4.7 FUNCTIONAL AREA 207 - BRAKE INSTALLATION AND PERFORMANCE

4.7.1 Description of Functional Area

This functional area addresses safety issues associated with the construction and performance of maglev vehicle brakes, except the on-board and wayside computer control systems which monitor brake behavior and control service and emergency braking.

The regular service brake, the emergency or back-up brake used to ensure that a vehicle can achieve the desired braking performance with a very high degree of certainty, and the parking brake to secure an out-of-service or unattended vehicle are included.

Other functional areas having an interface with this functional area are:

Functional Area 101, System Safety, is concerned with the proper integration of all safety-critical subsystems and components to achieve the desired overall level of safety performance. The braking system is a major such subsystem. In addition, the emergency brake is a vital component of the "safe hover" and designated stopping-place approach of responding to emergencies.

Functional Area 102, Reliability and Availability, discusses definitions and techniques for achieving adequate safety levels in safety-critical systems such as the braking system.

Functional Area 105, Computer Safety for Vehicle and Operations Control Systems, discusses the software and hardware requirements for computer systems used for safety-critical functions. The vehicle on-board brake control computer and wayside train control systems are systems of this type.

Functional Area 401, Operations Control System Design, addresses three major subareas - guideway occupancy and status, the interlocking systems, and safety speed enforcement. The safe speed enforcement subsystem has a direct interface with the brake system, and relies on the brake system to respond to braking commands.

4.7.2 Safety Baseline

The regular service or emergency braking system must be capable of bringing the maglev vehicle to a stop with a very high degree of certainty, and within a stopping distance compatible with the train control system. Required stopping distances are a function of headways between trains and train control system architecture. The brake system must be controllable so that the train can be brought to rest at a designed stopping point under regular service or emergency conditions. Stopping away from a designated stopping place may be permissible in an extreme emergency, but in any case, stops must be achieved without significant damage to either the vehicle or guideway and without exceeding acceptable deceleration rates with respect to vehicle occupant safety. A parking brake or equivalent means must be provided to ensure that an out-of-service or unattended vehicle is secure against unintentional movement.

4.7.3 Description of Existing Safety Requirements

The existing safety requirements identified for this functional area are listed in Table 4-14 and are described below under three headings: German, United States, and other foreign and international.

4.7.3.1 German Requirements

Chapter 1 of the RW MSB, Section 5, Braking Systems, specifies the overall braking system requirement that the vehicle must be capable of controlled braking at all times. Forces exerted on the vehicle and guideway during braking must not exceed design loadings. Primary service braking is achieved through reversal of the linear motor. In addition, a secondary or safety braking system must be available that is independent of the propulsion system, and made up of multiple independent units to ensure reliability. The braking control system, using either the primary or secondary brake must be capable of bringing the vehicle to rest at a designated stopping point.

Chapter 2 of the RW MSB, Propulsion Including Energy Supply, states that there must be a highly reliable system to shut-off propulsion power on initiation of emergency braking with the secondary brake. The primary braking system (reversing propulsion system thrust) is not considered a safety critical system, since failure of the power supply could occur.

Chapter 4 of the RW MSB, On-Board Control System, specifies that the secondary (safety) braking system on the vehicle must be capable of operating independently in the event of a loss of communication between the vehicle and the operations control center. The secondary brake system must comprise several independent units, and must be capable of meeting stopping requirements with one unit inoperative. The vehicle may operate with one brake unit inoperative, but mandatory emergency stop is required after a second failure.

Chapter 4 of the RW MSB also requires that a passenger emergency signal be provided in each vehicle section or compartment. Upon use, the signal notifies the on-board operator and the operations control center of an emergency, but does not automatically initiate braking.

Section 3.6 of the draft MBO states that two independent brake systems are required. One of these systems, the emergency or secondary brake must be independent of the propulsion system. The explanatory notes to the draft MBO indicate that the secondary brake is needed because primary braking by linear motor reversal is not fail-safe. The notes also state the emergency braking must be such that it can be initiated on the vehicle and in the absence of an external energy supply.

The draft MBO requires a parking brake be provided that does not need an external energy supply. The explanatory notes state that setting the vehicle down on skids is an acceptable

TABLE 4-14. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 207 - BRAKE INSTALLATION AND PERFORMANCE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1	System Properties: Section 5, Braking System	Maglev
		Chapter 2	Propulsion, Including Energy Supply, Paragraph 4.2, Safety Shutoff	
		Chapter 4	On-Board Control System, Part 7, Safety Braking System	
German Government	Draft MBO	3.6	Vehicles, Braking System	Maglev
	EBO	Section 3	Paragraph 23, Brakes	Railroad
		Section 4	Paragraph 35, Equipping Trains with Brakes	
UIC	410, Composition and Calculation of the Weight and Braking of Passenger Trains			Railroad
	540, Brakes - Air Brakes for Freight and Passenger Trains			
	541, Brakes - Regulations Concerning the Construction of the Various Brake Components	541-05	Wheel-Slip Prevention Equipment	
		541-5	Electropneumatic Brakes for Passenger and Freight Trains	

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-14. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 207 - BRAKE INSTALLATION AND PERFORMANCE (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
UIC	543, Brakes - Regulations Relative to the Equipment and Use of the Vehicles	541-6	Tests of Electropneumatic Brakes	Railroad
	544, Brakes - High Power Brakes for Passenger Trains	544-1	Brakes - Braking Power	
FRA	49 CFR, Transportation	232	Railroad Power Brakes and Drawbars	Railroad
		231.12-231.14	Railroad Safety Appliance Standards	
FAA	14 CFR, Part 25 Airworthiness Standards, Transport Category Airplanes	Part 25.125 Part 25.735	Landing Brakes	Commercial Aviation
AAR	Manual of Standards and Recommended Practices	Section E	Brakes and Brake Equipment	Railroad
		Standard S-401-64	Basic Freight Car Design Data	
		Standards S-461-76 and S-469-47	Performance Standards for Freight Brakes	

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-14. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 207 - BRAKE INSTALLATION AND PERFORMANCE (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
AAR	Manual of Standards and Recommended Practices	Standards S-463-77 and S-464-78	Performance Testing Procedure for Freight Brakes	Railroad
		Standard S-467-77	Environmental Chamber Tests on Brake Control Valves	
APTA	Guidelines for Design of Rapid Transit Facilities	Section 4.5.1	Performance Standards Acceleration and Braking Levels	Rail Mass Transit
Canadian Government	Draft Passenger Car Safety Requirements	Paragraph 32	Handbrake	Railroad
		Paragraph 33	Conductors Valve	

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

form of parking under the assumption that the friction coefficient is sufficient to hold the vehicle stationary even on the steepest gradient.

The EBO requirements for conventional rail vehicles, in Paragraph 23, state that all vehicles must be equipped with a continuous automatic brake. A continuous brake is one that acts on all vehicles in a train, and automatic means that the brake is activated when there is any unintentional interruption of the brake line. It must be possible to activate the brake from the operators cab, and by using emergency brake handles situated in each passenger car. These handles must be in a conspicuous location, easily seen and reached by passengers and train crew. Paragraph 23 also states that all tractive vehicles must have a hand brake or a self-locking brake, and unpowered cars must be equipped with a sufficient number of hand brakes.

Paragraph 35 of the EBO states that all trains operating at more than 50 km/h must be equipped with continuous brakes. Maximum permitted stopping distance is 1000 m (3284 ft) unless an exception has been authorized by a responsible authority.

4.7.3.2 U.S. Requirements

The FRA regulation contained in 49 CFR, Part 232 describes requirements for conventional railroad brakes. The principal relevant requirements are:

- Part 232.1 specifies that not less than 85 percent of the cars in a train shall have operating brakes under the control of the train operator.

- Part 232.3 references the Appendix to Part 232, which specifies construction and performance requirements for railroad brakes, as follows:

  - Paragraphs 14-17 in the Appendix state that the operating valve shall be such as to ensure safe, efficient and controllable brake operation, that the entry of foreign matter into the brake system is prevented, and that the brake can easily be cleaned, maintained and repaired.

  - Paragraphs 18-33 specify the performance requirements for normal service braking, especially regarding consistency of the relationship between brake pipe pressure reductions and pressure in the brake cylinder. Time limits are specified for the delay between brake application between the front and rear of a long train (150 cars), and for release time.

  - Paragraphs 34-43 specify the performance requirements for emergency braking. Emergency braking provides higher deceleration than normal service braking. The most important requirement is that emergency braking must always be available regardless of the existing state or stage of operation of the brake system. The remainder of the requirements specify maximum response times and maximum and minimum brake cylinder pressures in the emergency braking mode.

The other brake requirements in Part 232 are concerned with inspection, maintenance and operating procedures and are discussed under Functional Areas 210, Vehicle Inspection and Maintenance, and 602, Operating Rules and Practices, as appropriate.

The FRA requirement contained in 49 CFR, Part 231 specifies hand brake requirements for each type of railroad vehicle. Parts 231.12 to 231.14 specify that each passenger car must be equipped with an efficient hand brake that operates in harmony with the power brake, and be located so that it can be safely operated with the car in motion.

The FAA specifies the requirement for aircraft braking systems in 14 CFR, Part 25.

- Part 25.125 states that landing distances must be determined for all operational conditions of the aircraft. Brakes other than wheel brakes may be used, provided they are safe and reliable, that consistent results may be expected, and they do not require exceptional skill in operation. Landing distances must be determined without the use of any device that depends on the operation of any engine.

- Part 25.735 requires that brake systems be constructed such that if any connecting or transmitting element fails, or any single power source used for brake operation is lost, braking deceleration must not be reduced by more than 50 percent. Any anti-skid system must be such that there will be no hazardous loss of braking ability or directional control in the event of any probable malfunction. An analysis of braking performance must be performed to demonstrate that there is adequate energy absorption capability in the brake system to bring aircraft to a stop under the most demanding conditions (maximum weight and landing speed). The analysis should also show that reasonable limits of wheel-to-runway friction are not exceeded in the most demanding landing conditions.

The AAR Manual of Standards and Recommended Practices, Section E provides specifications for brake equipment. A large part of Section E provides detailed design specifications for railroad air brake system components which have little relevance to maglev brake systems. Requirements which have a purpose or intent relevant to a maglev braking system are as follows:

- Standard S-401-64, Basic Freight Car Design Data, specifies the minimum requirements for freight car equipment, in particular, performance requirements and tests of brake linkages and friction materials to ensure that a given brake cylinder air pressure will produce a specified retardation force.

- Standards S-461-76 and S-469-47, Performance Requirements for Freight Brakes, are substantially identical to the FRA performance requirements in the Appendix to Part 232.

- Standards S-463-77 and S-464-78 together specify test equipment and procedures for testing all aspects of air brake performance in the laboratory to ensure that AAR and FRA requirements are met. The tests are very comprehensive, requiring that performance standards are met in a total of 99 operating conditions.

- Standard S-467-77 specifies environmental chamber tests to ensure that brake control valves will operate at all temperatures between -58°C and +66°C (-50°F to +150°F).

The APTA Guidelines for the Design of Rapid Transit Facilities, Section 4.5, recommends that the following maximum braking rates be observed, based on a review of the ability of elderly seated passengers to safely resist acceleration forces.

Service Braking	1.55-2.01 m/sec^2 (3.5-4.5 mph/sec)
Emergency Braking	2.01-3.58 m/sec^2 (4.5-8.0 mph/sec)

Braking rates over 2.23 m/sec^2 (5 mph/sec) should only be used in extreme emergencies to avoid a collision, as some risk of injury to vehicle occupants is present. In any case, good jerk control (rate of change of acceleration) is recommended to prevent the sudden application of high accelerations.

4.7.3.3 Other Foreign and International Requirements

Several UIC codes address brake system requirements. As with FRA and AAR requirements in the United States, all UIC codes are written for the conventional railroad air brake system. Several of the codes refer to "Braking Weight," and Brake Weight percentages, which are measures of brake performance used in the UIC codes. The brake weight is a measure of the retarding force produced by the braking system related to an arbitrary standard braking force. Brake weight percentage is the ratio between brake weight and vehicle weight. Specific codes are:

- Code 410, Composition and Calculation of the Weight and Braking of Passenger Trains, specifies the minimum brake weight percentage to be used on passenger trains by maximum speed, to ensure stopping distances are acceptable.

- Code 540, Air Brakes for Freight and Passenger Trains, provides general requirements for the functioning of the brake. The principal requirements are:

  - The brake must be automatic, meaning that it will automatically be applied in the case of rupture of the brake pipe.

  - Electric control can be used, provided that the brake is capable of compressed air operation at all times, and without needing any operator action.

  - The brake must be capable of both controllable normal service stops, and emergency braking using maximum retardation.

  - The brake must be inexhaustible, meaning that it must be capable of an infinite number of repeated applications, and that emergency braking capability must be available at all times.

  - Several paragraphs specify brake controllability and response time details.

- Code 541-05, Wheel Slip Prevention (WSP) Equipment, provides requirements for systems to minimize relative slipping between wheel and rail during braking by the monitoring and control of braking effort. Principal requirements of interest are that the WSP system must not impair the "inexhaustibility" requirement of Code 540 due to repeated application and release, that independent systems must be used on each truck or axle, and the WSP must function correctly when used in conjunction with non-adhesion brakes.

- Code 541-5, Electropneumatic Brakes for Passenger and Freight Trains, provides design requirements for electropneumatic brakes. The most significant requirement is that both the operating controls and the equipment on individual vehicles should automatically revert to pure pneumatic operation, and continue in the same braking state (no braking, service braking, or emergency braking) in the event of an electrical failure. Also, repeated brake applications on long, steep downgrades should not exhaust the brake, or impair the ability to apply emergency braking. The braking control valve (called a distributor) must operate satisfactorily at all temperatures between -50°C and +50°C (-58°F to 122°F). Brake response times to an operator action are also specified.

- Code 541-6 specifies a series of tests for electropneumatic brake systems, especially including operation under simulated electrical failure conditions.

- Code 543 specifies the general requirements for brake systems for passenger and freight vehicles. These include the following requirements:

  - Vehicles used in passenger trains must have a minimum brake weight percentage of 105.

  - Within specified limits, braking force must be adjusted as vehicle weight changes.

  - An emergency brake handle activating the brake must be fitted on each passenger coach in a position that is easily seen and reachable without having to pass through a door.

- Code 544-1, Braking Power, specifies the calculations and testing required to determine the "Brake Weight" of a vehicle. Brake tests with a 15-car train, and with an individual free-running vehicle must be conducted, and the lowest braking performance (i.e., that gives the longest braking distance) must be used in calculating braking weight. Vehicles using unconventional brakes, such as eddy current or electromagnetic brakes must be tested in the same way as for conventional systems. Brake weight is calculated from emergency stops from all speeds from 100 km/h up to a maximum speed in 10 km/h intervals. Repeated tests must be performed to ensure that a reliable result has been obtained.

- Code 546, High Power Brakes for Passenger Trains, contains some recommendations for brakes to be used on trains operated at up to 200 km/h (125 mph). These are:

- An average deceleration of 0.85 m/sec^2 (2.8 ft/sec^2 or 1.9 mph/sec) must be achieved in emergency braking from 200 km/h.

- A wheel slide protection system must be fitted.

- Use of dynamic brakes on powered vehicles is recommended.

Draft Canadian passenger car safety requirements, Paragraph 32, require that a hand brake be fitted to each car, capable of holding the fully-laden car on a five percent grade. It must be mechanically locked, located so it can be operated with the vehicle in motion, and equipped with a visible indicator showing applied or released condition.

Draft Canadian requirements, paragraph 33, require that a conductor's emergency brake valve be installed in every car. This valve, when activated, will cause an emergency brake application to occur, regardless of the braking state of the train.

4.7.4 Comparison and Assessment

The primary braking requirements which must be met to ensure that maglev vehicle braking is carried out safely are as follows:

- Stopping distances must be consistent with the headways between trains, and with assumptions on stopping distances used in formulating train control instructions.

- The overall brake control system must have very high reliability.

- Sufficient functioning of individual brake units must always be available.

- The brake system must provide the degree of controllability needed to stop the vehicle at a desired location within acceptable tolerances.

- The brake units must safely absorb and transmit the braking energy.

- The stop must be performed without damage to the vehicle or guideway or injury to vehicle occupants.

- The brake must function correctly in all operating environments likely to be encountered in service.

- The parking brake must adequately secure an unattended vehicle.

- Braking requirements for a passenger emergency alarm must be defined.

Safety requirements pertaining to each of these individual functions or performance requirements of a maglev braking system are reviewed below, assessing how each is addressed in the existing requirements, and discussing considerations to be taken into account for a high speed maglev braking system.

4.7.4.1 Brake Control System Integrity

All conventional railroad air brakes rely on an intrinsically fail-safe concept: air pressure is maintained in a train line, and control valves on each car cause the brakes to be applied when train line air pressure is reduced, either due to operator action, an automatic control command, or damage to the train line. Provided pre-departure tests are used to ensure that there are no blockages in the train line, this system provides the desired level of integrity. In a maglev vehicle, or a train with electrically controlled brakes, the function of the brake pipe is replaced by electrical signals produced by the on-board computer. A redundant or fault-tolerant approach must be used for this computer, and its supporting equipment such as power supplies and speed and location sensors, so that high integrity brake performance can be maintained as specified by RW MSB.

Detailed requirements for safety-critical computer systems are discussed in Functional Area 105.

4.7.4.2 Individual Brake Unit Requirements

Both maglev and conventional railroad brake systems rely on multiple independent individual braking units to achieve the necessary braking integrity. In the conventional air brake, each car has a separate brake system arranged such that a failure on any one car does not effect the performance of remaining brakes. Conventional railroad safety requirements, such as that of the FRA (49 CFR, Part 232) require that a specified minimum percentage of vehicles in a train must have a functioning brake.

The German maglev requirements for the secondary or safety brake are similar in concept. Multiple brake units are required, with independent power supplies, and vehicle operations are not permitted or must be stopped if more than one unit is inoperative. The implication of this requirement is that minimum acceptable braking performance must be attainable with one inoperative brake unit.

4.7.4.3 Braking Rate or Stopping Distance Requirements

Most of the requirements cited in Section 4.7.3 include a stopping distance or deceleration rate requirement. The EBO for conventional railroads in Germany uses a 1000 m stopping distance requirement; U.S. mass transit practice as defined by APTA uses a deceleration requirement, and the UIC requirements for high-speed conventional trains (Code 546), specify a deceleration rate of 0.85 m/sec^2. The FAA addresses braking distance needs for airplane landing in two stages, by requiring the airplane manufacturer to specify a landing distance, and then to show that the airplane can stop within the landing distance with the proposed braking system. Traditional railroad requirements as embodied in the FRA, AAR, and most

UIC requirements are generally design-oriented, specifying air pressures, component details, and a system configuration which is known to produce the required performance. Part of the reason for this approach in traditional railroad requirements is that vehicles belonging to different owners may operate in the same train, and compatibility is essential for safe operation. Compatibility between vehicles belonging to different owners is not expected to be an issue with maglev.

RW MSB and draft MBO requirements for German maglev systems do not explicitly require specific deceleration or stopping distance performance. This appears to be an omission, since braking distance has clearly been considered in the design of prototype maglev vehicles, as described in a paper by TüV [18].

Therefore, it is suggested that explicit minimum service and emergency deceleration rates be specified for a maglev system, and resulting stopping distances must be consistent with stopping distance criteria used for train control. Maximum emergency braking rates should not impose unacceptable loads on the guideway, or cause a hazard to vehicle occupants.

Another point regarding deceleration rates is the distinction between service and emergency braking rates and between primary and secondary or back-up braking systems. In normal railroad usage, a service braking rate is that which will normally be used to stop the train at stations, or respond to train control instructions. An emergency braking rate is the maximum that the braking system will be required to provide under the most demanding circumstances.

The distinction between a primary and secondary braking system is made only in the German maglev requirements and is not used in conventional railroad braking practice. The maglev primary brake is a non-fail-safe linear motor brake used in normal service, and the secondary or back-up brake is the high reliability brake on the vehicle. The secondary brake is the one that is important for safety performance, and the one that should be expected to meet performance requirements analogous to those of the conventional railroad air brake. Electrical resistance or regenerative brakes used in many conventional railroad and rail transit systems are analogous to the maglev linear motor brake, and thus are not usually expected to function as a safety brake in the U.S.

4.7.4.4 Brake Controllability

In conventional railroad practice, there is limited control over an emergency brake application. Once initiated, the train will simply stop at the emergency deceleration rate, with little or no ability to adjust the braking rate. Because the German maglev safety concept is defined as always being able to reach a safe stopping place in an emergency, emergency braking should be more closely controlled. However, there will be some degree of error in maglev braking. The eddy-current emergency brake is controllable, but is only effective down to about 50 km/h (30 mph). Then the vehicle is lowered into its skids for the last stage of braking to a stop. This last stage is less well controlled. Therefore, it will be important to quantify the variability of stopping distance, and make sure that this is compatible with the design of the emergency stopping places.

4.7.4.5 Brake Energy and Power Performance

Brake components should be sized to absorb or transmit the braking energy without damage or an excessive temperature rise. Braking power and energy requirements are not addressed in conventional railroad brake requirements, in the RW MSB or draft MBO maglev brake requirements. Analyses to demonstrate that brake energy/power capabilities are sufficient for worst case conditions are required for aircraft landing brakes. Information of a similar nature would be desirable for maglev braking systems in order to demonstrate that the brake system can satisfactorily absorb the energy from a maximum rate stop without vehicle or guideway damage.

4.7.4.6 Braking Loads and Deceleration Rates

The RW MSB states that the safety braking must take place without damage to the guideway or vehicle. The requirements for vehicle and guideway structural design (Functional Areas 201 and 301, respectively) include maximum braking rate load cases which address this requirement.

High deceleration rates also have the potential to cause injury to vehicle occupants, especially elderly or handicapped passengers. Transit experience, as cited by APTA indicates that maximum deceleration should not exceed 2.23 m/sec^2 (5 mph/sec) to avoid such risks. High jerk rates (rate of change of acceleration) should also be avoided. This issue was discussed in Railroad Passenger Ride Safety [19]. This report suggests that provided jerk rates are below 0.2 g/sec, there are no adverse effects on vehicle occupants additional to those produced by the deceleration.

4.7.4.7 Environmental Effects

Both UIC and AAR requirements for conventional railroads include specifications for the temperature range over which brake equipment should perform satisfactorily. There is no equivalent requirement in the RW MSB or draft MBO for maglev brakes, raising the question of a need for requirements for temperature range, and environmental sensitivity. Brake equipment outside the vehicle is exposed to heat and cold, moisture, and potentially blowing sand or snow. The equipment should be capable of operating satisfactorily under all such environmental conditions likely to be encountered in operation.

4.7.4.8 Parking Brake

Virtually all the existing requirements reviewed require vehicles to be equipped with a parking brake in order to secure an inoperative or unattended vehicle. These existing requirements indicate that the desirable characteristics of a parking brake are that it should not require external power for operation, or to secure the vehicle indefinitely, and that it should be capable of preventing movement on the steepest gradient on the system.

The MBO indicates that simply supporting the maglev vehicle on skids should meet the parking brake requirement. However, a requirement to demonstrate by test and/or analysis that this will be adequate under the most adverse circumstances (e.g., steepest gradient, wet conditions) would be desirable.

4.7.4.9 Passenger Alarm

Conventional railroad requirements (e.g., UIC) require a passenger emergency valve in each vehicle which automatically initiates emergency braking when activated. This approach is not appropriate for a maglev system, since it may result in stopping the vehicle at a point at which it will be difficult to respond to an emergency. Instead, the passenger alarm alerts the on-board operator and control center, who then determine appropriate action. Passenger alarms are further discussed in Functional Area 601, Emergency Features and Equipment, Including Access and Egress.

4.7.5 Findings

The FRA braking requirements, as well as AAR and UIC requirements, are primarily specific to conventional railroad compressed air brakes, and to conventional railroad operations with regard to operator responsibilities and expected brake performance (deceleration rates and stopping distances). Thus, these conventional brake system requirements cannot be applied to maglev brakes as currently written, although the underlying purpose of conventional railroad brake requirements, to ensure highly reliable and consistent brake operation, is applicable.

The RW MSB and the draft MBO provide the most complete performance requirements for a maglev brake system, but even these requirements should be modified to ensure that they are complete, of general applicability, and are not specific to one maglev system design. The brake requirements are also contained in several different chapters and paragraphs of the RW MSB. Brake requirements are addressed with other vehicle and guideway systems such as on-board controls and the propulsion system, rather than in a separate braking chapter. As a result, the RS MSB brake requirements are somewhat difficult to follow.

For U.S. maglev system applications, consideration should be given to more focused, performance-oriented safety requirements for maglev brake systems. The requirements should be generally based on the German requirements and also should be consistent with the underlying purpose of conventional railroad air-brake design requirements.

The safety requirements should be specifically applicable to the safety and parking brakes of a maglev system. A safety brake is that brake or combination of brakes which is expected to be able to stop the vehicle at all times with a very low probability of failure. Vehicles may also be fitted with other non-safety brakes for use in routine operations that do not need to meet the safety requirements of a safety brake. For example, in the German Transrapid maglev system, an on-board eddy-current brake is the safety brake, and linear motor reversal is a non-safety brake used in routine operations.

The primary performance requirement of a safety brake system is that the occurrence of a unsafe failure leading to an inability to stop within a specified distance is extremely improbable. Appropriate fail-safe, redundant, or fault-tolerant design techniques should be used to achieve this performance. Use of multiple independent brake units and a very high integrity brake control system is a common, and normally applicable way of achieving the desired safety performance. Braking should automatically be initiated if component or subsystem failures reduce the level of redundancy sufficiently to reduce overall system safety performance below minimum acceptable levels.

Other brake system performance criteria that are normally necessary to successfully meet the overall performance goals are:

- Maximum rate safety braking should not impose unacceptable mechanical loads on the vehicle or guideway, or impose potentially hazardous deceleration rates on vehicle occupants.

- A design braking performance should be specified in terms of minimum average deceleration or stopping distances, consistent with stopping distance criteria used in the train control system design.

- The linear motor propulsion system and any non-safety brake should be reliably shut off on initiation of safety braking.

- The safety brake system should be entirely self-contained, not dependent on any external power supply, and always available for operation when the vehicle is in motion.

- A failed individual brake unit should not interfere either with normal operation of the vehicle or the performance of other operative safety brake units.

In addition to performance requirements for a safety brake, it is necessary to ensure that unintended movements of parked vehicles are prevented. Thus, all vehicles capable of independent operation should be provided with a parking brake which will prevent movement of the vehicle on the steepest grade on the system, and which can be applied when all on-board and wayside power supplies are unavailable.

Finally, tests should be performed to demonstrate that the safety and parking brakes meet the performance requirements under all operating conditions, including operation with failed individual brake units.

4.7.6 Further Studies

The maglev vehicle braking system is complex, requiring many subsystems to work together to achieve the required safety and performance levels. It has been possible to conduct only a preliminary review of the safety concerns in this study. A further in-depth study of the safety performance of maglev primary and secondary braking systems including all associated subsystems and components is suggested. This would provide a thorough understanding of how needed safety levels are achieved and ensure that there are no critical flaws in the proposed systems.

4.8 FUNCTIONAL AREA 208 - VEHICLE-GUIDEWAY INTERACTION

4.8.1 Description of Functional Area

This functional area addresses potential safety issues associated with the magnitude of forces and deflections generated at the vehicle-guideway interface. The loads imposed by the vehicle on the guideway and the resulting guideway structural deflections should not exceed safe limits. The vehicle must be able to operate at all speeds up to the design maximum without encountering unacceptable conditions such as an excessively rough ride, contact between the vehicle suspension system and the guideway, or excessive loadings on suspension system components.

Other functional areas having an interface with this functional area are as follows:

Functional Area 101, System Safety, in which the overall requirements for a maglev system suspension and guidance system are addressed.

Functional Area 105, Computer Safety for Vehicle and Operations Control Systems, provides a discussion of the requirements for the computers monitoring and controlling the maglev support and guidance magnets, and other safety-critical systems.

Functional Area 206, Suspension Design and Construction, covers safety-critical mechanical and electrical components of the maglev vehicle suspension and guidance system and its components.

Functional Area 301, Guideway Design and Construction, addresses guideway loading specification, design procedures for steel and concrete structures, and manufacturing and construction processes for guideway structures and attachments.

4.8.2 Safety Baseline

The safe operation of a maglev vehicle over a guideway requires that a number of potentially unsafe conditions or events be avoided:

- The imposition of unacceptably high loads on the guideway potentially leading to guideway damage or unacceptably large structural deflections. There are several potential causes of excess loading, including dynamic instabilities in the suspension and guidance system, undesirable resonance effects, excessive aerodynamic loads on the vehicle, and vehicle response to excessively large guideway geometrical irregularities.

- Impacts between the vehicle support and guidance magnets and the guideway. These occur when the support or guidance magnets cannot accommodate the imposed forces or guideway geometrical conditions within the available air gap. Examples of such conditions include short wavelength or step-like geometrical irregularities in the guideway structures and guideway-mounted components, or very severe curves or other irregularities that cannot be accommodated within the magnet air-gap and maximum suspension deflections.

- An excessively poor vehicle ride, which can cause slipping and falling accidents among vehicle occupants, or affect the ability of vehicle crew members to perform their duties. Such poor ride quality could result from dynamic instabilities in the suspension system, poor guideway geometry, or an inadequate response to reasonable guideway geometry irregularities due to poor selection of vehicle suspension stiffness and damping rates.

A lack of adequate passenger ride quality comfort is not a safety concern, but can have the same causes as excessively poor ride quality as discussed above.

4.8.3 Description of Existing Safety Requirements

The existing safety requirements are listed in Table 4-15, and are described below by origin under three headings: German, United States, and other foreign and international.

4.8.3.1 German Requirements

German requirements for vehicle guideway interaction are contained only in the RW MSB and the draft MBO. No DIN standards or similar requirements were cited by RW MSB in connection with this functional area.

Chapter 5 of the RW MSB outlines the load assumptions to be used in designing both the maglev vehicle and the guideway structure. The chapter specifies the types of loading to be taken into account in determining vehicle-guideway loads for vehicle and guideway design as follows:

- External factors, such as from wind, temperature variations, settlement of guideway support piers, etc.

- Loads due to the vehicle response-to-guideway geometrical deviations.

- Loads arising from electromagnetic forces generated by the magnetic levitation and guidance systems, and the linear motor propulsion system.

- Loads generated in all phases and conditions of operation, including acceleration, braking and curving, and under emergency or partial failure conditions.

Chapter 6 of the RW MSB, Stability Analyses (Guideway/Vehicle), elaborates on the load specifications for the vehicle and guideway by classifying loads into primary, secondary, and special loads, and defining load cases (specified combinations of loads) for which the vehicle and guideway structure must be designed. Primary loads are those resulting from normal vehicle operations, for which a large number of load cycles are expected. Secondary loads

TABLE 4-15. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 208 - VEHICLE-GUIDEWAY INTERACTION

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 5 Chapter 6 Chapter 7	Load Assumptions Stability Analysis Guideway/Vehicle Design Production and Quality Assurance of Mechanical Structures, Section 2.2 Guideway	Maglev
German Government	Draft MBO	2.1.2 2.1.3 3.2	Guideway Geometry Terracing Stresses from the Vehicle	Maglev
FRA	49 CFR, Transportation	Part 213 Part 215 Part 229	Track Safety Standards Freight Car Safety Standards Railroad Locomotive Safety Standards	Railroad
UIC	505-2 - Kinematic Gauge for Coaches and Vans used on International Services 515 - Coaches - Running Gear 560 - Coaches - Load Cases 711 - Geometry of Points and Crossing with UIC Rails Permitting Speeds of 100 KM/H or More on the Diverging Tracks 720 - Laying and Maintenance of Track Made Up of Continuously Welded Rail			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-15. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 208 - VEHICLE-GUIDEWAY INTERACTION (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
AREA	Manual for Railway Engineering	Chapters 1-5	Those Chapters Cover Railroad Track and Track Components	Railroad
AAR	Manual of Standards and Recommended Practices	Section C Part II M1001	Specifications for the Design, Fabrication and Construction of Freight Cars	Railroad
		Section D	Trucks and Truck Details	Railroad
		Section G	Wheels and Axles	
		Section H	Journal Bearings and Lubrication	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

are also loads encountered in normal operation but have a lower frequency of occurrence than primary loads. An example of a secondary load is the loading from a "design-case" high wind. Finally, special loads are those resulting from an emergency or partial failure condition, such as during emergency braking.

Chapter 6 specifies further that factors of safety used in structural analysis must reflect the severity of consequences of a failure; higher factors are used where consequences are more severe. Specific safety factors are not provided, but reference is made to DIN 18800 Part 1 for steel structures. This DIN is discussed in Functional Area 301, Guideway Design and Construction. Finally, Chapter 6 requires that vehicle and guideway deformations under the load cases must be such that there is no contact in normal operations between levitation or guidance magnets and the corresponding functional surfaces mounted on the guideway, taking into account the nominal magnet-guideway clearance and relative movements, and guideway tolerances. Any contact occurring during an emergency condition must be such that the resulting stresses do not exceed permissible values, and the vehicle can come to rest without danger to its occupants.

Chapter 7 of the RW MSB, Design, Production and Quality Assurance of Mechanical Structures, provides further information on the design and manufacture of structures to withstand the load cases specified in Chapter 6. In particular, Paragraph 2.2.2.1 requires that the maximum geometry deviation of the guideway surfaces must be established with due regard to the dynamic behavior of both the magnetic levitation and guidance systems, the guideway structure, and the maglev vehicle suspension.

The draft MBO includes the following requirements pertinent to vehicle-guideway interaction:

- Paragraph 2.1.2 and Appendix 1 specify standard dimensions for the guideway cross-section including the location of the reaction rails for support and guidance magnets.

- Paragraph 2.1.3 specifies that guideway horizontal, vertical and cross-section alignments must be structured for safe, comfortable and economic operation. Limits are specified for curvature (400 m [1313 ft]), superelevation (12°), and unbalanced lateral acceleration (1.0 m/sec or 0.1 g). The commentary on the MBO indicates that limits on vertical accelerations and gradients will be required, as well as geometrical limit values for initiation of maintenance.

- Paragraph 2.1.4 and Appendix 2 specifies a structural clearance diagram. Paragraph 3.3 states that the vehicle must remain within the diagram under all possible combinations of suspension movement relative to the guideway, including foreseeable failure conditions.

- Paragraph 3.2 specifies that stresses imposed on the guideway by the vehicle should not exceed safe limits.

- Paragraph 3.5 states that the levitation and guidance systems must be designed in such a way that safe guidance can be guaranteed in all operational states and environmental conditions.

4.8.3.2 U.S. Requirements

Several parts of the FRA railroad safety regulations contained in 49 CFR describe requirements relevant to guideway/vehicle interaction in conventional railroad operations:

- Part 213, Subpart C specifies dimensional limits for track geometry deviations as a function of operating speed. Subpart D specifies the minimum acceptable condition of track structure in terms of component wear or deterioration for each operating speed level.

- Part 215 specifies the minimum acceptable conditions for a freight car to be permitted to operate. Within this part, Subpart B specifies the minimum acceptable condition of components critical to safe operation such as wheels, axles, bearings and suspension components.

- Parts 229.63 to 229.75 of the specify the minimum acceptable condition of safety-critical suspension components for the locomotive to be allowed to operate. Critical suspension components include wheels, axles, bearings, trucks, and springing.

The AAR Manual of Standards and Recommended Practices also includes many requirements relevant to vehicle-guideway interaction for conventional railroad rolling stock. Specific sections of interest are:

- Section C, Part II, Specifications for Design Fabrication and Construction of Freight Cars, M-1001.

  This volume contains several requirements concerned with ensuring acceptable vehicle-guideway interaction performance of conventional railroad freight cars.

  - Chapter 2 specifies maximum dimensions and laden weights, and the minimum radius curves which the car must be able to negotiate.

  - Chapter 7 addresses the fatigue design of new freight cars, including in Section 7.3, details of the load spectrum applied to the car structure when operated in representative service over typical track conditions.

  - Chapter 8 provides requirements for freight cars used to transport trailers and containers, including specific limits for acceptable vehicle-guideway interaction performance. Vehicle-guideway interaction performance must be demonstrated by testing the car over perturbed track (track with deliberately introduced geometry irregularities) at specified speeds and lading conditions. Specified lateral/vertical force ratios, and wheel unloading limits must not be exceeded, and the vehicle must not exhibit dynamic instability (hunting).

- Chapter 11 requires specific analyses and tests to be carried out to ensure that vehicle-guideway interaction effects are within acceptable limits.

  Tests over unperturbed track, and track with specified periodic and "single-event" perturbations are required. Maximum acceptable vehicle body accelerations, movements, and wheel-to-rail lateral to vertical force ratios (L/V ratios) are specified for each test condition. Each test must be accompanied by a corresponding analysis using a validated mathematical model, and vehicle parameters obtained from suitable characterization tests.

- Section D, Trucks and Truck Details, specifies dimensions, materials and components to be used in standard U.S. freight car three-piece trucks.

- Section G specifies dimensions and materials for railroad car wheels.

- Section H specifies dimensions, materials, lubrication requirements and related matters for axle journal bearings to be used on freight cars.

The AREA Manual for Railway Engineering provides details of the construction of conventional railroad track, including rails, ties, tie spacing, ballast section, tie-rail fastening, and dimensional requirements.

4.8.3.3 Other Foreign and International Requirements

Several UIC codes contain requirements for conventional railroad vehicles concerned with, or relevant to ensuring that maglev vehicle-guideway interaction effects are within safe limits, as follows:

- UIC 515, Coaches, Running Gear, specifies ride quality and track force limits in Section 2, Technical Characteristics for the operation of conventional railroad passenger cars. Ride quality limits are expressed in terms of acceptable weighted root-mean-square accelerations, or a comfort rating expressed in hours, using the methods of ISO 2631 Ride Comfort Specification. Maximum acceptable lateral wheel-to-rail force is specified as a function of axleload, and must not be exceeded at maximum speed and cant deficiency. Finally, a criterion is provided maximum wheel unloading on twisted track. Instrumented tests must be carried out to demonstrate compliance with these requirements.

  Section 3.3.2 specifies that vehicles fitted with air springs must be able to operate safely with the air springs deflated at maximum speed, and must also meet the maximum wheel unloading criterion over twisted track.

- UIC 505 provides a kinematic (dynamic) clearance diagram which must not be exceeded by a passenger coach under all possible suspension movements or variations in component size (such as wheel diameter).

- UIC 711 provides details of the geometry of turnouts used for higher speeds (over 100 km/h) on the diverging track.

- UIC 720 specifies dimensional requirements and procedures for installing track made up of continuously welded rail. Particular attention is given to procedures for avoiding the buckling of welded track.

4.8.4 Comparison and Assessment

The requirements reviewed in Section 4.8.3 above include many requirements developed for conventional railroad systems (such as those of the FRA, AAR, AREA, and UIC) as well as the German maglev-specific requirements. In general, vehicle-guideway interaction requirements for conventional railroads are specified in terms of loadings, dimensional tolerances and other criteria that are specific to conventional railroads, and cannot be applied directly to maglev. However, the railroad criteria can provide useful guidance regarding equivalent criteria for maglev systems, including what kinds of criteria are required, how best to devise and define suitable criteria, and what performance assessment techniques are applicable.

Review of the requirements indicates that the approaches specified in the RW MSB for maglev systems and in the conventional railroad requirements for vehicle-guideway interaction are broadly similar, as summarized below:

- Use of a standard clearance diagram within which the vehicle must fit under all conditions of vehicle movement on its suspension, and all possible guideway deflections.

- Definition of the maximum acceptable forces, moments, and force ratios to be applied to the guideway by the vehicle under all operating conditions, including in emergency and partial failure conditions.

- Definition of maximum acceptable guideway geometric deviations which the vehicle should be able to negotiate safely at different speeds, including loads, minimum lateral and vertical curvature, rate of guideway twist, and dynamic deflection under a moving vehicle.

- Definition of minimum safety-related ride quality in the vehicle, including in quasi-static conditions such as cant deficiency in curves, and operation with a partial failure of the suspension system. A report by the FRA [19] provides useful information on safety-related ride quality.

Traditional railroad safety requirements are design-based rather than performance-based. For example, the FRA freight car and locomotive safety standards and the AAR requirements for wheelsets, bearings, and trucks are concerned with at ensuring that the vehicles do not impose unacceptable loads on the track; however, they define dimensions, materials, and specific designs, rather that specify performance in terms of maximum acceptable forces, etc.

These design-based requirements are not particularly relevant or helpful for developing maglev safety requirements.

Standardized guideway configurations and vehicle size and weight limits have not yet evolved for maglev systems. Therefore, numerical vehicle-guideway interaction force, deflection and geometry requirements are not appropriate. Maglev requirements, however, should address all types of undesired vehicle guideway interaction situations or behavior which could lead to potentially unsafe situations as defined in Section 4.8.2 of this discussion. The requirements in the RW MSB generally meet this need, but are distributed through Chapters 6 and 7, and are related to guideway and vehicle design rather than vehicle-guideway interaction performance as a separate subject. Also, specific requirements for dynamic vehicle-guideway interaction effects are lacking.

Conventional railroad vehicle-guideway interaction requirements are vehicle-oriented. The guideway (railroad track) is a "given," including its strength, stiffness, and the dimensional tolerances within which it is normally maintained. Vehicles are designed to operate over the pre-determined guideway, without exceeding safe force, deflection and other limits. At the present stage of development, maglev systems are different in that both the guideway and vehicle are being specified or designed together. Thus, the designer is able, within limits, to balance guideway tolerances and vehicle suspension performance to achieve the specified safety requirements. The safety requirements should preserve this design flexibility to the extent possible, but also ensure that the particular system chosen can operate safely. Safe loads, dimensional tolerances, and deflections for the guideway must be defined, and tests and analyses must be carried out to demonstrate that the vehicle can operate safely at the specified speed under these conditions.

4.8.5 Findings

Poor vehicle guideway interaction performance has been a significant cause of accidents on conventional rail systems. Most commonly, safe force or force ratios are exceeded, leading to the derailment or failure of the track structure. The unsafe force levels can be caused by poor dynamic performance of the vehicle, or by excessive track geometry deviations. Maglev vehicles could similarly exhibit poor dynamic performance and guideways could have unacceptable geometry deviations, leading to excessive vehicle-guideway forces, dangerously poor ride quality impacts between guideway and levitation or guidance magnets, and vehicle or guideway damage. Safety requirements are needed to protect the maglev system against these hazards.

The intent of existing FRA track, locomotive and car safety requirements for conventional railroads is to ensure that both car equipment and the track are adequately strong, and remain within safe geometrical limits that provide adequate vehicle-track interaction performance. However, the requirements are specific to conventional railroads, and are mostly expressed as wear and degradation limits. Thus, the FRA requirements cannot be applied directly to, or easily adapted for maglev systems.

The AAR requirements for freight car vehicle-guideway interaction are well structured with regard to car structural and dynamic analysis and acceptance testing, and provide good guidance regarding corresponding procedures for maglev vehicles. The specific force, strength and dimensional requirements of the AAR are specific to freight cars and cannot be applied to maglev system. The UIC requirements for railroad passenger vehicles are generally similar in content to the AAR requirements but are less detailed.

The RW MSB requirements focus primarily on the definition of load cases at the vehicle-guideway interface, and guideway geometry tolerances. Little information is provided on analyses and tests to ensure adequate dynamic performance of the vehicle on the guideway.

Thus, none of the referenced requirements fully address maglev vehicle-guideway interaction safety. For U.S. maglev system applications, consideration should be given to applying comprehensive vehicle-guideway interaction requirements as described below. The requirements are a combination of RW MSB requirements and adaptations of conventional railroad requirements.

4.8.5.1 Clearance Diagram

A maximum clearance diagram or envelope within which the vehicle should be contained at all times should be specified. This clearance diagram should be such that there is no conflict with the guideway itself, or with any structures adjacent to the guideway. Analyses should be carried out to demonstrate that the vehicle cannot violate the diagram under maximum movements on its suspension, or with a partial suspension failure (with which the vehicle may operate during an emergency).

4.8.5.2 Specification of Guideway Geometry Requirements and Tolerances

Requirements for both low-speed and high-speed operations are needed and should specify the maximum deviations acceptable on a properly maintained guideway.

Low-speed requirements define the most severe geometries that the vehicle must be able to negotiate without damaging itself or the guideway:

- Minimum vertical and lateral curvatures.
- Maximum rate of track twist (change in superelevation over a defined distance).
- Maximum variation in the relative position of "functional surfaces" - the reaction rails for the maglev support and guidance magnets.

A high-speed guideway geometry specification should include the following:

- Maximum magnitude of discrete and short wavelength irregularities in the lateral, vertical, and roll axes. Short wavelengths are defined as those less than the length of a single support or guidance maglev magnet.

- Maximum amplitude of longer wavelength irregularities. This could be expressed as a spacial power spectral density, and/or as the maximum amplitude of periodic repetitive deviations. An elevated guideway will have periodic deviations of a wavelength equal to the span between support piers which are likely to be an important factor in vehicle-guideway interaction performance.

4.8.5.3 Specification of the Maximum Acceptable Loads or Load Spectra on the Guideway

The maglev system designer should specify the maximum loads in all axes - vertical, lateral, longitudinal, and roll - which the guideway is designed to withstand. Loads may be governed either by guideway strength, or by maximum acceptable guideway dynamic deflections. Load cases can be as defined in the RW MSB requirements.

4.8.5.4 Safety Analyses and Tests

Both analyses and tests should be carried out to demonstrate that the maglev vehicle can safety operate over the "design case" track geometry deviations without exceeding acceptable loadings, as defined in paragraph 4.8.5.3, without reducing the air gap between the guideway functional surfaces and support and guidance magnets below an acceptable minimum, and without exceeding ride quality limits in the vehicle passenger or crew compartments. This performance should be demonstrated at all speeds up to the maximum speed allowed for the vehicle/guideway combination. The analyses and tests should include an adequate investigation of at least the following potentially unsafe conditions or situations:

- Potential dynamic instabilities due to the use of active or non-linear suspension elements on the vehicle.

- Resonance effects due to repetitive constant wavelength deviations in the guideway, such as might be present with a constant span elevated guideway.

- Coupling between guideway beam flexural deflections and the vehicle suspension in the lateral, vertical, and roll axes.

- Response to aerodynamic forces on the vehicle.

- Operation with partially inoperative suspension units, such as an individual air spring, or support or guidance magnet. All conditions in which the vehicle is expected to operate safely should be included.

- Analyses and tests of slow speed operation over minimum radius vertical and lateral curves, maximum track twist, and on a guideway with maximum superelevation to demonstrate that these geometries can be safely negotiated by the vehicle.

The tests should be carried out over a portion of guideway with deliberately introduced "design case" geometry deviations.

4.9 FUNCTIONAL AREA 209 - VEHICLE INSPECTION AND MAINTENANCE

4.9.1 Description of Functional Area

This functional area addresses inspection and maintenance procedures and practices needed to ensure that maglev vehicles are in safe operating condition at all times.

Vehicle systems and components that require regular inspection and/or maintenance include structures, suspension systems, brake systems, door mechanisms, on-board power supplies and batteries, and the onboard operations control computer and associated sensors.

Inspection and maintenance requirements are closely related to the design and installation requirements for all safety-critical vehicle systems and components that are subject to wear and degradation with time and usage. The specific vehicle system and component functional areas to which inspection and maintenance requirements apply are:

Functional Area 201, Vehicle and Cab Structural Integrity, particularly for structural defects such as fatigue cracks in high stress areas.

Functional Area 202, Vehicle Operator and Crew Compartments, in particular for the proper functioning of instruments and controls.

Functional Area 203, Passenger Vehicle Interior Fittings and Components, for local structural failures.

Functional Area 204, Passenger Vehicle Doors and Entryways, for the proper functioning of all door systems.

Functional Area 206, Suspension Design and Construction, where inspection and maintenance procedures are required for "active" elements such as springs, dampers, levitation and guidance magnets and associated systems, and the condition of structural components.

Functional Area 207, Brake Installation and Performance, where virtually all subsystems and components require regular inspection and maintenance.

Functional Area 602, Emergency Features and Equipment Including Access and Egress for the proper condition or functioning of emergency equipment such as fire extinguishers and alarms, and emergency exits.

4.9.2 Safety Baseline

To ensure continued safe operation, all systems and components in the maglev vehicle that are subject to wear and deterioration with time and usage should be regularly inspected and maintained. To ensure that this is performed correctly, plans and procedures typically contain:

- Schedules detailing the frequency (by time or distance operated) and nature of inspections that should be performed on each subsystem or component.
- Definition of component condition acceptability criteria, such as dimensional wear limits, freedom from structural flaws, and electrical/electronic outputs (e.g., from sensors), together with procedures for remedial actions to correct deficiencies.
- Requirements for preventative maintenance or replacements at defined time or distance intervals.

4.9.3 Description of Existing Safety Requirements

The existing safety requirements are listed in Table 4-16 and described below by origin under three headings: German, United States, and other foreign and international.

4.9.3.1 German Requirements

Chapter 4 of the RW MSB, On-Board Control System, makes a limited reference to maintenance and inspection requirements. If sufficient failures are present to reduce redundancy to minimum acceptable levels, the vehicle must be stopped and corrective maintenance performed.

Otherwise, the RW MSB is primarily concerned with safety requirements related to maglev system design and manufacture, and does not address maintenance requirements.

Paragraph 1.4 of the draft MBO, Paragraph 1.4, Basic Rules, contains a number of general inspection and maintenance requirements. Vehicles must be inspected regularly to ensure that they are in proper condition (Item 4), and the inspections should be properly dependent on the condition, loads, and construction of the vehicles and installations (Item 5). Pressure vessels shall be subject to initial and regular periodic tests by a competent authority (Items 6 and 7). No detailed requirements are provided for the inspection and maintenance of specific subsystems and components.

Paragraph 1.5 of the draft MBO states that the operator must keep installation vehicles and appurtenances in good, operationally safe condition. No more specific inspection and maintenance requirements are provided.

Section 3 of the EBO, Rolling Stock, contains a number of maintenance and inspection requirements for conventional railroad vehicles. Paragraph 32 states the following:

- New vehicles must be subject to an acceptance inspection before placing in service.
- Vehicles must be systematically inspected.

TABLE 4-16. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 209 - VEHICLE INSPECTION AND MAINTENANCE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 4	On-Board Control System	Maglev
German Government	Draft MBO	Chapter 1	Basic Rules	Maglev
	EBO	Section 3, Paragraphs 32, 33	Acceptance and Inspection of Rolling Stock	Railroad
TÜV Rheinland	Safety Reliability for Certification of Transrapid Maglev Technology	-		Maglev
FRA	49 CFR	Part 215 Part 229	Freight Car Safety Standards Railroad Locomotive Safety Standards	Railroad
FAA	14 CFR	Part 43 Part 121	Maintenance, Preventative Maintenance, Rebuilding and Alterations Responsibilities of Commercial Air Carriers - Subpart L Inspection and Maintenance	Commercial Aircraft
AAR	Field Manual of the AAR Interchange Rules			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-16. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 209 - VEHICLE INSPECTION AND MAINTENANCE (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
Canadian Government	Draft Railway Passenger Car Inspection, Safety and Design Standards	Part I Part II	General-Safety Inspection Inspection Safety Standards	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

- There must be at least one inspection every six years, and

- Records must be kept of vehicle inspections.

Paragraph 33 of the EBO provides detailed requirements for the inspection of locomotive boilers and other pressure vessels. Pressure vessels must be visually inspected annually and receive a water pressure test every nine years, or after any repairs or modifications. Inspections and tests must be performed by responsible experts.

Apart from pressure vessels, the draft MBO or EBO contain no specific requirements for inspection processes or the acceptability of vehicle condition.

TüV Rheinland, in a paper discussing certification requirements [10], makes the general statement in Paragraph 5.5 that periodic inspections will need to be defined according to the risks of a malfunction in each subsystem, but no specifics are provided.

A technical paper by authors involved in German maglev development: <u>Operational Fields of the New High-Speed Rail Systems in the Federal Republic of Germany</u> [20], describes an inspection maintenance philosophy for a high-speed magnetic levitation system. The principal elements of the approach described are:

- Types of maintenance and inspection activity are defined as follows:

  - *Hard Time Limits*, where components are replaced or overhauled after a specified period of time regardless of condition. This is also termed preventative maintenance.

  - *On-Condition Maintenance*, to be performed when inspections and tests indicate that condition is at a minimum acceptable level.

  - *Condition Monitoring* is an on-going monitoring of component condition or functionality to indicate need for repair or replacement.

- A hierarchy of inspection and maintenance goals is defined:

  - Ensure safety
  - Ensure operational availability
  - Ensure all passenger amenities are operational

- Vehicle components and subsystems are classified according to the way in which they fail or degrade.

  - Components that fail suddenly without any prior indication of degradation (e.g., electronic components)

  - Components subject to visible wear and deterioration with usage (e.g., friction brake linings)

- Components which lose functionality mainly because of reaching the end of service life (e.g., structures failing because of corrosion or metal fatigue)

- Components which simultaneously lose functionality as a result of both degraded performance and reaching the end of their service life (e.g., electrical storage batteries)

- A maintenance approach is developed according to how components fail, and which maintenance goal (safety, availability, amenity) is impacted by the failure, as summarized in Table 4-17.

Reference 20 provides a detailed example of an inspection and maintenance program for the maglev guideway.

4.9.3.2. U.S. Requirements

The FRA regulations contained in 49 CFR contain numerous inspection requirements and acceptability criteria for conventional railroad cars and locomotives. The principal requirements of interest are in Part 215 and Part 229.

49 CFR, Part 215 specifies inspection requirements and maximum acceptable wear and degradation limits for safety-critical components of freight cars. Vehicles with defects exceeding the acceptable criteria cannot continue in service and must be moved directly to a suitable facility for repair. Part 215.13 states that a pre-departure inspection must be made by a qualified inspector whenever a freight car is placed in a train. Subpart B, Parts 215.101.129 provide specific wear limits and other acceptability criteria for safety critical components, such as wheels, axles, bearings, truck components, couplers and car body structures.

49 CFR, Part 229 contains inspection and maintenance requirements for locomotives. Subpart B specifies periodic inspection requirements for locomotives as follows:

- Part 229.21, Daily Inspection, specifies that each locomotive in use shall be inspected at least once per day by a qualified person. Non-complying conditions must be reported and repaired before the locomotive is used.

- Part 229.23, Periodic Inspection, applies to locomotives and steam generators, and specifies that the period between inspections should not exceed 92 days (3-month cycles). Non-complying equipment shall be reported and repaired.

- Part 229.25 specifies that every 92 days, periodic inspection must include tests and inspection of gauges for braking, electrical devices and visible insulation, cable connections, and all automatic controls, alarms and protective devices.

- Part 229.27 specifies annual tests primarily concerned with brake equipment. Parts 229.57 and 229.59 provide brake wear and leakage acceptability criteria used for these tests.

TABLE 4-17. INSPECTION AND MAINTENANCE APPROACH BY COMPONENT FAILURE MODE AND CRITICALITY

Failure Mode	Failure Criticality		
	Safety Critical	Availability Critical	Amenity Critical
Sudden Failure, No Warning	Multiple redundant or fault-tolerant systems, with on-line condition-monitoring and diagnostic systems to indicate failure. Failed parts are replaced, e.g., at end of day. Intermittently used systems (e.g., safety brake) tested periodically.	Not usually redundant. Replace when fail. Low "time to repair" critical. If not possible, redundancy may be justified.	Repair and replace when failed. No condition monitoring.
Components with Gradual Wear or Loss of Functionality	Condition monitoring by inspection, with repair/replacement when acceptable limits are reached. Hard time limits also used.	No redundancy used. On-condition repair or hard-time limit. Governed by cost-effectiveness.	As above
Service Life Loss of Functionality	Condition monitoring by inspection, with repair when acceptable limits are reached. Hard time limits also used.	As above.	As above.
Service Life and Performance Loss of Functionality	Condition monitoring by inspection, with replacement/repair when acceptable limits are reached. Hard time limits also used.	As above, but hard time limits commonly most appropriate in this category.	As above

Source: Reference 20

- Part 229.29 specifies that the brake controllers on locomotives are to be cleaned and tested at no more than 736-day intervals (2 years).

- Part 229.31 specifies tests and inspection of air brake air reservoirs, also to be performed at not more than 736-day intervals.

Subpart C, Safety Requirements, Parts 229.46-229.91 include wear limits and other component condition safety criteria for locomotive brakes, wheels and suspension systems, drawgear and electrical systems.

Overall, the FRA safety requirements are only applicable to conventional railroad equipment.

Federal Aviation Administration regulations for commercial air carriers (Subpart L of 14 CFR, Part 121) state that:

- A comprehensive inspection, preventative maintenance and maintenance manual shall be assembled for each airplane type operated complying with FAA directives and manufacturers' recommendations.

- Properly qualified staff, and proper tools and equipment shall be available.

- Procedures shall be in place to ensure that inspections and maintenance are properly carried out.

- Detailed records shall be kept of aircraft operations and all inspection results and maintenance work. These records must be subject to continuing analysis and surveillance so that problems can be identified and corrected.

Other Federal Aviation Administration regulations of relevance are provided in 14 CFR, Part 43 which gives details regarding the qualifications of maintenance and inspection personnel (see Functional Area 501, Qualifications and Training), and requirements for the content of required 100-hour and annual inspections.

The AAR Interchange Rules for freight cars specify full details of wear and deterioration limits for freight car components, together with approved repair or replacement actions to correct defects. Mandatory life limits or test intervals are specified for some components.

4.9.3.3 Other Foreign and International Requirements

The draft Canadian Railway Passenger Car Minimum Inspection, Safety and Design Standards specify when inspections are to be performed and the detailed inspection criteria for safety-critical components. Inspections by a certified inspector must be performed at the stations where a passenger train is made up, and where the consist is changed. Specific acceptability limits are defined for wheels, axles, bearings, truck components, car bodies, couplers, electric jumper cables (between cars) and safety appliances.

An example of an inspection schedule for a high-speed wheel-on-rail train (the French TGV) has been provided in a paper by Brand and Lucas [21], as shown in Table 4-18.

TABLE 4-18. INSPECTION SCHEDULE FOR FRENCH TGV TRAINS

Inspection Interval	Action
2 days	Visual inspection and testing of operational systems.
9 days	Interior inspection (lighting, p.a. system, heating/cooling)
18 days	Inspection of running gear
5 weeks	Mechanical system inspection, level 1
10 weeks	Mechanical system inspection, level 2
20 weeks	General inspection, level 1
40 weeks	General inspection, level 2
18 months	Part disassembly and general inspection

Extensive use is made of on-line sensors and diagnostic systems on the TGV to monitor for unacceptable conditions.

4.9.4 Comparison and Assessment

Conventional railroad inspection requirements consist of two main components: the first component is a series of graduated inspection intervals starting with daily inspection and going up to very comprehensive inspections conducted at one- or two-year intervals, together with a definition of what is to be inspected or tested on each occasion. The second component contains detailed definitions of maximum acceptable wear and deterioration.

Conventional rail vehicles are designed such that most safety-critical components are readily accessible for test and road inspection, and the inspections themselves can be carried out visually or using simple gauges and instruments. For equipment that is not easily inspected, use is made of mandatory disassembly, replacement, or reconditioning intervals. Roller bearings and air brake control valves are maintained at predetermined intervals, with the intervals being based on past service experience. The FRA regulations and industry standards such as the AAR Interchange Rules reflect the customary approach. French practice for the TGV train is similar, except that inspections are made at more frequent intervals and are more comprehensive, and increasing use is being made of on-line monitoring systems.

The FAA requirements for commercial aircraft inspection and maintenance are largely driven by the requirement to develop a comprehensive inspection and maintenance manual reflecting FAA directives and manufacturers' recommendations. The requirements are specific to individual aircraft and engine models. Use is made of mandatory intervals for disassembling systems and components for thorough inspection and replacement, including engines and airframe structural components. This is particularly used for components and systems that cannot easily be inspected in-situ. The inspection intervals are based on service experience and performance in tests. Both rail and aviation requirements specify comprehensive recordkeeping of inspection results and maintenance work.

The maglev vehicle differs from conventional railroads and aircraft primarily in the nature of the safety-critical systems and components for which inspection and maintenance procedures must be designed. In particular, extensive use is made of microprocessors in the vehicle for control of the support and guidance magnets, and of the safety brake. Solid state electrical power control devices are used in power supplies, support and guidance magnets, and the safety brake system. All these systems may fail without warning. Conversely, maglev vehicles have very few safety-critical moving parts subject to mechanical wear, the suspension system being the principal area. The maglev vehicle will resemble conventional rail vehicles with regard to the need for inspection and maintenance of vehicle body structures.

Another factor in maglev vehicle inspection and maintenance is the use of condition monitoring systems. Such systems are essential to detecting faults in fault-tolerant and redundant electronic and computer systems, and are increasingly used to monitor real time systems that would otherwise need to be inspected at frequent intervals. Similar techniques are being introduced into conventional railroad practice, especially high-speed wheel-on-rail trains. An important question is the extent to which monitoring systems can replace regular conventional inspections.

The German paper, Operational Fields of the New High-Speed Rail Systems in the Federal Republic of Germany [20], makes a good start in providing a framework for developing maglev condition monitoring, inspection and maintenance requirements based on component failure characteristics and safety criticality. This approach clearly merits further development, leading to requirements for individual components and subsystems.

4.9.5 Findings

Regularly applied and appropriate inspection and maintenance procedures will be essential to ensure that maglev vehicles do not develop potentially hazardous defects in services.

Existing FRA regulations for inspection and maintenance primarily contain inspection intervals and vehicle component condition requirements designed for conventional rail vehicle components such as wheels, bearings, and air-brake components. These requirements cannot be applied to, or easily adapted for maglev vehicles.

The German paper [20] provides a useful framework for developing maintenance and inspection requirements for maglev vehicles, but considerable further work is needed to develop actual requirements. The RW MSB does not contain any maintenance and inspection requirements, and no DIN or other requirement is referenced in this functional area.

The FAA requirement in 14 CFR, Part 121 Subpart L for developing and following a comprehensive maintenance manual for a specific airplane is applicable to maglev vehicles.

For U.S. maglev system applications, consideration should be given to developing inspection and maintenance requirements that combine the approaches of the FAA in 14 CFR Part 121 and Reference 20. The requirements should comprise the following.

- A comprehensive condition monitoring inspection, preventative maintenance, and a maintenance manual be prepared for each type of maglev vehicle. The manual should reflect manufacturers' recommendations and other available and relevant knowledge regarding component failure modes and criticality.

- Properly qualified staff, and proper tools and equipment should be available.

- Safety-critical electronic and computer systems, including sensors (e.g., for magnet gap, or vehicle location) should be continuously monitored for correct functioning and for faults that reduce the level of fault tolerance or redundancy. Systems that operate intermittently (such as the safety brake) shall be tested at intervals that will ensure a very high certainty level of functioning when needed, based on the best available estimate of failure rates.

- Safety-critical mechanical components (such as suspension components, and set-down skids) shall be inspected daily and should be subject to periodic non-destructive tests for structural integrity.

- Records should be kept of maintenance inspection results and the operations history. The records should be subject to continuing analysis and review so that problems can be identified and corrected.

- Thorough inspection and functionality tests should be carried out on new vehicles prior to being put into service and on the relevant subsystems of vehicles after the installation of new or rebuilt components.

4.9.6 Further Studies

Insufficient information is available at present to make recommendations regarding condition monitoring and inspection techniques, inspection intervals, and specific preventative maintenance needs. Further research is recommended, particularly with regard to monitoring requirements for sensors, microcomputers, and solid state electric power control components used in safety-critical systems.

4.10 FUNCTIONAL AREA 210 - INTERIOR VEHICLE NOISE

4.10.1 Description of Functional Area

Virtually all transportation vehicles produce noise inside the vehicle when in operation. The noise is produced by equipment on the vehicle and by disturbance of the air when the vehicle is in motion. This functional area addresses safety issues relating to noise levels inside the maglev vehicle.

4.10.2 Safety Baseline

Occupants of a maglev vehicle should be protected from excessive discomfort or potential injury due to high noise levels.

Vehicle occupants, especially operators and other crewmembers, may suffer fatigue or disorientation caused by high noise levels, leading to a reduction in ability to perform their duties. Also, hearing loss may result from long-term exposure to high noise levels.

4.10.3 Description of Existing Safety Requirements

Interior noise requirements are not addressed in the RW MSB requirements, and there are no noise requirements in the UIC code. Therefore, only U.S. requirements are discussed in this section. The requirements identified are listed in Table 4-19 and a description is provided below.

The FRA regulation for locomotive cab noise contained in 49 CFR, Part 229.121 requires that exposure limits in a locomotive cab should not exceed an eight hour time-weighted average of 90 dB(A), with a doubling rate of 5 dB(A), as indicated in Table 4-20.

TABLE 4-19. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 210 - INTERIOR AND EXTERIOR NOISE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FRA	49 CFR, Transportation	Part 210 Part 229 Paragraph 121	Railroad Noise Emission Compliance Regulations Locomotive Cab Noise	Railroad
APTA	1981 Guidelines for Design of Rapid Transit Facilities	2.7	Noise and Vibration	Mass Transit
MBTA	RE 648 Technical Provisions for No. 2 Red Line Rapid Transit Cars	Section 13	Noise	Mass Transit

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 4-20. FRA LOCOMOTIVE CAB NOISE REQUIREMENTS

Duration Permitted (hours)	Sound Level [(dB(A)]
12	87
8	90
6	92
4	95
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

Continuous noise exposure is composed of two or more periods of exposure of different noise levels, their combined effect being considered. Exposure to different levels for various periods of time shall be computed according to the following formula:

$$D=T_1/L_1+T_2/L_2+....T_n/L_n$$

Where:

D = noise dose
T = the duration of exposure (in hours) at a given continuous noise level.
L = the limit (in hours) for the level present during the time T (from the table).

If the of D value exceeds 1, the exposure exceeds permissible levels.

Exposure to continuous noise shall not exceed 115 db(A)

The APTA guidelines for rail rapid transit facilities recommends the following maximum interior noise levels:

In open (ballast and tie) at maximum speed on welded rail (+5 dBA on jointed rail)	70 dB(A)
In open (concrete trackbed) at maximum speed	74 dB(A)

In tunnels at maximum speed	80 dB(A)
All auxiliaries operating, car stationary	68 dB(A)

These noise levels should be measured in an empty, but fully equipped car at 1.2 m (4.0 ft) above the floor along the centerline of the car. A "Type 2" sound level meter meeting ANSI S1.4-1971 requirements should be used.

APTA does not provide guidelines for noise levels in an operator's cab.

The MBTA New Red Line Car Builders Specification is a representative example of mass transit practice for an individual system. The requirements are as follows:

- Continuous sound level in the cab shall not exceed a 12-hour, time-weighted average of 78 dB(A).

- Exposure to continuous noise (any sound with a rise time of more than 35 milliseconds to peak intensity and a duration of more than 500 milliseconds to the time when the level is 20 db below the peak) in the cab shall not exceed 115 dB(A) at any time.

- In the passenger-seating area, sound with crush load of passengers, measured 1.2 to 1.9 m (4 to 6 feet) above the floor and at least 0.3 m (1 foot) from the side walls, shall not exceed 70 dB(A) when the car is operated on open, dry, level, tangent-ballasted track - in any normal mode of acceleration, deceleration, or coasting with all systems operating at speeds up to 80 km/h (50 mph). With the car stationary, on open, ballasted track, the sound level with all systems operating, except the traction motor circuit, shall not exceed 68 dB(A).

4.10.4 Comparison and Assessment

All the requirements described in Section 4.10.3 above have been developed for application to transportation systems in the United States. Therefore, they are potentially suitable for application to high-speed maglev systems in the United States in comparable operating conditions.

The interior noise requirements in the FRA regulations have the purpose of limiting adverse impacts of high noise levels on the ability of cab occupants to carry out their duties, and the risk of locomotive crews suffering hearing damage due to long-term exposure to excessive noise.

A representative mass transit requirement of 78 dB(A) over 12 hours for an operator cab is much lower than the FRA requirement for locomotive cabs for the same exposure time of 87 dBA. The rail mass transit requirement may be more appropriate for high-speed maglev vehicles. The relatively high sound levels permitted by the FRA locomotive cab noise requirements reflect the difficulty of silencing a high-power diesel engine. A lower noise level, leading to a better working environment is desirable and should be achievable in a maglev vehicle with very little on-board moving machinery.

Requirements for maximum noise levels in the passenger compartments in the open at normal operating speed are typically 70 dB(A) for rail mass transit equipment. Similar or lower levels are specified for intercity rail passenger cars. The objective of these requirements are to ensure an adequate level of passenger comfort. These sound levels are well below any level that could be considered harmful.

4.10.5 Findings

Safety requirements that limit interior noise levels are appropriate for maglev vehicles in the U.S. to ensure that vehicle operators and crewmembers can perform their duties properly, and to ensure that vehicle occupants do not experience significant discomfort or injury due to high noise levels.

Existing FRA noise requirements for locomotives are not appropriate for maglev vehicles. Relatively high noise levels are permitted because of the practical limitations on applying sound insulation to a locomotive cab adjacent a high power diesel engine on new and existing locomotives. Lower noise levels, typified by those specified for rail mass transit vehicles are more appropriate for maglev vehicles. Therefore, consideration should be given to adopting a representative rail transit car interior noise safety requirement for U.S. maglev system applications:

- A 12-hour time-weighted average of 78 dB(A) should not be exceeded.
- Continuous noise should not exceed 115 dB(A). Continuous noise is defined as any sound with a rise time of more than 35 milliseconds and a duration of more than 500 milliseconds to the point when the level is 20 dB below the peak level.
- Sound measurement equipment should meet the requirements of ANSI S1.4 - 1971, Type 2.

The above requirements can be applied to passenger compartments for health and safety purposes. However, for passenger comfort reasons, most maglev operators will require sound levels of 70 dB (A) or lower in passenger compartments.

5. GUIDEWAY

5.1 FUNCTIONAL AREA 301 - GUIDEWAY DESIGN AND CONSTRUCTION

5.1.1 Description of Functional Area

This functional area is concerned with all aspects of the design and construction of the maglev guideway. All elements of the guideway structure are included, such as foundations, support piers, guideway beams, and the mechanical attachments for the linear motor stator, and magnetic levitation and guidance reaction rails. The technical subjects addressed in this functional area are the determination of loads from the vehicle and other sources, the design of a structure (in steel or reinforced concrete) that can withstand the loads, and ensuring that the necessary construction quality is maintained, including dimensional tolerances.

This functional area is closely related with several other functional areas as follows:

Functional Area 104, Quality Assurance, provides details of quality assurance procedures to be used in the design and construction of all structures and equipment to be used in the maglev system.

Functional Areas 206, Vehicle Suspension Design and Construction, and 208, Vehicle-Guideway Interaction, both of which, in part, are concerned with loadings generated between the vehicle and guideway under normal and exceptional operating conditions.

Functional Area 302, Guideway Inspection and Maintenance, addresses actions and procedures needed to ensure that the guideway remains in serviceable condition.

Functional Area 303, Guideway Switch, addresses requirements for the bending beam switch. The switch shares many safety requirements with the fixed portion of the guideway.

5.1.2 Safety Baseline

The guideway must be designed and constructed so that it can safely support all vehicle and externally applied loads without damage or distortion over its service life, and so that maglev vehicles can be safely operated over the guideway at the design maximum speed.

A complete guideway design and construction process must include the following elements:

- A specification of loads to be withstood by the guideway structure, which include:
  - Live loads from maglev vehicles, both when operating normally at any speed, and under degraded conditions following a "survivable" fault of any kind.

- Environmental loading, such as from expansion due to temperature variations, high winds, snowfall, and earthquakes where applicable.

- The dead (static) loads from the weight of the guideway structure.

- Appropriate design procedures for steel and reinforced concrete structures, including allowable stresses and safety factors for static, cyclic, and extreme load cases.

- Specifications for materials and construction processes used for the guideway structures.

- Dimensional tolerances for the location of maglev support and guidance reaction rails, the linear motor stator segments, and for guideway lateral and vertical curvature, twist, superelevation, and gradient.

5.1.3 Description of Existing Safety Requirements

Existing German and U.S. safety requirements are listed in Table 5-1 and described below by origin under two headings: German and the United States.

Since guideway design and construction cover a number of individual safety-related subjects, the discussion is further divided into four sub-areas, as follows:

- The development of design loads and load cases for which the guideway must be designed. Load cases consist of various combinations of the weight of the structure, loads imposed by maglev vehicles, and other externally imposed loads such as those due to wind, snow, thermal expansion or contraction of the structure, and differential settlement of foundations.

- The criteria used to design a structure to withstand the specified loads, particularly concentrating on how allowable working stresses are calculated for different types of load from the properties of the construction material (such as yield and ultimate compression and tensile strength).

- Requirements for manufacturing or construction processes, particularly welded and bolted joints, to ensure that the structure, as built, has the strength assumed in the design calculations.

- Dimensional tolerances required for guideway structures, including requirements for maximum dynamic deflection under vehicle loads.

TABLE 5-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 301 - GUIDEWAY DESIGN AND CONSTRUCTION

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 5 Chapter 6 Chapter 7	Load Assumptions Stability Analyses Design, Production and Quality Assurance of Mechanical Structures	Maglev
German Government	Draft MBO EBO	Part 2 Section 2	Operating Installations Railroad Installations	Maglev Railroad
DIN	1045 - Structural Use of Concrete - Design and Construction			General Construction
DIN	1055 - Design Loads for Buildings	Parts 1, 2, 3, 4, 6		
DIN	1072 - Road and Foot Bridges, Design Loads			
DIN	1075 - Concrete Bridges, Dimensioning and Construction			
DIN	1079 - Steel Road Bridges: Principles for Structural Design*			
DIN	1084 - Quality Supervision in Concrete and Reinforced Concrete Construction			
DIN	4149 - Building in German Earthquake Zones - Design Loads, etc.			
DIN	4227 - Prestressed Concrete	Parts 2, 3, 4, 5, 6		
DIN	18200 - Inspection of Construction Materials, Structural Members, and Types of Construction			General Construction
DIN	18800 - Steel Structures, Design and Construction			
DIN	18809 - Steel Road Bridges and Footbridges			
Thyssen-Henschel	NVA 0320/02/89 Guideway of The Transrapid	Part II	Load Assumption	Maglev

*Although referenced in RW MSB, DIN 1079 has been withdrawn, and replaced by DIN 18809.
Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 5-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 301 - GUIDEWAY DESIGN AND CONSTRUCTION (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Chapter, etc.	Applicability or Intent
German Federal Railways	DS 804 - Code for Railroad Bridges and other Structures DS 899/59 - Supplementary Requirements for Railroad Bridges on New Lines			Railroad Railroad
FRA	49 CFR, Transportation	Part 213	Track Safety Standards	Railroad
AREA	Manual for Railway Engineering	Chapter 8 Chapter 15	Concrete Structures Steel Structures	Railroad Structures
AASHTO	Standard Specifications for Highway Bridges 14th Edition, 1989			Highway Structures
AISC	Specification for the Design, Fabrication and Erection of Structural Steel for Buildings 9th Edition, 1989			Steel Structures
ACI	318-89 - Building Code Requirements for Reinforced Concrete			Concrete Structures
Prestressed Concrete Institute	Design Handbook			Concrete Structures
ASTM	A6/A6M 90 General Requirements for Rolled Steel Plates, Shapes, Sheet Piling and Bars for Structural Use			General Construction

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

5.1.3.1 German Requirements

5.1.3.1.1 Loadings and other Design Requirements

Chapter 5, Load Assumptions, and Chapter 6, Stability Proofs, of the RW MSB provide detailed specifications for load cases to be considered in structural design, adapted from the DS series bridge requirements of German Federal Railways and DIN 1055, 1072, and 1079. Loads from the vehicle are based on vehicle static and dynamic loadings, plus forces generated by the magnetic support and guidance systems, and the propulsion and braking systems. DS 804 and the DINs are referenced for non-vehicular loads such as from snow, wind, temperature extremes, behavior of beam support bearings, differential settlement of foundations, and residual stresses in structural members. DS 804 frequently references the DINs for non-railroad-specific requirements.

The design loads specified in the RW MSB take into account additional loads resulting from the relatively higher speeds and tolerance restrictions associated with the operation of the maglev system as compared with a conventional railroad.

Chapter 6 of the RW MSB explains the classification of the loads into the three categories.

- Primary loads (P) are maximum loads occurring frequently during normal operations.
- Secondary loads (Se) are loads that occur infrequently during normal service.
- Special loads (Sp) occur as a result of an emergency situation or another type of unusual event.

Chapters 5 and 6 of the RW MSB describe the load assumptions for both guideway and vehicle and subdivides them into external guideway loads, external vehicle loads and interface loads. Table 5-2 lists the loads and the corresponding load categories for external loads on the guideway. These do not include loads imposed by the maglev vehicle. Table 5-3 lists the interface loads applied by the vehicle to the guideway.

The loads are combined to form load-cases for which the structure should be designed, as listed in Table 5-4.

The guideway must be designed for external guideway loads and interface loads imposed on the guideway by the vehicle.

External guideway loads listed in Table 5-2 are loads acting on the guideway girders and substructures and foundations other than those due to maglev vehicles. The loads include those due to dead weight, welding stress, creeping and shrinkage of concrete, girder slackening, subsoil movement, wind, snow, ice, temperature, friction in bearings, setting and locking forces in bending switches, impact of land vehicles, ground pressure loads, ice pressure, impact from other vehicles, earthquake and construction loads, etc.

TABLE 5-2. CLASSIFICATION OF EXTERNAL GUIDEWAY LOADS

Type of Load	Steel Guideway Open Track	Steel Guideway Stopping Points	Concrete Guideway Open Track	Concrete Guideway Stopping Points
Dead weight of guideway structure	P	P	P	P
Dead weight of guideway equipment	P	P	P	P
Creepage and contraction	-	-	P	P
Prestress forces	-	-	P	P
Girder slackening	P	P	P	P
Probable foundation soil movement	P	P	P	P
Possible foundation soil movement	Se	Se	Se	Se
Lifting of the guideway for change of bearing	Sp	Sp	Sp	Sp
Wind load	Se	Se	Se	Se
Ground pressure loads	P	P	P	P
Assembly equipment (in building phase)	P	P	P	P
Snow load	Se	Se	Se	Se
Thermal effects	Se	Se	Se	Se
Displacement resistance of the bearings	Se	Se	Se	Se
Forced deformation (only in switches)	P	P	-	-
Impact loads of vehicles	Sp	Sp	Sp	Sp
Ice impact and thermal ice pressure	Sp	Sp	Sp	Sp
Effects of earthquake	Sp	Sp	Sp	Sp

[Source: RW MSB Chapter 6]

TABLE 5-3. CLASSIFICATION OF GUIDEWAY-BASED INTERFACE LOADS

Type of Load	Guideway Open Track	Guideway Stopping Points	Guideway Equipment
Forces of Gravity			
- Due to hovering	P	P	P
- Due to initiating hovering	Se	P	P
- Due to setting out, accelerating or braking (operationally)	P	P	P
- Due to emergency braking	Sp	Sp	Sp
- Due to operational setdown	Se	P	P
- Due to set-down vehicle	Se	P	-
- Due to centrifugal forces while banking	P	-[1]	P
- Due to discontinuities in the guideway geometry	P	P	P
- Due to deviations of the guideway geometry from planned values	P	P	P
Aerodynamic Forces			
- On the set-down vehicle	Se	Se	-
- Crosswind			
V_s ($V_s \leq V_1$)	P	P	P
V_s ($V_1 < V_s \leq V_2$)	Se	Se	Se
- During tunnel entry or exit	P	-	P
- In tunnel	P	-	P
- Opposing traffic	P	-	P
- When passing structures near the track	P	P	P

[1]If possible, stopping points should be provided only along straight track.

Source: RW MSB Chapter 6

TABLE 5-4. MAGLEV GUIDEWAY LOAD CASES

Load case P:	Primary loads in the most unfavorable configuration If only one secondary load is present aside from the primary loads, then it should also be treated as a primary load
Load case PSe:	Primary and secondary loads in the most unfavorable configuration
Load case $PSeSP_1$:	Primary, secondary and special loads from emergency braking
Load case $PSeSP_2$:	Primary and special loads from ice impact or thermal ice pressure or impact with watercraft
Load case $PSeSP_3$:	Primary, secondary, and special loads from earthquakes
Load case Sp_4:	Continual loads and special loads from impact with vehicles

Source: RW MSB Chapter 6

Interface loads are loads that act between vehicle and guideway. As listed in Table 5-3, these loads include: static and dynamic loads imposed on the guideway by the vehicle, centrifugal forces, and traction and braking loads under normal and emergency conditions.

Document No. NVA 0320/02/89, Guideway of the Transrapid: Load Assumptions lists the loads for design of the guideway of the Transrapid high speed magnetic railway. Primary, secondary, and special loads are classified and defined together with load situations and combinations, and design loads. The design loads were established in accordance with DS804 unless otherwise stated.

The specification of guideway structure design loads is necessarily specific to maglev systems. Therefore, only the RW MSB and other maglev-specific requirements are discussed in this section. There are no applicable DIN requirements.

As well as design loads, it is customary in a guided transportation system guideway design requirement to specify limits on curvature and superelevation. Such limits are specified in the draft MBO, section 2.1.3 as follows:

- Minimum radius of curvature 400 m (1312 ft)
- Maximum Guideway cant (superelevation) 12 degrees
- Maximum unbalanced lateral acceleration 1.0 m/sec (0.1g)

5.1.3.1.2 Design Procedures

The general design procedure for concrete used in Germany is to define the service loads acting on a structure, and apply a load factor to these loads. The required ultimate strength for the members is designed using those factored loads. The design procedure for steel structures is somewhat different, in that the design codes specify safe working stresses for the grade of steel and the type of load. Chapter 6 of the RW MSB (Section 4) states that structural safety factors should be a function of the probability of occurrence of the load case, and the severity of consequences should the structure fail. Guideway structure components must be assigned to the highest severity class (catastrophic risk). Particular attention must be paid to fastenings for the linear motor stator packs mounted on the guideway, where adequate redundancy must be used, considering expected incidence of failed fastenings and anticipated inspection intervals and repair times.

Chapter 7, Design, Production and Quality Assurance of Mechanical Structures, of the RW MSB (Section 2.2.2.3) specifies that "diverse mounting" (redundancy) shall be used for the fastenings of guideway-mounted equipment, repeating the requirement in Chapter 6.

The RW MSB references several German structural engineering requirements documents for structural design procedures. These requirements are listed below:

- DS 804, Code for Railroad Bridges and Other Structures is a comprehensive manual containing German Federal Railway's requirements for the design and construction of railroad bridges for speeds up to 200 km/h. The manual provides requirements for loadings, allowable working stresses and loadfactors, and material selection and construction practices. Section 3 of the Manual, the title of which translates as 'Dimensioning' contains instructions for carrying out design calculations for both steel and concrete structures. Information on the actual load factors and allowable stresses specified in this and the other German requirements described below is provided in Section 5.1.4, comparing German and U.S. practice.

- DS 899/59, Supplementary Requirements for Railroad Bridges on New Lines covers provisions for loadings, design procedures,and construction for structures for speeds exceeding 200 km/h. The principal variations from practice for conventional speed structures as given in DS 804 are adjustments to the loadings and to specified design calculations resulting from high speed operation and the use of different track structures. Higher loads from high braking rates, higher cant deficiences, and thermal loads with welded rail are mentioned.

- DIN 1045, Structural Use of Concrete is a comprehensive manual covering the design and construction of plain and reinforced concrete structures and structural members. The manual provides full details of material requirements for concrete and reinforcing bar, concrete testing. construction procedures, design analysis procedures, and detailed design instructions for specific structural members such as slabs, beams and compression members.

- DIN 1072, Road and Foot Bridges covers the design loads to be taken into consideration for the design and construction of road and foot bridges, and specifies the design loads to be used in the calculation. This DIN applies equally to concrete and steel bridges, but does not contain any requirements specific to non highway bridges. However, the system of classifying loads which is common to many German structural design procedures is applied. This system classifies loads as Main, or primary loads, Additional or secondary loads, and Special loads. Main loads are loads that are regularly applied to the structure such as the weight of the structure itself, and traffic loads. Additional loads are those that are applied less frequently, such as wind, thermal, snow and vehicle braking loads. Special loads are those arising from rare events, such as accidents, and during construction.

- DIN 1075, Concrete Bridges covers design and construction requirements applicable to the superstructures and substructures and also to the foundations of bridges made of concrete, reinforced concrete, and prestressed concrete. DIN 1075 is also applicable to other structures which are loaded in accordance with DIN 1072 or DS804 (e.g., retaining walls supporting backfills).

- DIN 1079, Steel Road Bridges, Principles for Structural Design referenced in RW MSB has been superseded by DIN 18800 Parts 1 and 7 and DIN 18809, as described below.

- DIN 18800, Steel Structures is a general guide to the design and construction of steel structures of all types.

  Part 1, Design and Construction, applies to the design and construction of load bearing members in steel supporting either static or variable loads. Recommendations are provided for allowable stresses in structural members and in bolted, riveted, and welded joints as a function of the type of loading (static, or variable) and material specification.

  Part 7, Fabrication, Verification of Suitability for Welding, covers procedures for making welded and bolted joints, and procedures for qualifying welders and welding firms.

- DIN 18809, Steel Road Bridges and Footbridges specifies design loadings and required analyses for steel bridges. Loadings are taken from DIN 1072, described above. Design requirements for structural members and joints, and permissible stresses for different materials and joining methods (bolts, rivets, welds) are provided, with numerous references to DIN 18800, Part 1. Overall, this DIN is written as a supplement to DIN 18800 providing special requirements for bridges where these differ from those for steel structures in general.

- DIN 4227, Prestressed Concrete is a comprehensive guide for the design of prestressed concrete structures.

  Detailed specifications are provided in the individual parts of DIN 4227 for normal and lightweight prestressed concrete, the design of joints in segmented structures, the injection of cement into prestressing ducts, and the design of structural members using unbonded prestressed steel.

5.1.3.1.3 Manufacturing and Construction Requirements

German manufacturing and construction procedures are described in the following requirements documents:

- DS804, Code for Railroad Bridges and Other Structures covers general provisions for design and construction of railroad structures for speeds up to 200 km/hr (124 mph).

- DS899/59, Supplementary Requirements for Railroad Bridges on New Lines covers provisions for design and construction of railroad structures for speeds ranging from 200 to 250 km/hr (155 mph).

- DIN 1045, Structural Use of Concrete is a comprehensive standard which covers the design and construction of plain and reinforced concrete structures and structural members.

- DIN 1075, Concrete Bridges contains the design and construction requirements applicable to the superstructures and substructures and the foundations of bridges made of concrete, reinforced concrete, and prestressed concrete. DIN 1075 is also applicable to other structures which are loaded in accordance with DIN 1072 or DS804, such as retaining walls for fills which carry traffic loads.

- DIN 4227, Prestressed Concrete is described above in the discussion of design loadings.

- DIN 18800, Steel Structures; Part 7, Fabrication, Verification of Suitability for Welding provides requirements for the fabrication of load-bearing steel structural members and includes procedures for cutting, drilling, and weld preparation of steel plates and sections, and the assembly of welded, bolted, and riveted structures.

Chapter 7 of the RW MSB also references DIN 29 591, DIN 65 118, and DVS 1603-1611 concerned with welding procedures and the qualification of welders. The same documents were referenced for maglev vehicle construction, and descriptions of the contents of each document have been provided in Functional Area 201, Vehicle and Cab Structural Integrity.

5.1.3.1.4 Dimensional Tolerances

Dimensional tolerance requirements include those for the longitudinal alignment of the guideway and the dimensions of guideway cross-section, specifically the positioning of the "functional surfaces" which react to levitation and guidance forces.

Chapter 7 of the RW MSB (Paragraph 2.2.2) provides some general requirements for guideway tolerances, mentioning that requirements for both random long wavelength deviations and short wavelength discontinuities must be specified. Tolerances must be compatible with vehicle geometrical arrangements and the properties (including air gap) of the support and guidance magnets. Proprietary Transrapid documents are referenced for tolerance dimensions.

Section 2 of the draft MBO requires compliance with cross-section dimensional requirements given in the appendices. The appendices provide standard dimensions for the relative positions of the support and guidance reaction rails and the linear motor long stator. Tolerances on these dimensions are not given, but the guideway-to-magnet air gaps are given as 8-10 mm. The draft MBO indicates that these dimensions are preliminary. Dimensioned clearance diagrams both for the vehicle and wayside structures are also provided.

5.1.3.2 U.S. Requirements

5.1.3.2.1 Design Loadings

The American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges (the AASHTO Standard, 15th Edition, 1992, defines the design loads in Division I, Section 3, as follows:

- Dead Load:	Section 3.3
- Live Load & Impact (Dynamic effect):	Section 3.4 to 3.12
- Wind:	Section 3.15
- Thermal:	Section 3.16
- Forces from stream current, floating ice and drift:	Section 3.18
- Buoyancy:	Section 3.19
- Earthquake:	Section 3.21

Section 3.22 specifices the load combinations required to be considered.

The AREA Manual for Railway Engineering defines the design loads for steel structures in Chapter 15, and for concrete structures in Chapter 8 as follows:

- Chapter 15, Part 1, Section 1.3 specifies dead load, live load, impact, wind, centrifugal, longitudinal, continuous welded rail, and other lateral loads.

- Chapter 8, Part 2, Section 2.2.3 contains the same listing as above, and in addition earthquake, stream flow, ice pressure, and other forces. Section 2.2.4 lists the various load combinations for which the structural components shall be designed.

- Chapter 8, Part 17, Section 17.2 specifies loading requirements for prestressed bridges.

The nine (9) load combinations required to be considered in the AREA specifications along with their allowable stress increase are also used in the AASHTO specification along with two (2) additional combinations.

5.1.3.2.2 Design Procedures

Reinforced concrete may be designed by either of two (2) methods recognized by both the AASHTO Standard and the AREA Manual: Service Load Design or Strength Design. The allowable stresses and design assumptions are the same for both specifications, except for Strength Design in which the basic load factor used in the AASHTO standard is 1.3 and the AREA Manual uses a factor of 1.4.

The Allowable Stress Design method is the most commonly used method for designing steel members. Both the AASHTO and the AREA specifications contain basically the same allowable stresses, except in the case of axial compression where the AASHTO uses a factor of safety of 2.12 and the AREA uses a factor of safety varying between 1.78 to 2.12 depending on the slenderness of the member. The criteria used for combining axial compression and bending is also more conservative using the AASHTO criteria. This is because of higher magnification factors applied to the bending stresses which results from a higher factor of safety applied to the Euler buckling stress. The AASHTO specification also allwos structural steel to be designed by the Strength Design method which is not allowed by AREA specification.

Design procedures for specific structural elements are described in the AASHTO Standard and the AREA Manual as indicated in Table 5-5.

The American Welding Society Bridge Welding Code (AWS D1.5-88) provides welding design procedures.

TABLE 5-5. STRUCTURAL DESIGN REQUIREMENTS

Subject	AASHTO Standard Division I	AREA Manual
Concrete Design		Chapter 8
Foundation	Section 4	Parts 3 and 4
Retaining Walls	Section 5	Parts 5 and 6
Substructures	Section 7	
Reinforced Concrete	Section 8	Parts 1 and 2
Prestressed Concrete	Section 9	Part 17
Bridge Bearings		Part 18
Steel Design		
Steel Piles	Section 4	Chapter 8, Section 4
Structural Steel	Section 10	Chapter 15, Parts 1, 2 and 5

5.1.3.2.3 Manufacturing and Construction Requirements

Manufacturing and construction requirements are described in the AASHTO Standard, Division II, which covers the basic technical construction specifications needed for the construction of highway bridges and in the AREA Manual for railroad bridges. Table 5-6 indicates the location of various requirements. The AWS D1.5-88 Bridge Welding Code provides welding procedures and testing requirements for steel bridges.

TABLE 5-6. BRIDGE CONSTRUCTION REQUIREMENTS

Subject	AASHTO Standard Division II	AREA Manual
Concrete Structures	Section 8	Chapter 8, Part 1
Reinforced Steel	Section 9	Chapter 8, Part 1
Prestressing	Section 10	Chapter 8, Part 17
Steel Structures	Section 11	Chapter 15, Parts 3 and 4
Steel and Flooring	Section 12	Chapter 15, Parts 3 and 4
Painting	Section 13	Chapter 15, Part 4
Bridge Bearings	Section 18	Chapter 8, Part 18 Chapter 15, Part 4
Moveable Bridge		Chapter 15, Part 6

5.1.3.2.4 Dimensional Tolerances

Safety-related dimensional tolerances for conventional railroad track are provided in the FRA requirements contained in 49 CFR, Part 213, Subpart C. Maximum permitted dimensional deviations for alignment, crosslevel, profile, and gauge are provided as a function of track class and the corresponding maximum operating speeds. Part 213, Appendix A specifies maximum speed on curves as a function of track superelevation, based on a maximum deficiency of superelevation of 3°.

Chapter 5 of the AREA Manual specifies parameters for lateral and vertical curves, including spirals at the beginning and end of lateral curves. AREA does not specify any dimensional requirements for newly constructed track.

Representative construction tolerances for civil engineering structures and structural components are contained in the AASHTO standards, Division II, and the AISC, Prestressed Concrete Institute, and ASTM A6.

Fabrication tolerances for steel structures are covered in the American Society for Testing and Materials Specification, ASTM A6. Typical length tolerances for rolled beams and columns over 30 feet long and for beams over 24 inches deep are -1/2 inch (under) and 1/2 inch (over) plus 1/16 inch for each additional 5 feet or fraction thereof.

Field connections of continuous beams and plate girders shall be preassembled prior to erection as necessary to verify the geometry of the completed structure, and to verify or prepare field splices. Attaining accurate geometry is the responsibility of the contractor.

The Prestressed Concrete Institute Design Handbook covers the various tolerances associated with the fabrication of precast and prestressed concrete members.

Typical tolerances for prestressed concrete members are as follows:

Rectangular beams and box beams	Length:	± 3/4 inch
I-beams and piles	Length:	± 1 inch
Bearing plates	Position:	± 5/8 inch
Bearing plates	tipping and flushness:	± 1/8 inch

5.1.4 Comparison and Assessment

5.1.4.1 Design Loadings

The definition of guideway structural design loads is the first step in the guideway design process. All the transportation structural design codes and procedures define three distinct types of loads: the dead load from the self-weight of the structure, the live load or interface load imposed by the moving vehicle, and non-vehicle external loads. The dead load results from designing the structure for the other two load types.

The live loads imposed by the vehicle will be specific to a maglev system. Vehicle weight, propulsion and braking system characteristics, suspension behavior, and other factors that affect vehicle-to-guideway load will be quite different from live loads from other types of vehicles. Thus, vehicle loadings defined for highway or conventional railroad structures do not apply, and maglev-specific vehicle loads such as those listed in Table 5-3 should be used.

Non-vehicle loads on the guideway are primarily a function of local climatic and geographical features, and include wind and snow loadings, thermal loads due to temperature variance, the potential for loads from differential settlement of foundations, and earthquake loads. Local conditions must be taken into account in defining these loads, and use of loads developed for a different country or region will be inappropriate. Therefore, non-vehicle loads derived for the U.S. environment and applicable to the region in which the maglev guideway is being built must be used. Use of loads defined in the German requirement such as the DINs and German Federal Railway DS-series is not appropriate. However, the listing of types of load given in Table 5-2 is universally applicable.

The RW MSB process for combining individual loads into load cases (as listed in Table 5-4) is reasonable, and similar to that used in the AASHTO and AREA specifications. Allowable stresses are increased for load combinations which are less likely to occur.

5.1.4.2 Design Procedures

In general, the U.S. and Germany have a basically similar approach with respect to the design of reinforced concrete and steel structures to support defined loadings. The design methodology, as well as a comparison between the two approaches, is described below.

In the U.S., there are two methods by which reinforced concrete structures are designed. The first method involves the calculation of stresses caused by the working (or service) loads and their comparison with certain allowable concrete stresses. The second method is strength design (or ultimate strength design) in which the working loads are multiplied by certain *load factors* (L_f) that are greater than one. The load factors are used to account for possible unusual increases in load beyond those estimated, or due to inaccurate assessment of effects of loading, or other reasons. In addition, to accurately estimate the ultimate strength of a structure, it is necessary to take into account the uncertainties in material strength, dimensions, and workmanship. Therefore, an additional factor called *strength reduction factor* (S_f), which is less than one, is applied to the theoretical ultimate strength. (Strength reductions factors vary with the type of stress being considered.) The German design analysis procedure, based on DIN standards, uses one safety factor which allows for a safety margin between the working load and the design ultimate load. The safety factor in the German procedure is equivalent to the combination of the strength reduction factor and the load factor in the U.S. procedure.

An example can be used to illustrate the difference and similarity between the U.S. and German approaches. The design strength in flexure of a cross-section can be expressed as:

$$M_u = A_s f_y Z / \text{Safety Factor}$$

Where M_u is the ultimate resistance moment.
A_s is the area of tension reinforcement.
f_y is the specified yield strength of the reinforcement.
Z is the lever arm.
German Safety Factor = L_f/S_f, in U.S. and Britain

The load factor L_f is different for dead loads and live loads (or imposed loads) since the designer can estimate the magnitude of dead loads much better than the magnitude of live loads. Table 5-7 lists the various safety factors for a cross-section in flexure in accordance with the various requirements discussed.

The two U.S. transportation requirements use a significantly higher safety factor for live load than the German requirements, but a lower dead load factor. Without details of actual live and dead loads, it is not possible to determine whether using the German or U.S. procedures will result in significantly different structures. The ACI and CP110 requirements are primarily used for buildings rather than bridges, where live loads are typically much lower than the dead loads, and have a relatively low influence on the structural design. In contrast, live loads are very substantial in highway and railroad bridges, and will also be significant for maglev guideway structures.

Another limit used in concrete design is that on maximum compressive strain. In the U.S., the limit is 0.003 (AASHTO and AREA), whereas the German limit is 0.0035 (DIN 1045). As in the discussion of safety factors it is not possible to determine whether this difference will lead to a significantly different structure, without carrying out design calculations for specific load combinations.

TABLE 5-7. COMPARISON OF SAFETY FACTORS FOR A CONCRETE CROSS-SECTION IN FLEXURE

Requirement	Load Factor L_f		Strength Reduction Factor S_f	Safety Factor L_f/S_f	
--	Dead Load	Live Load	--	Dead Load	Live Load
DIN 1075 DS 804	1.75	1.75	1.0	1.75	1.75
AASHTO	1.3	2.17	0.9	1.44	2.41
AREA	1.4	2.33	0.9	1.55	2.59
ACI	1.4	1.7	0.9	1.55	1.89
CP110*	1.4	1.6	0.87	1.61	1.84

*British Code of Practice for structural use of concrete.

Structural steel in both the U.S. and Germany is most commonly designed by the Allowable Stress Design Method. Table 5-8 shows a comparison of various allowable stresses specified in the AASHTO and AREA specifications and the German requirements. These allowable stresses are permitted to be increased by both the U.S. and German requirements when certain load combinations are considered.

TABLE 5-8. COMPARISON OF ALLOWABLE STRESSES FOR STRUCTURAL STEEL

TYPE OF STRESS	REQUIREMENT		
	AASHTO	AREA	GERMAN REQUIREMENTS[1]
AXIAL TENSION ON NET SECTION	.55Fy	.55Fy	.58Fy
FLEXURE COMPRESSION[2]	.55Fy	.55Fy	.67Fy
TENSION GROSS SECTION	.55Fy	—	
NET SECTION	.55Fu[3]	.55Fy	.67Fy
AXIAL COMPRESSION: MAXIMUM	.47Fy	.55Fy	.58Fy
SHEAR	.33Fy	.35Fy	.38Fy

NOTES:

1. German allowable stresses based on DS804, DS899, and DIN 18800.
2. Compression flange assumed to be laterally supported in flexure.
3. Fu=Minimum tensile strength for type of steel (FU≈1.2 to 1.6 FY).

Apart from the design of the overall guideway structure, a particular area of concern is the design of equipment fastened to the guideway. In particular, linear motor stator packs are fastened to the guideway structure and are subject to frequent load cycles from vehicle propulsion and braking forces. The stator packs themselves, and the stator-to-guideway fastenings must be designed so that there is a very low risk of a failure of the fastening, or the stator pack assembly. The RW MSB specifies a redundant fastening system, and for the fastening to be arranged so that defective fastening can be easily identified during inspection.

Stiffness criteria rather than stress criteria may govern the design of certain guideway elements. The deformation tolerances applicable to a high-speed maglev system guideway are very tight. The structural stiffness needed to keep the maximum dynamic deflection of the guideway within acceptable limits, under normal live load cases, may be the governing factor in structural design. Calculation of the dynamic deflection under the moving load is essential, to confirm that the guideway structure stiffness is acceptable.

5.1.4.3 Manufacturing and Construction Processes

The structures must be manufactured or constructed so that they will provide the expected service life under normal operating loads without structural damage or failure. A number of the requirements referenced in the RW MSB address structure quality, for example the welding and welder qualification requirements (DVS-series). Overall, the U.S. requirements for construction and fabrication processes appear to be similar to the German requirements and should produce a structure of equivalent quality.

5.1.4.4 Dimensional Tolerances

The dimensional tolerances in normal civil engineering construction and fabrication, as described in Section 8.1.3 above, do not provide the cross-sectional dimensional accuracy required for the maglev levitation and guidance reaction rails as specified in Chapter 7, Design, Production and Quality Assurance of Mechanical Structures, of the RW MSB. Therefore, ways need to be developed for either adjusting the attachment of the reaction rails to the guideway beams to achieve the desired position accuracy, or of improving the steel fabrication or concrete casting processes to substantially improve upon conventional tolerances.

Very high accuracy in guideway longitudinal geometry is also required to ensure a safe vehicle ride, and to ensure that there is no risk of guideway-magnet impacts.

A discussion of vehicle-guideway interaction and permitted guideway dimensional tolerances is provided in Functional Area 208, Vehicle/Guideway Interaction. In that discussion, it was recommended that a guideway geometry specification should include the following requirements:

- Maximum amplitudes of discrete or short-wave length irregularities in the lateral, vertical or twist axes, consistent with the magnet air gaps to prevent magnet-guideway impacts.

- Maximum amplitudes of long wavelength irregularities, expressed as a spacial power spectral density, or as a maximum amplitude of individual or periodic repetitive irregularities, to ensure a safe vehicle ride.

In both cases, guideway irregularities are the sum of construction tolerances, live load deflections, deflections due to external loads from wind and temperature variations, and movements over time due to foundation settlement and similar effects which cannot be corrected effectively by maintenance adjustments.

Overall, a careful analysis of dimensional tolerances and structural deflections under load is essential to ensure that guideway geometry requirements for a high-speed maglev system operation can be met.

The RW MSB also specifies a number of other dimensional requirements such as minimum curvature, and maximum guideway superelevation. The maximum superelevation specified is 12°, which may be excessive. If a vehicle has to travel over a curve with this superelevation at slow speed, the occupants will be subject to much higher lateral forces than is normal in guided transportation systems, where a limit of 6° is normal.

5.1.4.5 Proof of Performance

In most civil engineering structures, inspection and review of design calculations, materials and workmanship by a qualified engineer, and tests on material samples are normally considered sufficient to guarantee that the structure will meet service requirements. In the case of a maglev guideway, there is less certainty as to the actual loads the guideway will be subject to, and thus of the stresses and deflections under these working loads. Therefore, instrumented tests will be needed on new-design structures to measure dynamic force stresses and deflections to ensure that acceptable levels are not exceeded, in addition to the application of normal design review and quality control procedures.

5.1.5 Findings

Collapse of transportation structures due to inadequate design has not historically been a major cause of transportation accidents. Some highway bridges have collapsed, but the fault seems to have been a lack of adequate inspection rather than faulty design. However, a maglev guideway structure is distinctly different from conventional highway and railroad bridges. In particular, the guideway must be constructed and positioned to very fine dimensional tolerances. Therefore, safety requirements for guideway structures are necessary, particularly for new designs for which test data and service experience are lacking.

There are no existing FRA regulations for bridges and other structures. The detailed technical requirements for railroad and highway bridges and structures developed by the AREA and AASHTO are customarily used to guide the design and construction of bridges in the U.S. The AREA and AASHTO requirements cover the same subjects as the German Federal Railways' DS requirement and the DINs cited in the RW MSB. The principal difference observed in this review is that the German requirements may allow slightly higher stresses in steel and concrete structures than the U.S. requirements. More detailed calculations are needed to determine the exact effect of this difference on an actual maglev guideway structure, since the difference depends on the relative magnitude of dead and live loads. The other area of difference concerns non-vehicular load estimates due to temperature range, high wind, snowfall, or earthquake activity. Since geographical conditions vary, and conditions in the U.S. are distinctly different from those in Germany, load estimates applicable to the region where the guideway is being built should be used in place of the German requirements.

The actual live loads imposed on the guideway by a maglev vehicle will differ substantially from those imposed by the conventional rail or highway vehicle. Therefore, careful analysis must be applied to estimating maglev vehicle loadings to ensure that all applicable loads and load conditions have been considered. The RW MSB provides good guidance for these loads and load combinations.

Therefore, for U.S. maglev system applications, consideration should be given to the following safety requirements for the design and construction of guideway structures.

5.1.5.1 Specification of Operating Loads and Load-Cases

German requirements contained in the RW MSB which specify live loads imposed on the guideway by the maglev vehicle should be used in the U.S.

Customary U.S. requirements with respect to externally applied loads contained in the AASHTO standards or the AREA Manual should be used to reflect the U.S. operating environment. Estimated loads due to high winds (including hurricanes), temperature variations, and earthquakes should reflect local conditions in the region in which the guideway is being constructed.

Guideway structure load cases equivalent to those given in Chapter 6 of the RW MSB should be used for maglev guideway structure design. Additionally, static and fatigue load cases should be clearly distinguished and fatigue load cases should include a specification of the number and magnitude of load cycles during the expected life of the structure, as in the AREA requirements. The load cases should reflect all phases of vehicle operation: acceleration, braking, maximum speed operation, emergency braking, etc.

5.1.5.2 Design of Guideway Structures

The recommended general requirement is that the design analysis, allowable stresses, structural safety factors, and design details should all conform to established engineering practice as specified by AASHTO, AREA, DIN, or by another recognized requirement - a setting organization for the same or similar purpose.

Particular attention must be paid to the design of equipment fastened to the guideway and the fastener system used. The requirements contained in Chapter 7 of the RW MSB should be followed. A redundant fastening arrangement must be used such that the failure of a fastener will not result in any loss of attachment, and that a failed fastener is easily detected in inspection.

Since excessive foundation movement would result in an "out-of-tolerance" maglev guideway, consideration should be given to using deep foundations, especially where scour, erosion, or settlement may occur, even though the bearing capacity of the soil is sufficient to make practical, the use of shallow foundations.

5.1.5.3 Construction and Manufacture

The construction and manufacture of structures, including steel or concrete structures, foundations and all other elements should follow the requirements of AASHTO, AREA, DIN, German Federal Railways, or equivalent recognized technical requirements.

5.1.5.4 Tolerances

A detailed review of guideway dimensional tolerances must be carried out to ensure that the guideway will meet the requirements specified in Functional Area 208. This review shall include at least manufacturing and construction dimensional deviations, and deflections under vehicle and external loads, and settlement of foundations, creep, temperature and wind. If any special manufacturing or construction process is used to ensure dimensional accuracy, it should be reviewed to ensure that structural strength is not impaired.

5.1.5.5 Proof of Performance

Normal design reviews and material and structure inspections as specified by AASHTO and AREA are applicable to maglev guideway structures in the U.S. In addition, instrumented tests are recommended for *new and untried guideway designs* for which adequate test data or operational experience is lacking. The tests should involve measurement of loads, stresses and deflections for comparison with design calculations, and confirmation that measured values are with acceptable limits.

5.1.6 Further Studies

The exact differences between elevated maglev guideway structures designed using U.S. and Germany structural design procedures is a complex function of the mix of loads of different types (dead load, live vehicle load, environmental loads) applied to the structure. A detailed analysis of a representative maglev guideway structure in concrete and steel should be carried out to better understand the significance of any differences. The question of whether load or guideway structure stiffness governs elevated structure design would also be worth investigation. The RW MSB does not discuss structure stiffness in any detail, but structural experts in the U.S. consider that structure stiffness will be a critical design goal.

5.2 FUNCTIONAL AREA 302 - GUIDEWAY INSPECTION AND MAINTENANCE

5.2.1 Description of Functional Area

Inspection and maintenance procedures and practices are required to ensure that the guideway is in safe operating condition at all times. The procedures and practices will be applicable to foundations, support piers, guideway beams, and mechanical and structural features of equipment mounted on the guideway such as linear motor stator packs.

Other functional areas closely related to this functional area are as follows:

Functional Area 210, Vehicle-Guideway Interaction, discusses acceptable guideway loadings and geometrical requirements as a function of vehicle speed and suspension characteristics.

Functional Area 301, Guideway Design and Construction, covers all activities up to the point at which a newly constructed guideway is ready for service.

5.2.2 Safety Baseline

To ensure safe operation, the guideway and its attachments must be maintained in a condition which ensures that it can support all expected service loads and meet the geometrical requirements discussed in Functional Area 208, Vehicle/Guideway Interaction. Particular requirements are as follows:

- Guideway support foundations must be free of excessive scour, erosion, or settlement.
- Guideway structures must be free of significant structural defects such as excessive corrosion, cracking, or loose or missing fasteners.
- Guideway attachments and fasteners must be maintained such that there is no possibility of any equipment becoming distorted or detached from the guideway. In particular, defective attachments or fasteners must be promptly detected and replaced.
- Both longitudinal and cross-section guideway geometrical deviations should be within acceptable limits for the speed of operation, and for the magnet-to-guideway air gap used.

5.2.3 Description of Existing Safety Requirements

The existing safety requirements are listed in Table 5-9 and described below by origin under three headings: German, United States, and other foreign and international.

TABLE 5-9. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 302 - GUIDEWAY INSPECTION AND MAINTENANCE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Chapter, etc.	Applicabiliaty or Intent
RW MSB	Maglev Safety Requirements	Chapter 6 Chapter 7	Stability Analyses Design Production and Quality Assurance of Mechanical Structures	Maglev
German Government	Draft MBO	Section 1.4 Section 2	Basic Rules Operating Installations	Maglev
	EBO	Paragraph 17	Operating Installations	Railroad
FRA	49 CFR, Transportation	Part 213	Track Safety Standards	Railroad
AREA	Manual for Railway Engineering	Chapter 2 Chapter 8 Chapter 15	Track Measuring Systems Concrete Structures Steel Structures	Railroad
AASHTO	Manual for Maintenance Inspection of Bridges			Highways

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

5.2.3.1 German Requirements

Section 4.4 of Chapter 6, Stability Proofs, of the RW MSB requires that the mountings of the linear motor stator packs must be subject to regular tests or measurements to ensure that safety-threatening failures are prevented. The design of the fasteners of the stator, and other guideway-mounted equipment such as lateral guide rails and slide surfaces is required to be such that regular inspection can detect incipient failures. The inspection program must be consistent with the fault indications used for these fasteners.

Section 2.2.2 of Chapter 7, Design, Production and Quality Assurance of Mechanical Structures, of the RW MSB requires that the guideway must be maintained such that all geometrical deviations of the guide and support (slide) rails are within acceptable limits, both for short wavelength or discrete irregularities, and longer wavelength deviations. A measuring system must be available (preferably vehicle-based) that can determine the location and nature of unacceptable geometrical deviations.

Paragraph 1.4 of the draft MBO states that operating installations must be regularly inspected as regards their proper condition.

Paragraph 2.1.2 of the draft MBO states that guideway dimensional tolerances shall be specified by the operator. The back-up discussion associated with this paragraph indicates that the tolerances should be derived from a balance between operating speed, passenger comfort and engineering, and economic feasibility. This paragraph further states that limit values on geometric deviations should be specified for the initiation of maintenance measures.

Paragraph 17 of the EBO requires that the railroad be systematically inspected as to whether its condition complies with regulation. The nature, scope, and frequency of inspection must be determined by the condition and loading of the railroad, and allowable speeds.

5.2.3.2 U.S. Requirements

The FRA requirements contained in 49 CFR, Part 213 specify dimensional track geometry and track component condition requirements for each speed-defined track class. Required track inspection intervals are also specified. On high-density main-line track, the following inspections are required:

- Twice weekly visual inspection; for example, from a hi-rail vehicle.

- Annual automated rail flaw inspection.

- Monthly inspection of turnouts on foot.

- A special inspection after unusual events (such as a severe storm).

In addition to these requirements, it is the practice of many railroads to perform automated track geometry measurements approximately every six months.

The AREA Manual for Railway Engineering recommends that thorough inspections of steel and concrete structures be made at least once a year. Forms and checklists are provided in the AREA Manual to help organize the inspection process.

Chapter 8 of the AREA Manual (Part 21) provides requirements for the inspection of concrete and masonry structures. Conditions identified in an annual inspection should include scouring, erosion or settling of foundations, particularly those in a waterway; cracks in any prestressed or reinforced concrete beams and piers, and evidence of exposure and corrosion of reinforcing bars. Particular emphasis is given to evaluating the extent of any changes since the previous inspection.

Chapter 15 of the AREA Manual (Part 7) provides requirements for the inspection of steel structures. Conditions to be identified in inspection include corrosion, cracks or other flaws in any part of the structure, the condition of fasteners (bolts and rivets), and the condition of bridge bearings or expansion rollers.

Chapter 2 of the AREA Manual provides guidelines for the automatic measurement of track geometry and clearances including definitions of terminology and a description of a "generic" track geometry measurement car.

The AASHTO Manual for the Inspection of Bridges provides comprehensive guidelines for inspecting highway bridges of all types (steel, concrete or timber). This includes the qualifications of inspectors (who should be registered Professional Engineers (PE) or equivalent), inspection procedures for all parts of the structure, including foundations, piers, beams, and road surfaces, recordkeeping and methods for assessing the strength of existing bridges. Inspection intervals must exceed two years.

5.2.3.3 Other Foreign and International Requirements

The paper, Operating and Maintenance Costs and File TGV High Speed Rail System [21], provides details of the inspection and maintenance procedure for the French TGV high-speed lines. The inspections performed are as follows:

- Weekly acceleration monitoring with vehicle-based instrumentation to provide an assessment of track geometry condition.
- Automated track geometry inspection at three-month intervals.
- Rail defect detector car inspections at one year after construction, and then after eight years, and every two years thereafter.
- Catenary inspection at six-month intervals.

5.2.4 Comparison and Assessment

This functional area is primarily concerned with inspection requirements to ensure that the guideway remains in a safe operating condition. Within the general subject of inspection, there are three sub-areas to be reviewed, as follows:

- Overall guideway structural condition.
- Condition of guideway-mounted equipment and fastenings.
- Guideway geometry

5.2.4.1 Guideway Structural Condition

Both AREA for railroads, and AASHTO for highways require regular condition inspections of bridge structures for any defects which may impair the ability of the bridge to carry traffic loads. AREA requires annual inspections, and AASHTO requires inspections every two years. Both AREA and AASHTO provide detailed instructions for inspections and recordkeeping procedures. Recordkeeping is important because the rate of deterioration of a structure is as important as its absolute condition. There is also a very extensive body of literature on structural inspection and repair procedures, e.g., see Reference 22. Many structural problems encountered in maglev structures have already been encountered in rail and highway bridge inspection and maintenance, and procedures will be available for addressing the problem, assuming traditional practices. However, if innovative structural applications are used, such as non-metallic nonconducting rebar or post tensioning rods, new procedures will be necessary. Both railroads and highway authorities are responsible for large populations of bridges of varying age and condition, and these inspection intervals are designed for such populations.

The AREA and AASHTO inspection guidelines are similar, and are applicable to maglev guideway structures. Given that maglev structures will be of new construction, the AREA one-year inspection interval would appear unnecessary, and the AASHTO two-year interval would be appropriate. Both requirements recommend more frequent inspections if a specific structure has a significant defect, which would also be an appropriate practice for maglev structures.

5.2.4.2 Condition of Guideway Mounted Equipment and Fastenings

The condition of guideway-mounted equipment and its fastenings is of particular concern with a maglev guideway. Loose or out-of-position guideway-mounted equipment could foul the levitation or guidance magnets, damaging the vehicle and possibly causing an accident. Equipment fastenings must be inspected regularly as required by RW MSB. The nearest comparable requirement in the US is the FRA requirement for regular visual inspection of railroad tracks, which must be performed weekly or twice weekly, depending on traffic levels. Such inspections are normally made from a high-rail vehicle travelling at slow speed.

A significant concern with maglev guideway inspections is the ability to detect defective guideway-mounted equipment and fastenings. RW MSB requires redundancy in fastenings so that a single failure will not result in loose or misplaced equipment. Redundancy is effective only if the defective fastening is located and replaced before a second failure occurs at the same location. Thus, the inspection process must be able to locate any such failure with a high degree of reliability. This means that the fastening system must be designed so that there is a visible indication of a failed fastener, and the inspection process must be able to check for this visible indication. Inspection intervals must be a direct function of the frequency of failures of fasteners or other potentially hazardous defects, and must be chosen to reduce the probability for a second failure occurring before the first failure is repaired. Failure frequency will be unknown until the maglev system is operational. Therefore, initial inspections should be very frequent; for example, daily, until enough data has been obtained to set an experience-based schedule.

5.2.4.3 Guideway Geometry

Guideway geometry deviations must be keep within acceptable limits. Geometry limits are related to maglev vehicle magnet air gap dimensions and vehicle response-to-geometry deviations at speeds up to the maximum operated, as discussed in Functional Area 208. Chapter 7 of the RW MSB, requires regular automated inspections of guideway geometry. Conventional high speed and other railroads conduct regular automated track geometry inspections at intervals of one to six months: Amtrak on the high-speed portions of the Northeast Corridor conducts track geometry inspections at one-month intervals. The accuracy of a guideway geometry measurement system must be consistent with the magnitude of guideway deviations that could adversely affect the vehicle. Discrete or short wavelength geometry defects in the maglev guidance or support surfaces must be measured with an accuracy on the order of 1 mm. This is a function of the suspension stiffness, not the momentum gap. The measurement system must also be capable of detecting the longest wavelength irregularities likely to affect the vehicle, which could be on the order of 150m (500 ft). Geometry data should be processed on-line to produce measures of guideway geometry quality which relate to maglev vehicle response-to-geometry conditions, and which permit the detection of potentially unsafe conditions. It is also essential to retain geometry records, and have the ability to compare the results of successive inspections to identify locations where rapid geometry degradation is occurring. Such locations can then be investigated on-site to determine the cause of such degradation and appropriate remedial actions.

5.2.5 Findings

Since deterioration or failure of the guideway structure can occur, components attached to the guideway are potential causes of accidents on a high speed maglev system. Well organized and carefully executed inspection procedures are required to ensure that the guideway remains in safe condition at all times.

Existing FRA regulations for railroad track inspection and maintenance contained in 49 CFR, Part 213 are intended to ensure that the track is in safe condition at all times, but are specific to conventional track and cannot be applied to a maglev guideway. New, maglev-specific requirements are needed.

Existing AASHTO and AREA requirements for the inspection of steel and concrete bridge structures are applicable to maglev-elevated guideway structures.

The German requirements in the RW MSB for the regular inspection of equipment attached to the guideway are an essential part of guideway inspection and should be applied in the U.S.

Therefore, for U.S. maglev system applications, consideration should be given to inspection and maintenance safety requirements in the following areas:

5.2.5.1 Overall Guideway Structural Inspections

Regular comprehensive inspections should be carried out of guideway structures, including foundations, piers and guideway beams, following established procedures as recommended by AREA or AASHTO. Records must be maintained of each inspection, organized so that instances of rapid change in structural conditions can be identified. Inspections should be performed one year after the initiation of service, and at two-year intervals thereafter.

5.2.5.2 Inspection of Guideway Attachments and Fastenings

Regular inspections should be performed of equipment attached to the guideway and the fastenings used for such attachments as specified in Chapter 6 of the RW MSB. The inspection procedures must be capable of detecting loose, missing, broken, or otherwise defective components. Inspection intervals must be based on known failure rates of attachments and fastenings to ensure that there is a very low probability of a hazardous failure. If the failure rate is unknown because the guideway is of a new design, then at least visual inspections must be carried out daily until failure data is available.

5.2.5.3 Guideway Geometry Inspection

Regular automated inspections of guideway geometry should be carried out. Parameters measured at the magnetic levitation support and guidance rails should include guideway vertical profile, lateral alignment, twist, and relative positions of the levitation and guidance rails. Measurement system accuracy must be sufficient to detect all geometry conditions likely to create a hazard, as described under Functional Area 208, Vehicle/Guideway Interaction. Measurement records should be maintained in a form that permits comparison of successive inspections to detect instances of rapid geometry change.

5.2.5.4 Miscellaneous

Additional inspections of all types should be made of the affected portions of the guideway before resuming operation after "unusual events." The following can be considered unusual events:

- Unintended loss of levitation or guidance of a maglev vehicle.

- A collision of any kind.

- Severe environmental events, such as a detectable earthquake or a hurricane (sustained winds over 60 knots).

- Any impact with a maglev guideway structure from an external object of any kind (e.g., highway vehicle).

5.2.6 Further Studies

Further study is needed of automated geometry inspection methods having the necessary degree of accuracy, and of the effectiveness of ways of indicating the presence of defective mounted equipment and fastenings on guideways.

5.3 FUNCTIONAL AREA 303 - GUIDEWAY SWITCH

5.3.1 Description of Functional Area

This functional area addresses the mechanical and structural aspects of the guideway switch, including the structure of the moveable portion of the guideway, the mechanism that produces movement, and the mechanical locking devices used to ensure that the switch is properly aligned with the adjacent fixed portions of the guideway.

Other functional areas closely related to this functional area are as follows:

Functional Area 208, Vehicle-Guideway Interaction, in which guideway geometry requirements for acceptable vehicle performance and maximum guideway-vehicle loads are discussed.

Functional Area 301, Guideway Design and Construction, discusses many guideway structural requirements that are equally applicable to guideway switch structures.

Functional Area 302, Guideway Inspection and Maintenance, discusses appropriate inspection procedures for maintaining the guideway and its attachments in good operating condition, and which are equally applicable to the guideway switch.

Functional Areas 401, Operations and Control System Design, and 402, Operations Control System Inspection and Maintenance discuss the control aspects of switch operation, particularly the systems-issuing commands to move the switch, and the sensors that monitor switch position and locking status.

5.3.2 Safety Baseline

As with the guideway itself, the switch structure has to be designed and constructed so that it can safely support all vehicle and externally applied loads without damage or excessive distortion. In addition, the mechanism used to move the switch must be safe and reliable, and reliable positive locking systems must be used to accurately position and hold the switch in line with the adjacent fixed guideway. In more detail, the switch system and structure should have the following characteristics.

- Both the moveable and fixed portions of switch structures must be designed and constructed so that they can safety support all vehicle and externally applied loads without damage or unacceptable distortion.

- The mechanism used to move the switch must be safe and reliable, and address safety concerns associated with any high pressure pneumatic or hydraulic systems.

- The locking mechanism used to hold the moveable part of the switch in line with the fixed guideway must provide a safe positive lock that cannot become loose or disengage in normal operations.

- Guideway geometry must be of a standard that permits safe vehicle operation at maximum design speeds for the switch.

5.3.3 Description of Existing Safety Requirements

All existing requirements identified and described under Functional Area 301, Guideway Design and Construction, are applicable also to this functional area. Further requirements specific to switch design and construction are listed in Table 5.10 and described below by origin under three headings: German, U.S., and other foreign and international.

5.3.3.1 German Requirements

The requirements in RW MSB, Chapters 5, 6, and 7 for the loadings, design and construction of the guideway, as discussed under Functional Area 301, Guideway Design and Construction, apply equally to the switch structure.

Chapter 8, Switch, of the RW MSB provides detailed requirements for a bending-beam type of switch, driven by either an electric or hydraulic actuation system. Other possible types of switches (for example, a moveable rigid section of guideway) are not covered. The requirements in Chapter 8 are primarily concerned with the actuation mechanism and the mechanism used to lock the bending beam in line with the fixed portion of the guideway.

Section 2 of Chapter 8 specifies general safety requirements for the switch. Movement of a maglev vehicle over the switch is considered safe if the following conditions are satisfied:

- The switch is safely closed (i.e., positioned) at all "setting points" along the length of the switch.

- The end of the moveable part of the switch is be properly aligned with the adjacent fixed guideway in the vertical and horizontal directions, within permissible tolerances for alignment of magnetic levitation and guidance reaction rails (termed "functional surfaces" in RW MSB).

- The switch will remain locked and unanticipated movements prevented even in the case of a breakdown of the switch locking or actuating mechanisms.

- Safeguards are provided against excessive loads being applied to the switch structure as a result of any fault in the electrical or hydraulic switch actuating mechanism.

- Components containing gas or hydraulic fluid under pressure meet the relevant pressure vessel regulations of TRB and TRGL.

Chapter 8 of the RW MSB also requires that if the switch is held in position by a non-positive system (such as pressure in a hydraulic cylinder), then the lock must convert to a positive lock in case of a fault such as a hydraulic leak. A hydraulic check (non-return) valve

TABLE 5-10. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 303 - GUIDEWAY SWITCH

Issuing Organization	Title and/or Reference Number	Part Chapter, etc.	Title Complete Document and Part	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 5 Chapter 6 Chapter 7 Chapter 8	Load Assumptions Stability Analysis Design Production and Quality Assurance of Mechanical Structure Switch	Maglev
German Government	Draft MBO	Section 2.1.7	Operating Installations, Moveable Guideway Elements	Maglev
German Government	EBO	Section 2, Paragraph 14	Railroad Installations; Signals and Switches	Railroad
VDE	0831 Electrical Equipment for Railway Signalling			Railroad
DIN	24343 Fluid Technology: Hydraulics Servicing and Inspection			General Industrial
DIN	24346 Hydraulic Systems: General Rules for Applications			General Industrial
TRB (German Government Agency)	Technical Regulations for Pressure Vessels			General Industrial
TRGL	Technical Regulations for High-Pressure Gas Lines			General Industrial

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 5-10. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 303 - GUIDEWAY SWITCH (cont.)

Issuing Organization	Title and/or Reference Number	Part Chapter, etc.	Title Complete Document and Part	Applicability or Intent
FRA	49 CFR, Transportation	Parts 213.133 to 213.143 Part 236.312 Parts 236.314 to 236.3334	Turnout Requirements Locking of Moveable Bridges Switch Locking Requirements	Railroad Railroad Railroad
AREA	Manual for Railway Engineering	Chapter 5 Chapter 15, Part 6 - Chapter 27, Section 2.4	Track Moveable Bridges Portfolio of Plans Hydraulic Systems	Railroad
ASME	Boiler and Pressure Vessel Code	Section VIII	Pressure Vessels	General Industrial
SAE	Handbook			General and Automotive
NFPA*	Recommendations			General Industrial

* National Fluid Power Association

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

can be used to meet this requirement, or a second independent locking mechanism may be provided. In any case, an independent mechanical lock must be provided between the fixed guideway and the end of the moveable switch beam.

Other requirements in Chapter 8 of the RW MSB are concerned with switch monitoring and control, and are discussed under Functional Area 401, Operations Control System Design.

Section 2.1.7 of the draft MBO provides requirements for moveable guideway elements such as switches. The requirements are that switches must be safeguarded against an unintended change in position, and that they must be equipped with sensors to determine that the switch is properly aligned and trains can operate over it without danger.

Paragraph 14 of the EBO Signals and Switches requires that the mechanical locking mechanisms on moveable bridges must be interlocked with signals, such that traffic can proceed only when the bridge is secured.

Several DIN and other requirements are referenced in the RW MSB as applying to switch systems, as follows:

- VDE 0831, Electrical Equipment for Railway Signalling, Section 7.3 specifies that all point (i.e., switch) mechanisms shall be capable of being locked. Section 5.3 requires that the switch motors be equipped with mechanical overload protection such as a slipping clutch.

- DIN 24343, Fluid Technology, Hydraulics Servicing and Inspection provides checklists for servicing and inspecting all components of a hydraulic power system including pumps, valves, transmission pipes, accumulators and controls.

- DIN 24346, Hydraulic Systems, General Rules for Application provides design guidance for such systems. The form of this DIN is of a model specification for purchase of a hydraulic system or components, and covers the general requirements of good design and assembly of such systems.

Two government pressure-vessel regulations are referenced in the RW MSB as being applicable to any pressure vessels (such as hydraulic accumulators) used in the switch actuating mechanism. These are as follows:

- The TRB series, Technical Regulations for Pressure Vessels includes numerous requirements for design, materials, manufacture, testing and installation of pressure vessels of all types. Qualification tests for manufacturers are included.

- The TRGL series, Technical Regulations for High Pressure Gas Pipes covers the design, manufacture, installation and testing of pipes, couplings and associated components.

5.3.3.2 U.S. Requirements

The FRA track safety standards contained in 49 CFR, Parts 213.133 to 213.143 specify dimensional and other requirements for conventional railroad turnouts. These requirements specify that turnout components shall be properly secured in place, with all fastenings tight and undamaged.

Part 236 of the FRA regulations covers signal and train control devices, including those associated with switches and moveable bridges as follows:

- Part 236.312 specifies requirements for the locking of moveable bridges. Bridge locking members must be interlocked with signals so that the signal cannot display a proceed aspect unless the moveable part of the bridge is properly aligned and locked. Rails on the moveable portion of the bridge and the fixed abutments must be aligned to within 9 mm (3/8 inch) laterally and horizontally.

- Part 236.314 requires that all hand-operated switches within interlocking limits must be equipped with an electric lock.

- Parts 236.327, 328, 329, 330, and 334 all specify various mechanical details of the locking mechanisms of conventional railroad switches to ensure that trains can safely operate over the switch.

The AREA Manual for Railway Engineering, Portfolio of Plans provides detailed requirements for the design and construction of conventional railroad turnouts.

Chapter 5 of the AREA Manual specifies requirements for track construction, including some general requirements for turnouts.

Chapter 15 of the AREA Manual, provides requirements for moveable bridges, which are the closest analogy to the maglev switch found in conventional railroad systems. The principal requirements of the bridge locking and interlocking systems are:

- Train movements can only be permitted when the bridge is properly locked in position.

- The proper sequence of events during movement of the bridge must be ensured. For example, attempts to move the bridge before train movements are complete and locks are released must be prevented.

- A stand-by power source is required.

- Limit switches and brakes or other devices must be provided to prevent excessive force from being applied to bridges in the fully open or fully closed positions.

There is a large body of U.S. requirements applicable to hydraulic power systems that may be used to operate a maglev switch. These are identified below:

- The ASME Boiler and Pressure Vessel Code, Section VIII specifies requirements for pressure vessels.
- The AREA Manual, Chapter 27, Section 2.4 provides general requirements for hydraulic systems incorporated into railroad maintenance-of-way equipment.
- The Society of Automotive Engineers (SAE) Handbook contains numerous engineering specifications for components of hydraulic systems, such as hoses, couplings, cylinders, pumps, accumulators and piping.
- The National Fluid Power Association (NFPA) makes numerous recommendations regarding the design, installation, and maintenance of hydraulic systems.

5.3.4 Comparison and Assessment

With regard to the structure of both the moveable and fixed parts of the switch, the load cases and design and construction recommendations developed in the discussion of Functional Area 301 are equally applicable to switch structures.

For the moveable portion of the switch, loads produced by the bending action of the guideway beam (if this design is adopted) should be added to the other loads. This forced deformation load is identified in the structural loads listed in Table 5-3. A particular concern with the bending switch structure is to ensure that it is not subject to excessive loads as a result of a lack of synchronization among the multiple actuators used to move the switch. The actuators need to be equipped with an overload protection mechanism, so that the force exerted by each actuator (whether hydraulic or electric) cannot exceed a pre-determined level. This requirement is similar to the overload protection required by the AREA for moveable railroad bridges. If an overload protection system is lacking, there is a danger of the actuating forces damaging or distorting the moveable portion of the switch, and creating a hazard.

Both the RW MSB and FRA and AREA requirements for conventional railroad track and turnouts include requirements for the adequate locking of the switch in the operating position. There is general agreement regarding the intent of these requirements that switches or turnouts shall be adequately locked before vehicle movements are permitted, and that locking system faults cannot lead to an undesired release of the lock. Mechanical arrangements and dimensional requirements naturally differ between the maglev guideway and conventional railroad track.

In the case of the maglev switch, the locking mechanism must ensure that the vertical and lateral alignment where the moveable portion of the switch connects to the fixed guideway is within acceptable limits and can be safely negotiated by the vehicle.

U.S. practice in conventional railroad turnouts is to use electro-mechanical locks. Past experience with hydraulically activated locks has been unsatisfactory and they are not used, although such locks are not specifically prohibited. Hydraulic railroad switch locks and switch motors are used in Europe.

Switch locks used to hold the end of the moveable portion of the switch in line with the adjacent fixed guideway, and those used along the length of the moveable portion to maintain the correct guideway curvature should be accurate, reliable, and sufficiently strong to resist any forces tending to cause undesired movement of the switch. A positive mechanical lock is required, arranged such that there is no possibility of the lock becoming disengaged in any single failure condition of switch components, or under the normal loads and vibration levels produced by the passage of vehicles over the switch. In particular, the lock should stay in position in the event of loss of hydraulic pressure, including in the cylinder itself. The RW MSB allows hydraulically locked cylinders to be used to hold the switch in operating condition, but this practice is vulnerable to certain kinds of failure (e.g., of a piston seal).

The RW MSB references a number of DINs and other requirements for hydraulic systems used to activate the switch. The DINs describing hydraulic systems appear to be general in nature, describing the elements of good practice without specifying particular devices, materials, and operating parameters (such as working pressure). These requirements appear to be representative of good practice in general, and would be unlikely to conflict with any U.S. requirement.

The TRB pressure-vessel requirements referenced in RW MSB are German government regulations, and may differ from U.S. requirements in some respects. Since there are likely to be legal federal or local government requirements relating to pressure-vessels in the U.S. (such as requiring pressure vessels to comply with the ASME code), and that existing U.S. codes include certification of manufacturers, it will be desirable to use only pressure vessels manufactured to U.S. requirements in any maglev switch mechanism.

5.3.5 Findings

Defects in the design of the guideway switch structures and mechanisms have the potential of producing an improperly aligned or distorted guideway, leading to an accident. Safety requirements for the guideway switch are essential to ensure safety.

The intent of the existing FRA regulation for railroad turnouts and moveable bridges and the railroad industry requirements in the AREA manual are applicable to maglev guideway switches. However, the mechanical equipment used in a maglev guideway switch is very different from that used for a conventional railroad. Maglev-specific switch safety requirements, such as those contained in the RW MSB, are needed to adapt the intent of existing requirements to the maglev system.

For U.S. maglev system applications, consideration should be given to the following switch safety requirements.

5.3.5.1 Switch Structural Load Cases, Design and Construction

Guideway switch structures should comply with all requirements developed for Functional Area 301, Guideway Design and Construction, and also be able to satisfactorily sustain any loads generated by the switch operating mechanism and in bending the guideway beam.

5.3.5.2 Switch Operating Mechanism

System design and components of hydraulic, pneumatic or electro-mechanical switch operating mechanisms should conform to generally accepted technical requirements such as DINS and the NFPA in the U.S. The requirements may be either of U.S. or German origin, with the exception that any pressure vessels used must comply with applicable U.S. regulations. Hydraulic, pneumatic, or electromechanical actuators used to move the switch should be equipped with an overload protection mechanism so that individual actuators cannot exert a force that could accidently damage or distort the moveable portion of the guideway.

5.3.5.3 Switch Locking Mechanism

A positive mechanical locking system must be provided to hold the end of the switch in line with the fixed portion of the guideway, and to maintain the correct position of the moveable portion of the guideway along its length. The accuracy of locking must be consistent with the overall guideway geometry requirements as specified in the recommendations in Functional Area 301, Guideway Design and Construction, and Functional Area 208, Vehicle-Guideway Interaction.

The locking system should be arranged such that the locks will stay in position without any externally applied force or power, cannot vibrate loose in any way with the passage of vehicles, and can resist normal operational loads tending to move the switch.

5.3.6 Further Studies

The safety of a bending beam switch depends on the adequacy of design and performance of the structure itself and several electronic, electrical, hydraulic, and mechanical systems which move and lock the switch. Only a preliminary review has been possible in this study, and more detailed review is suggested to provide better assurance of the safety of different maglev switch systems.

5.4 FUNCTIONAL AREA 304 - RIGHT-OF-WAY SECURITY

5.4.1 Description of Functional Area

Right-of-way (R-O-W) security is concerned with minimizing the risk of foreign objects intruding on the guideway, or into the clearance needed to safely operate the maglev vehicle. Also included are measures to minimize risk from animals or unauthorized persons on the guideway or other maglev facilities, or any object being dropped, thrown or propelled at a train which could threaten the safety of the vehicle or its occupants. A further concern is minimizing risks from events that could damage or distort the guideway, such as impact by vehicles encroaching from an adjacent guideway or right-of-way, or severe weather or an earthquake. Both accidental events and malicious acts are included. This functional area is concerned only with risks that result from events external to the guideway and vehicle, not malfunctions of the vehicle or guideway itself, or damage-resistance aspects of vehicle or guideway design. Measures to detect and/or prevent the occurrence of these events are included.

Other functional areas address issues related to R-O-W security. These are:

Functional Area 201, Overall Vehicle and Cab Structural Integrity, and 202, On-Board Operator and Crew Compartments, discuss a maglev vehicle's ability to survive a collision with an obstruction on, adjacent to, or in the air above the guideway.

Functional Areas 401, Signalling and Train Control Design, and 403, Communications, both systems which have to interface with, and must respond to, a signal from any automatic system used to detect violations of R-O-W security.

Functional Area 602, Operating Rules and Practices, where actions to be taken in the event of a guideway obstruction or other security threat may be specified.

5.4.2 Safety Baseline

The guideway must be protected from external events that could lead to an obstruction on or near the guideway, or damage to the guideway or system facilities. Specific system features which may be needed to provide this protection are:

- Physical barriers, such as fences, to limit the access of unauthorized persons to the guideway or other maglev system facilities. Barriers to discourage vandals from dropping or throwing objects onto the guideway, or to prevent such objects from reaching the guideway are included.

- Barriers to protect against encroachment or guideway damage by out-of-control vehicles from an adjacent transportation R-O-W, such as a highway or conventional railroad that is sharing a transportation corridor with the maglev system, or crossing over or under a maglev guideway.

- Detection systems to warn of obstructions on the guideway, encroachments onto the maglev R-O-W or vehicle clearance, and unauthorized entry into maglev facilities.

- Detection and warning systems for hazards due to extreme weather or earthquakes. Weather events could include high winds, snow accumulation, or flooding.

5.4.3 Description of Existing Safety Requirements

Existing safety requirements concerned with R-O-W security are listed in Table 5-11 and described below by origin under three headings, Germany, U.S., and other foreign and international.

5.4.3.1 German Requirements

Chapter 1 of the RW MSB, Section 4.1 requires precautions against environmental disruptions to maglev operations. In particular, RW MSB requires that sensors should be installed to detect guideway damage due to earthquake or sudden foundation subsidence.

There are no other specific requirements for R-O-W security described in the RW MSB, but statements in Chapter 9, Operational Control System imply a need for R-O-W security precautions, as follows:

- Section 1.2 states that the goal of guideway safety is to confirm that the guideway is free of obstruction, and precautions have been taken to ensure that no conceivable obstructions will get onto the guideway.

- Section 1.5 states that special operational modes will be needed in the case of special conditions such as maintenance or construction work on or near the guideway.

- Paragraph 2.2.2 states that a guideway element may be made operationally ready for a run only if:

  - it is confirmed that no technical installation has intruded within the wayside structure clearance.

  - it is not blocked for a reason other than as described above, or by other vehicles. Blockages could include obstructions on the guideway as a result of accidental events or malicious acts.

A similar requirement to the above is found in Section 2.2.2.2 of Chapter 7, Design, Production and Quality Assurance of Mechanical Structures, of the RW MSB which requires that measures to protect persons and property in the guideway area must be provided if necessary, implying that the guideway must be adequately segregated from adjacent activities.

TABLE 5-11. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 304 - RIGHT-OF-WAY SECURITY

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1, Section 4.1 Chapter 7 Chapter 9	Environmental Requirements Design Production and Quality Assurance of Mechanical Structures Operation Control Equipment	Maglev
German Government	Draft MBO	Section 1 Section 4	General Requirements of Railroad Operation	Maglev
German Government	EBO	Section 6	Safety and Order in Railroad Installation	Railroad
FRA	49 CFR, Transportation	213.37	Track Safety, Roadbed Vegetation	Railroad
APTA	Guidelines for Rapid Transit Facilities Design	Section 2.1	Way and Structures - Security	Rail Mass Transit
UIC	734 Adaptation of Safety Installations to High-Speed Requirements	Appendix A Section 6	Protection of Unexpected Obstacles	Railroad
AREA	Manual for Railway Engineering	Chapter 1	Roadway and Ballast, Part 6, Fencing	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

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

The EBO prohibits unauthorized persons from operating or tampering with railroad installations, or any other activity which might disrupt or endanger operations. Railroad police are given the responsibility to guard against such activities. Specific security precautions are not required.

5.4.3.2 U.S. Requirements

The FRA regulation contained in 49 CFR, Part 213.37 requires that vegetation on or immediately adjacent to a railroad roadbed must be controlled so that it does not become a fire hazard, obstruct visibility, or otherwise interfere with railroad operations.

The AREA Manual for Railway Engineering Chapter 1, Part 6, Section 6.5 provides a specification for R-O-W fence design. No requirements regarding where fences should be used are provided, except in the case of snow-fences. AREA specification fences are primarily designed to prevent animals straying onto the R-O-W.

The APTA Guidelines for Design of Rapid Transit Facilities (Section 2.1.1) describes security of facilities and R-O-W security provisions as follows:

- A pedestrian barrier or equivalent throughout should be provided having a minimum total height of 2.4 m (8 ft). Where possible, the top 0.3 m (1 ft) should be of barbed wire or an equivalent deterrent.
- Signs warning of electrical hazard should be provided at 150 m (500 ft) intervals, where applicable.
- Where the R-O-W is crossed by a street pedestrian walkway, barriers should effectively prevent objects from being dropped onto the R-O-W or passing transit cars.
- Vehicle barriers must be provided where necessary to prevent unauthorized access or accidental encroachment. Acceptable barriers include highway guard rails, barrier curbs, structural walls, or earth embankments. The barriers must be "collision-proof" (original wording).
- Intrusion alarms or surveillance systems are recommended to limit unauthorized access to system facilities such as traction power substations, and train control and communications facilities.

In urban areas in the U.S., highway and pedestrian bridges crossing another highway are customarily provided with high fences, or (in the case of footbridges) are fully enclosed to reduce the risk of objects being thrown or dropped on traffic passing underneath. Intercity and commuter railroads also install security fencing in urban areas where a high risk of vandalism or theft is judged to exist.

5.4.3.3 Foreign and International Requirements

UIC Code 738, Adaptation of Safety Installations to High Speed Requirements, Appendix A, Section 6 requires the installation of communication systems to enable a warning regarding any obstacle on the track to be sent instantly to the train control center, leading to stop commands being sent to trains approaching the obstacle. Access to these communication systems must be available to train crew and staff on the ground who may discover an obstacle. The normal train radios and manually operated wayside alarms or telephones are used to meet this requirement. Automatic obstacle detection systems (such as those to detect a road vehicle falling from an over-line bridge) must be directly connected to the signal system.

5.4.4 Comparison and Assessment

The most complete requirements identified for R-O-W security are those given in the APTA guidelines, Design of Rail Rapid Transit Facilities. APTA requires 2.4 m (8 ft) high fencing or equivalent throughout the R-O-W, and barriers to prevent objects from being dropped onto the track or trains from pedestrian overbridges. To prevent unauthorized entry, similar fences, plus intrusion alarms or surveillance systems are recommended at facilities such as power supply substations. Finally, vehicular barriers should be provided where necessary to prevent accidental encroachment or unauthorized access. Suitable locked gates are required for access and egress to transit system property, both for normal inspection and maintenance, and in an emergency. People retreating from a dangerous situation must be able to escape, for example at an emergency stopping place, and emergency services must have access.

The AREA specification for fencing appears to be designed for containing livestock, but would not be adequate to prevent trespass, where such protection is required.

Although not embodied in published requirements, a number of R-O-W security practices of relevance to maglev systems have been adopted by foreign high-speed wheel-on-rail systems, and U.S. rail mass transit systems to protect the R-O-W, as follows:

- High-speed rail systems in France and Japan are fenced throughout.

- Detectors are used on certain U.S. rail mass transit systems (e.g., in Washington and Atlanta) to warn of encroachments onto the R-O-W from adjacent highways or railroads, or to detect an impact with aerial structures. The most common kind of detector is a fragile wire. Breakage of the wire produces an encroachment alarm. A similar detector system is used on French Railways TGV high speed lines to provide an alarm when road vehicles fall from an overline bridge onto the track of a high-speed line, and on conventional U.S. railroads as a precaution against track obstruction by falling rocks. Vibration detectors have been used for the detection of impacts on rail transit system elevated guideway structures, but reliability problems have limited the value of such installations.

- The Japanese Shinkansen line is equipped with detector systems for high winds, excessive snow accumulation, and earthquakes. Information from these detectors is displayed in the central train control installations for action by train control staff. Similar earthquake detection systems are used on the San Francisco Bay Area Rapid Transit System. High wind detectors are used by U.S. freight railroads in some locations.

The UIC Code 738 requirement for the direct communication of an obstruction alarm to the signal and train control system, whether the obstruction is detected visually by train crew or infrastructure maintenance personnel or automatically, would be a valuable feature of any comprehensive R-O-W security system.

However, a potential problem with R-O-W obstruction or intrusion alarms, especially those having an automatic link with signalling and train control systems, is the potential for errors and false alarms. Experience on some rail transit systems indicate that false alarms disrupt operations at best, and if too frequent, will render the warning system useless. Thus, systems must be very reliable, and reliability analysis of the types discussed in Functional Area 103 is required to confirm that the warning system provides the desired performance.

The general question of the safety issues raised by operation of high-speed rail and maglev with other modes in a shared transportation corridor is the subject of a separate study [23]. This study provides further information on R-O-W security and intrusion threats, and ways of protecting against these threats. Other related research has also been carried out under the FRA maglev research programs [24].

5.4.5 Findings

There is a significant potential risk of accidents on a maglev system due to obstructions and intrusions on or adjacent to the guideway, or accident damage to guideway structures. Adequate precautions are needed to control these risks, either by using barriers to prevent intrusions, or by installing detection systems to provide reliable warning of intrusion.

Apart from the existing FRA requirement for controlling vegetation adjacent to the R-O-W, FRA regulations do not exist regarding R-O-W security. The German requirements (RW MSB and draft MBO) contain a general requirement to protect the maglev R-O-W against obstructions and damage but do not provide any specific guidance. The most complete existing requirements for R-O-W security are found in the APTA rail transit guidelines, which can be adapted for a high speed maglev system, and supplemented by adaptations of other requirements as described below. Further discussions of obstruction avoidance and detection is provided in the report on collision safety [9].

For U.S. maglev system applications, consideration should be given to the following R-O-W security requirements.

- The guideway and safety-critical fixed installations such as switch mechanisms, power supply and control substations, and communications facilities should be protected by a fence of at least 2.4 m (8 ft) total height or equivalent, wherever the guideway passes through an urban area, or other locations where there is a significant risk of trespass and vandalism. Fencing is not needed where the height of an elevated guideway above ground is sufficient to render the guideway inaccessible.

- Where vandalism is not a concern, fencing should conform to the AREA requirements.

- Means for emergency access and egress through guideway security fencing should be provided, as required in NFPA 130.

- Vehicle and pedestrian bridges over the guideway should have an 8 ft high fence, plus barriers to prevent or catch objects being thrown or dropped onto the guideway. Suitable crash barriers such as conventional highway bridge-rails should be provided to minimize the risk of an out-of-control road vehicle falling onto the guideway, and an automatic system should be provided to detect when a vehicle or other heavy object is not contained by the barriers, and falls on the guideway.

- Automated detection systems for earthquakes, potentially dangerous weather events (heavy snow accumulation, high wind, flooding), and impacts on guideway structures must be provided where necessary. Information from these detectors should be displayed in the system control center. Detector systems should be subject to reliability analysis as discussed in Functional Area 103, to ensure that false alarm incidence is within acceptable limits.

- Barriers and encroachment or impact detection systems may be required where the maglev guideway shares a corridor with another mode of transportation. Further information on this subject is provided in another study performed for the FRA [23].

6. OPERATIONS CONTROL, COMMUNICATIONS, AND ELECTRIC POWER SYSTEMS

6.1 FUNCTIONAL AREA 401 - OPERATIONS CONTROL SYSTEM DESIGN

6.1.1 Description of Functional Area

This functional area addresses the safety requirements for maglev operations control systems. The systems that perform the principal safety-critical functions of an operations control system are covered: the guideway status monitoring systems (including vehicle location), an interlocking system to prevent conflicting or otherwise unsafe movements, and a safe speed enforcement system. Other subjects in this functional area include the interfaces with related maglev system components such as switch control and monitoring systems, power controls, and communication systems.

The specific safety requirements for microprocessor software and hardware used in operations control systems are not addressed under this heading, but are reviewed in Functional Area 105, Computer Safety for Vehicle and Operations Control Systems.

Other functional areas closely related to or having an interface with this functional area are as follows:

Functional Area 101, System Safety, addresses the functions of the train operations control systems within the overall system safety concept.

Functional Area 103, Reliability and Availability, discusses definitions and system performance requirements for safety-critical systems.

Functional Area 207, Brake Installation and Performance, addresses the braking systems needed to ensure that a maglev vehicle or train can respond to train control instructions to reduce speed.

Functional Area 303, Guideway Switch, addresses the non-control aspects of maglev switch systems.

Functional Area 402, Operations Control System Inspection and Maintenance, covers inspection and maintenance procedures and practices needed to keep a train control system in good working order.

Functional Area 403, Communications, includes the safety-critical communication links between the components of an operations control system.

6.1.2. Safety Baseline

Both the overall system architecture of an operations control system and the design and performance of individual subsystems and components must be such that a very high level of safety performance is maintained. Performance in this context means a very low incidence of "unsafe" defects which could potentially permit, or fail to prevent, conflicting or excessive speed maglev vehicle movements. The performance level should be comparable to that currently achieved with automated guided transit systems, or with the Automatic Train Protection (ATP) systems used on high speed wheel-on-rail railroad systems.

The safety requirements for the three main elements of an operations control system to meet this overall goal are as follows:

- The vehicle location and guideway status system must reliably detect the location of all vehicles on the system and any guideway condition such as the switch position or the presence of a significant obstruction that would affect the availability of the guideway for vehicle movements. This information must be conveyed reliably to the interlocking logic unit.

  In particular, the vehicle location detection subsystem must be designed in such a manner that the real time location of a train cannot be "lost," or misinterpreted by the interlocking system logic. Maglev vehicles cannot use the closed loop technology of conventional railroad track circuitry. The detection system must be of a fail-safe or fault-tolerant design that can ensure that train location is not lost due to a malfunction of the train detection equipment or vital communications link.

- The interlocking logic unit must reliably perform the function of ensuring that only safe vehicle movements with respect to location and operating speed are permitted, based on vehicle location and guideway status.

- The safe speed enforcement system must reliably ensure that speed is controlled so that the maglev vehicle remains in compliance with the location and operating speed authority issued by the interlocking logic unit. Speed enforcement and monitoring must guarantee adequate vehicle separation relative to safe braking and stopping distance parameters.

Performance requirements for each of the elements should be defined, either by comparison with a system that is known to perform satisfactorily through sufficient operational experience, or by a quantitative definition of maximum acceptable unsafe failure rate.

6.1.3 Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6-1 and are described under three headings: German, United States, and other foreign and international.

Within each heading, the safety requirements are discussed by the three major operations control system functions - vehicle location and guideway status, interlocking units, and safe speed enforcement.

6.1.3.1 German Requirements

German maglev operations control system requirements as defined in Chapters 1, 4, and 9 of the RW MSB are designed for the control system structure used on the Transrapid maglev system. This control system has the following principal characteristics:

- Normal service vehicle movements are controlled from the operations control center, from which propulsion and braking commands are issued to the wayside power control substations and the long stator linear motor. An interlocking system ensures that only safe vehicle movements and speeds are permitted. Permitted speed and location data are also transmitted to the vehicle.

- Vehicle location is determined on the vehicle by reading passive guideway-mounted transponders. Location information is transmitted from the vehicle to the interlocking system, and is also compared on-board with the authorized speed and location information transmitted from the interlocking system.

- The on-board control system initiates "safe programmed braking" (defined below) if any one of a number of potentially unsafe events occurs, including:

  - Loss of the vehicle to control center communication links
  - Loss of redundancy in the on-board vehicle location system
  - Vehicle speed outside the permitted speed band at any location
  - Defined malfunctions in various safety-critical on-board systems such as the levitation and guidance magnets

Specific technical requirements for German maglev systems are contained in Chapters 1, 4, 8, and 9 of the RW MSB.

Chapter 1, System Properties, discusses overall maglev system safety, specifically focusing on the "safe hover" and "safe programmed braking" requirements. The safe hover concept involves using appropriate design techniques to ensure that the magnetic levitation and guidance system is highly reliable, with a very low risk of a failure that would prevent vehicle movement. Use of a safe hover approach prevents the imposition of unacceptable loads on the guideway structure due to an unintended set-down at high speed. Safe programmed braking is used in combination with safe hover to ensure that in an emergency, vehicle braking can be controlled so as to stop the vehicle at a safe stopping point. Safe

TABLE 6-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 401 - OPERATIONS CONTROL SYSTEM DESIGN

Issuing Organization	Title and or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1 Chapter 4 Chapter 8 Chapter 9	System Properties On-Board Control System Switch Operational Control Equipment	Maglev
German Government	Draft MBO EBO	Section 2.4 Section 4.4 Paragraphs 14, 15, 16, 39	Railway Safety Systems Speed Switches, Signals, Train Control, and Train Speed	Maglev Railroad
German Federal Railways	MUe 8004 Principles of Technical Approval of Signalling and Communication Engineering			Railroad •
DIN VDE	0831 Electrical Equipment for Railway Signalling			Railroad
FRA	49 CFR, Transportation	Part 236	Regulations for the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems	Railroad
AAR	Signal Manual of Recommended Practice		Communication Signals	Railroad
UIC Code	512 - Rolling Stock: Conditions to be Fulfilled in Order to Avoid Difficulties in Operation of Track Circuits and Treadles			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 6-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 401 - OPERATIONS CONTROL SYSTEM DESIGN (cont.)

Issuing Organization	Title and or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
UIC Code	641 - Conditions to be Fulfilled by Automatic Vigilance Devices Used in International Traffic			Railroad
	734 - Adaptation of Safety Installation to High Speed Requirements			
	736 - Signalling Relays			
	737-2 - Measures to be Taken for Improving Sensitivity in the Shunting of Track Circuits			
	738 - Processing and Transmission of Safety Information			
	755 - Laying of Telecommunications and Signalling Cables and their Protection against Mechanical Damage			
	780 - Remote Control of Signalling Installations			
	781 - Transmission Systems and Methods of Remote Control for Signalling Installations			

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

stopping points provide for emergency evacuation of maglev vehicle occupants from a vehicle traveling on an elevated guideway. The operations control system must be designed to ensure that safe programmed braking can be carried out at any time during a maglev vehicle movement. The vehicle must be provided continuously with location and speed data, and the on-board control computer must be programmed to control braking to the next available stopping point.

Chapter 4 of the RW MSB, On-Board Control System, specifies the functions of the on-board safety computer. High security data transmission methods must be used for safety-critical data provided to the computers, such as location, speed, and levitation system status. The vehicle location system must have three or more sensors and the on-board computer system must initiate safe programmed braking if only one operative location sensor is available.

Chapter 8 of the RW MSB, Switch, provides requirements for the safety of the switching system, including all structures, mechanisms and controls of the equipment required to provide a switch in the guideway system.

Sections 3 and 5 of Chapter 8 require that fail-safe reporting of switch useability must be provided by means of limit switches or an equivalent system that can detect proper closure of the switch within guideway geometrical tolerances. Additionally, the switch mechanism must be prevented from initiating switch movement once vehicle movements over the switch have been authorized until such movements are complete. Additionally, times to change switch position must be monitored. Vehicle movements must be stopped if excessive time is taken, and the apparent problem investigated.

Chapter 9 of the RW MSB, Operational Control Equipment, provides safety requirements for construction, equipment, and function of the operational control system. The guideway is defined to be safe and available for vehicle movements if all guideway elements are free of detectable obstacles, and precautions have been taken such that no conceivable objects will get onto the guideway.

The vehicle protection systems ensure that vehicle speed is maintained between maximum and minimum levels, based upon guideway conditions, and the speed needed to reach the next safe stopping point under the most unfavorable conditions. Control of vehicle speed, including braking, is provided by the operations control system, with back-up from the on-board safety computer and braking system.

The overall operations control system comprises an operational control center and wayside and vehicle-borne decentralized control elements. The following must be provided for by the control element:

- Wayside - status of all guideway elements, including occupancy and breakdown, and position and lock status of any movable guideway elements such as switches.
- Vehicle - the status of each vehicle including speed, current location, operational safety elements that includes running status, breakdown reports, and general operational readiness.

The RW MSB refers to VDE 0831, VDE 0801, MWE 8004, and UIC Code 738 for further operational control systems requirements as described below.

The draft MBO contains the following requirements:

- Paragraph 1.7 requires that vehicle speed must be controlled so that vehicles can reach auxiliary (i.e., safe) stopping points in all cases.

- Paragraph 2.1 requires that movable guideway elements (such as switches), must feature elements that safely report whether trains can operate over them without danger.

- Paragraph 2.4 requires that vehicle-safety installations must be reliable and fail-safe.

Paragraph 4.3, Requirements for Railroad Operation, Running Safety states that vehicle runs may be allowed if the guideway is properly set and clear of other vehicle occupation or movement. At speeds over 50 km/h (30 mph), the guideway status must be technically safeguarded until all vehicle movement is completed. The speed must be technically monitored and automatic braking action initiated if vehicle operation does not react to vehicle control instructions.

Paragraph 14 of the EBO provides requirements for conventional railway signalling systems. Where speeds exceed 100 km/h (62 mph), a train control system that will automatically stop the train must be used. An ATC system, or a "deadman" control at the operator's position meets this requirement.

VDE 0831; Electrical Equipment for Railway Signaling provides relevant requirements for high speed rail systems, and includes items similar to current regulations of CFR 49, Parts 233, 235 and 236 and the recommendations of the AAR Manual. VDE 0831 contains numerous detailed requirements for individual materials and components used in conventional railway signalling systems such as cable, signal lamps, insulation, power suppliers, and switch machines. Signal system requirements are provided in Section 6 of VDE 0831, and include the following:

- No single fault shall lead to an impermissible fault condition - one which could endanger railway operation.

- Single faults shall, if possible, be indicated at once, or lead to a fail-safe "locked" condition of affected parts of the signalling system. Specific faults to be taken into account are listed.

MUe 8004; Principles for Technical Approval in Signaling and Communication Engineering provides the requirements used by the German Federal Railway (DB) for system design materials, components, installation, and testing of railway signalling systems.

MUe 8004 is structured as a specification document for the purchase of signal systems and components, and includes the following:

- The approval process to qualify equipment from an individual supplier for installation on the railway.

- General and detailed requirements for fail-safe operation of vital (safety-critical) systems.

- Definitions of terms, including signal system components and failure categories.

- Requirements for individual system components and features such as cable insulation, signal lamps, and relays.

- Requirements for conventional relay-based interlocking systems.

Much of the content of MUe 8004 is identical to VDE 0831, referenced as DIN 57831 in the available copy of MUe 8004.

Chapters 4 and 6 of MUe 8004 provide requirements for programmable computer systems used for safety-critical functions, in signal systems, and are discussed under Functional Area 105, Computer Safety for Vehicle and Operations Control Systems.

6.1.3.2 U.S. Requirements

The FRA regulations contained in 49 CFR, Part 236 apply to all railroads that operate on standard gauge track and are part of the general railroad system in the United States. The regulations do not apply to fully segregated rail mass transit systems. These regulations do not currently contain requirements for electronic components or microprocessor-based systems, except by equivalence with relay-based systems where applicable.

Key requirements of 49 CFR, Part 236 include the following:

- Fail-safe vital circuit methods should be used for all vital circuits, whereby no single probable failure can result in an unsafe condition controlling train movement.

- Methods of train detection and route integrity assurance are covered, including all vital mechanical system monitoring that provides for route integrity.

- Test requirements and certain operational requirements of train control systems and components are provided.

The AAR Communications and Signals (C&S) Division publishes the Signal Manual of Recommended Practice containing recommended materials, methods and procedures for signal systems.

The AAR Manual provides numerous detailed requirements for system design, installation and testing, and all components and materials used in conventional railroad signalling, train control, and communications systems.

The AAR Manual (Part 2.2.12) also provides recommendations for microprocessor- based interlocking systems. The general requirements in the manual refer to meeting the requirements of the Federal Communications Commission (Part 15, Subpart J) regarding spurious emissions. It further describes the manufacturer's responsibilities of meeting electrical safety requirements and electronic component standards. Electrical and mechanical designs are recommended to meet other established standards. Safety design standards are provided for software to provide vital assurance levels equivalent to that provided by vital relay systems. The manufacturer is recommended to do all executive and vital software programming which should be installed in the system such that unintentional changes by the user are prevented. System operation speed should be such that total communication and processing time to react to any vital field input shall not be less than one second, or alternately, two seconds. User-vital software should be by means of a high-level language, and should be stored in non-volatile memory.

6.1.3.3 Other Foreign and International Requirements

The UIC Code 734, Adaptation of Railway Signaling Systems to Meet the Requirements of High Speeds, provides for the adaptation of safety installations for high speed operation at up to 300 km/h (187 mph). The requirements state that high-speed lines should not have at-grade highway crossings at speeds above 200 km/h (125 mph). Broken rail protection and signal system interfacing of hot-bearing detectors are recommended. Braking distance curves must be met on high speed lines without the use of electromagnetic rail brakes.

The problems associated with high speeds and visual observance and reaction to signals are discussed and appropriate practices are recommended for high speed operation. The cab should be manned at all times and provided with a continuous display of signal system information and automatic monitoring of the operator's actions. Automatic initiation of braking is required whenever the train exceeds a speed limit, or fails to follow a pre-set braking curve in response to a more restrictive signal indication or track speed-limit. A headway of three minutes is stated as a minimum safe separation of high speed trains.

Finally, Code 734 requires a method by which the driver can transmit a signal that will automatically cause trains on his line, or adjacent lines to be signalled to stop. This capability requires a vital ground-to-train communication link.

UIC Code 738, Processing and Transmission of Safety Information, is concerned with the safety of microprocessor and communication system hardware and software used for safety-critical train control processes. Code 738 is based on the work of ORE Committees A155 and A118 on the use of electronics in railway signalling.

The introduction to Code 738 points out that 100% prevention of any dangerous state is not attainable. However, systems that provide indication of potentially dangerous failures in all cases except a highly improbable failure may be accepted as fail-safe. Code 738 also points out that back-up operating procedures typically used following a signal system failure rely on manual control, and have a high error rate.

Further discussion of the contents of UIC Code 738 is provided in Functional Area 105, Computer Systems for Vehicle and Operations Control.

In addition to Codes 734 and 738, the UIC issues a number of other codes for aspects of conventional railroad signalling systems. These are briefly described below:

Code 512, Rolling Stock, Conditions to be Fulfilled in Order to Avoid Difficulties in the Operation of Track Circuits and Treadles, and Code 737-2, Measures to be Taken for Improving Sensitivity in the Shunting of Track Circuits are concerned with measures to ensure that the presence of a train is always detected by track circuits and treadles.

Code 641, Conditions to be Fulfilled by Automatic Vigilance Devices provides requirements for devices which will initiate braking if a train operator is incapacitated.

Code 736, Signalling Relays provides a functional and design specification for relays used in conventional signal and interlocking systems.

Code 755, Laying of Telecommunication and Signalling Cables specifies appropriate installation methods to avoid electrical and mechanical damage.

Code 780, Remote Control of Signalling Installations provides good-practice guidelines for Centralized Train Control (CTC) installation.

Code 781, Transmission Systems and Methods of Remote Control for Signalling Installations provides good-practice guidelines for communication systems that form part of a CTC installation.

6.1.4 Comparison and Assessment

The reviewed documents address two aspects of operations control system requirements: the definition of functions the system must perform with an appropriately high safety level, and requirements for components and devices to carry out the functions.

6.1.4.1 Operations Control System Functions

The key requirements for a high-speed maglev system are specified in Chapter 9 of the RW MSB and Section 4 of the draft MBO, and can be summarized as follows:

- Monitor the guideway status for vehicle location and speed, the position of movable elements, and the presence of any obstruction that would prevent safe operation.

- Provide a system to ensure that vehicle movements are only permitted when the guideway is clear of obstructions, other vehicles, etc. This function is performed by an interlocking system.

- Provide a system to ensure that the vehicle does not violate safe maximum and minimum speed limits at any time, and at any location along the guideway.

Conventional railroad interlocking and signalling systems as specified in the existing FRA regulation contained in 49 CFR, Part 236 provide functions equivalent to the first two items above, except that vehicle or train speed is not monitored by the signal system, and the capability to detect obstructions on the track is limited to a few special situations (such as rock-fall fences). The third requirement is not met by such conventional signal systems, except in part where ATC systems are installed. An ATC system will initiate braking if a train operator fails to respond to a more restrictive signal aspect, but does not otherwise monitor maximum speed. High-speed wheel-on-rail signal systems as specified in UIC Code 734 provide in-cab signalling, continuous speed monitoring on the vehicle, and automatic initiation of braking if speed exceeds that permitted by track conditions or signal indications. Systems with equivalent capabilities are used on many heavy-rail mass-transit systems, often with the addition of Automatic Train Operation (ATO).

Thus, control system functions required by the RW MSB and the draft MBO for high-speed maglev systems differ from those for conventional railroad systems, as given in 49 CFR Part 236, in that conventional systems lack a complete "safe speed enforcement" feature. However, the required maglev control systems functions are closely comparable to practice on wheel-on-rail high-speed systems, as specified in UIC Code 734, and used on automated heavy-rail mass transit systems.

It is not clear that automatic vehicle operation is a necessary safety requirement provided an automated "safe-speed enforcement" system is used. The enforcement system will prevent violation of speed limits whether the vehicle is manually or automatically operated, suggesting that automatic operation need not be a requirement. However, automatic operation is likely to be the practical choice for precision operation at very high-speed, and must be configured so that safe-speed enforcement is not compromised.

6.1.4.2 Requirements for Operations Control System Devices and Components

Devices and components used in high-speed maglev operational control systems will necessarily differ in some respect from those used in conventional railroad signal and train control systems. The differences arise because there is no contact between vehicle and guideway, and normal propulsion and braking control is provided at wayside using the long stator linear motor instead of on-board as with a conventional railroad vehicle. Specific safety-relevant issues are discussed below:

- Requirements for software-controlled computer systems used to provide the interlocking function, and the vehicle on-board speed monitoring and control functions are discussed in Functional Area 105 - Computer Safety for Vehicle and Operational Control Systems.

- Sensors and devices used to determine switch position and locking status on a maglev system are functionally similar to equivalent devices used on conventional railroad switches, although the mechanical arrangements must differ. Thus, it is reasonable to expect that the devices used should have a safety performance comparable to the equivalent devices on conventional railroad switches. The locking and position status sensors must be such that a false "OK" signal cannot be generated under any anticipated failure condition, and any unintended unlocking and movement of the switch must be prevented while the guideway is cleared for operations.

- The vehicle location and speed-sensing systems are unique to maglev. Because of the non-contact nature of maglev suspension, track circuits that are almost universally used on conventional railroads for train location are not applicable. Location data is critical to the interlocking function, safe speed enforcement, and the ability to stop the vehicle at a safe stopping point. Several vehicle location systems conceptually could be used on a maglev system such as transponders on the guideway or vehicle, or radio location systems such as GPS. There is limited experience in using such systems in a safety-critical function, especially where the location data has to be available both on the vehicle and to the wayside interlocking unit. Existing railroad-oriented requirements, such as FRA, AAR, MUe 8004 and VDE 0831 provide little information to help in resolving concerns about innovative speed and location systems.

- Vehicle-to-guideway communication systems are needed to convey train location and speed information from vehicle to guideway, and to convey permitted speed data to the vehicle, based on guideway status and the location of other vehicles. Since loss of this communication link cannot be ruled out, the vehicle must be able to act autonomously to stop at the next available safe stopping point in the event of communication loss, and the control system must be able to ensure the safety of following vehicles. Specific requirements for communications systems are addressed in Functional Area 403.

6.1.4.3 Overall Safety Concerns

Some individual devices, such as switch position and locking status sensors are very similar to equivalent conventional railroad equipment, and the most appropriate guidance on safety requirements can be obtained from conventional railroad requirements. Some individual devices and subsystems differ significantly from conventional railroad equipment, and existing railroad-oriented requirements are not applicable. The most notable example is the vehicle location and speed detection system, and the means of transmitting this information to both the interlocking logic unit and the vehicle on-board safe speed enforcement system. Overall, the vehicle operations control system for a high-speed maglev is somewhat different from, and more complex than a high-speed wheel-on-rail system, and will embody devices not previously widely used in safety-critical applications. This means that failure frequency, failure modes and consequences may not be well understood. Therefore, it will be essential to carry out thorough FMEA and quantitative failure rate analyses to provide assurance that the system is adequately safe.

6.1.5 Findings

An adequately safe operations control system is absolutely critical for safe maglev systems operation. Existing FRA requirements, however, are mostly specific to operations control systems and components used on conventional railroads and cannot be applied to high-speed maglev systems without modifications and additions. Other U.S., foreign and international requirements developed for conventional railroad signalling equipment (AAR, UIC, VDE 0851 and MUe 8004) similarly cannot be applied directly to maglev systems. However, the underlying purpose of all signal system requirements - to ensure that safety-critical operations control system functions are provided with a very low probability of unsafe faults - is common to all guided transportation systems.

The primary operations control systems safety functions on a high-speed maglev system can be summarized as follows:

- Ensure guideway integrity, by continuously monitoring vehicle locations and speeds, switch status, and the status of any guideway obstruction detection systems to ensure that vehicle movements are only permitted when the guideway is clear and no conflicting vehicle movements have previously been authorized. On conventional rail systems, this function is provided by the interlocking system.

- Communicate movement authorities, typically in the form of permitted speeds by position along the guideway, to the vehicle operating system (propulsion and braking controls).

- Provide a safe speed enforcement system to ensure that safe maximum and minimum speed limits are not violated, taking into account guideway and vehicle conditions, locations of safe stopping places, and the point at which the vehicle must be able to stop.

Some of the individual subsystems or devices used in a maglev operations control system will be identical to those used for an equivalent purpose on conventional railroads or rail mass transit systems. For U.S. maglev system applications, it is appropriate to follow recognized conventional requirements such as those of the FRA, AAR, UIC, MUe 8004 or VDE 0831.

Requirements for programmable computer systems used for interlocking systems, or an on-board safe-speed enforcement system have been addressed in Functional Area 105, Computer Safety for Vehicle and Operations Control System.

A maglev operations control system will also include subsystems and devices which are not commonly used in conventional rail signalling and train control systems. Examples may include guideway-to-vehicle communication systems, and vehicle speed and location detection systems. In addition, the overall architecture of a maglev operations control system will likely differ from that of a conventional railroad or rail mass transit system. For a U.S. application of such novel systems and components, consideration should be given to requiring a detailed system-safety analysis of the operations control system, to assure that performance is consistent with overall maglev system safety goals. Assurance that there is a safe response to all probable safety-critical failure conditions is particularly critical.

6.1.6 Further Studies

A maglev operations control system is likely to include devices and subsystems for which established safety requirements and safety performance data are lacking. Such devices and subsystems could include vehicle speed and location detection systems and vehicle-guideway communications systems. Further studies are suggested to develop safety requirements and safety performance data for such equipment, which can include novel transponder or satellite-based vehicle location systems, vital radio communications, and devices monitoring the status of other safety-critical systems. In addition, study is needed into how to apply systems safety analysis techniques to the overall operations control system.

6.2 FUNCTIONAL AREA 402 - OPERATIONS CONTROL SYSTEM INSPECTION AND MAINTENANCE

6.2.1 Description of Functional Area

This functional area addresses requirements for maintenance and inspection procedures to ensure that the operations control system is in safe condition at all times. All sensors, communication systems, and information processing equipment must receive such inspection and maintenance. The types of maintenance and inspection needed will be a function of the types of degradation and failure modes of the equipment, and whether or not automatic failure indicators are used.

This functional area closely relates to the other functional areas concerned with operations control equipment. Specifically these are:

Functional Area 102, Reliability and Availability, addresses the techniques and methods by which high safety levels are achieved in safety-critical systems.

Functional Area 105, Computer Safety for Vehicle and Operations Control Systems. covers computer systems used in operational control systems.

Functional Area 303, Guideway Switch, addresses the structural and operating aspects of the switch.

Functional Area 401, Operations Control System Design, covers design requirements for the overall system, and system components of different types.

Functional Area 403, Communication Systems, includes communications between operations control system functional subsystems and components.

6.2.2 Safety Baseline

To ensure continued safe operation, all systems and components in the operations control system that are subject to deterioration in performance over time or which are subject to faults that are not automatically indicated to system operators, must be regularly inspected and maintained. It is particularly important that maintenance or modifications to operations control systems be carried out in a disciplined and careful manner, and that maintenance procedures include proper post-maintenance tests to ensure that systems are functioning correctly. Installation of faulty hardware or software in maintenance, or an incorrect maintenance action could leave the system in an unsafe condition. Thus, a properly structured maintenance program typically needs the following elements:

- Schedules detailing the frequency and nature of inspections and tests for each subsystem or component.

- Procedures for each type of maintenance performed, including precautions to limit vehicle operations while maintenance is being carried out, and responses to automatically indicated faults.

- Requirements for preventive maintenance or component replacements at defined intervals.

- Requirements for post-maintenance or modification testing and verification to ensure that no unsafe conditions have been introduced into the system as a result of maintenance.

- Requirements for keeping records of inspections and maintenance performed.

6.2.3 Description of Existing Safety Requirements

Existing safety requirements are listed in Table 6-2, and described below by origin under three headings: German, United States, and other foreign and international.

6.2.3.1 German Requirements

Chapter 4 of the RW MSB, On-Board Control System, states that the functional performance of on-board system components must be regularly checked if there is no automatic failure detection. The vehicle must be brought to a stop using safe programmed braking in the event of faults that reduce the redundancy in safety-critical systems below acceptable levels. Maintenance or replacement of the faulty equipment must be carried out before returning the vehicle to normal use.

Chapter 9 of the RW MSB, Operational Control Equipment, requires that recurrent tests of hardware are required during operation, and that the requirements for such tests are made part of the type approval process for such hardware. DIN VDE 0831 is referenced for more information on tests.

Section 1.4 of the draft MBO, requires that the installation be regularly inspected in terms of their proper condition, and that the frequency of these inspections should be appropriately dependent on equipment type and condition.

The EBO, Section 2, Paragraph 17 requires that a railroad be systematically inspected to determine whether its condition complies with regulations. Inspection frequency and type should be determined by the condition and loading of the railroad.

DIN VDE 0831, Electrical Equipment for Railway Signalling, Section 9, Maintenance requires that regular maintenance be performed and that full records of maintenance work be kept. Proper precautions regarding personnel safety must be taken when working on high voltage equipment. Section 8 of DIN VDE 0831 requires that post-modification testing must be carried out in the same manner as for acceptance testing of new equipment.
TüV Rheinland, in a paper discussing certification requirements [10], makes the general statement in Paragraph 5.5 that periodic inspections will need to be defined according to the risks of a malfunction in each subsystem, but no specifics are provided.

TABLE 6-2. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 402 - OPERATIONS CONTROL SYSTEM, INSPECTION AND MAINTENANCE

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 4 Chapter 9	On-Board Control System Operational Control System	Maglev
German Government	Draft MBO EBO	Section 1.4 Section 2	Basic Rules Railroad Installations	Maglev Railroad
DIN VDE	0831 - Electrical Equipment for Railroad Signalling			Railroad
FRA	49 CFR	Part 236	Regulations for the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems	Railroad
AAR	Manual of Recommended Practices		Communications and Signal Division	Railroad
UIC	731 - Inspection of Signalling Installations			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

A technical paper by authors involved in German maglev development: Operational Fields of the New High-Speed Rail Systems in the Federal Republic of Germany [20], describes an inspection and maintenance philosophy for a high-speed magnetic levitation trains. The principal elements of the approach are as follows:

- Types of maintenance and inspection approaches are defined as follows:

  Hard Time Limits, where components are replaced or overhauled after a specified period of time regardless of condition. This is also termed preventive maintenance.

  On-Condition Maintenance, to be performed when inspections and tests indicate that condition is at a minimum-acceptable level.

  Condition Monitoring is on-going monitoring of component condition so that faults are indicated when they occur, leading to a need for repair or replacement.

- A hierarchy of inspection and maintenance goals is defined:

  - Ensure safety
  - Ensure operational availability
  - Ensure all passenger amenities are operational

- Maglev system components and subsystems are classified according to the way in which they fail or degrade.

  - Components that fail suddenly without any prior indication of degradation (e.g., electronic components)

  - Components subject to visible wear and deterioration with usage (e.g., a switch activating mechanism)

  - Components which lose functionality mainly because of reaching the end of service life (e.g., structures failing because of corrosion or metal fatigue)

  - Components which simultaneously lose functionality as a result of both degraded performance and reaching the end of their service life (e.g., electrical storage batteries)

- A maintenance approach is developed according to how components fail, and which of the maintenance goals (safety, availability, amenity) are impacted by the failure, as summarized in Table 6-3.

TABLE 6-3. INSPECTION AND MAINTENANCE APPROACH BY COMPONENT FAILURE MODE AND CRITICALITY

Failure Mode	Failure Criticality		
	Safety Critical	Availability Critical	Amenity Critical
Sudden Failure, No Warning	Multiple redundant or fault-tolerant systems, with on-line condition-monitoring and diagnostic systems to indicate failure. Failed parts are replaced, e.g., at end of day. Intermittently used systems (e.g., safety brake) tested periodically.	Not usually redundant. Replace when fail. Low 'time to repair' critical. If not possible, redundancy may be justified. Continuous condition monitoring may be used.	Repair and replace when failed. No condition monitoring. Monitoring by periodic inspection or test.
Components with Gradual Wear or Loss of Functionality	Condition monitoring by inspection, with repair/replacement when acceptable limits are reached. Hard time limits also used.	No redundancy used. On condition repair or hard-time limit. Governed by cost-effectiveness.	As above
Service Life Loss of Functionality	Condition monitoring by inspection, with repair when acceptable limits are reached. Hard time limits also used.	As above.	As above.
Service Life Loss of Functionality and Performance Decline	Condition monitoring by inspection, with replacement/repair when acceptable limits are reached. Hard time limits also used.	As above, but hard time limits commonly most appropriate in this category.	As above

Source: Reference [20]

6.2.3.2 Requirements

The FRA safety requirements contained in 49 CFR, Part 236 contain numerous inspection requirements and acceptability criteria for conventional railroad signalling systems. The principal requirements potentially relevant to a maglev system are as follows:

- Part 236.103 requires switch controllers and point detectors to be inspected every three months. Part 236.382 further requires that a switch obstruction test on switch locks be carried out monthly.

- Part 236.107 requires ground tests of power supplies to safety-critical circuits every three months.

- Part 236.108 requires cable insulation tests on installation, and then at least every ten years.

- Parts 236.376 to 236.381 require that interlocking systems be tested when installed, when modified or disarranged, or every two years.

- Parts 236.586 to 590 require that train control (ATC) devices be inspected daily, receive a departure functional test daily, be shop-tested at 92-day intervals, and be inspected and cleared every two years.

Full records shall be kept of all tests and maintenance work on signalling and train control devices.

A recent study, Analysis of Railroad Signalling Systems: Microprocessor Interlocking [25], investigated changes to the existing regulations to accommodate the special requirements of programmable microprocessor interlockings.

The AAR specifies numerous inspections and tests in the Manual of Recommended Practices. Tests have to be carried out at 1-, 3-, 6-, 12-, 24-, and 60-month intervals depending on the type of equipment. Cab signal and ATC equipment in a locomotive or driving cab have to be inspected daily in the shop and tested daily by the engineman on departure, or on entering ATC territory.

6.2.3.3 Other Foreign and International

UIC Code 731, Inspection of Signalling Installations, provides some general guidance regarding a signalling inspection program. The types of equipment that should be inspected are identified, and the need for qualified inspectors, and good recordkeeping of inspection results are emphasized. No specific recommendations for inspection frequency are given.

French National Railways (SNCF) uses a test car to make a monthly inspection of track-to-train communication systems and train detection systems on the new high-speed lines.

Portable test instruments are also used for on-site testing, and the control center for the new lines can simulate certain operating conditions in a test mode.

6.2.4 Comparison and Assessment

The requirements identified above are either very general statements to the effect that adequate maintenance is required (such as in the draft MBO), or are highly detailed requirements for devices used in conventional railroad installations such as relay interlockings, track circuits, or switch machines. Requirements for conventional railroad signal system components are contained in the FRA safety regulations and the AAR Manual.

Conventional existing railroad signalling and train control systems are such that satisfactory inspections can be performed visually or with the aid of relatively simple instruments. These methods can continue to be used for maglev operations control equipment when this equipment functions in a similar way to that used in conventional rail systems and is used for a similar purpose. Switch systems and wayside cabling are similar to equivalent conventional equipment, but vehicle location and speed detection, and vehicle-to-guideway communication systems are very different. These two systems are highly critical to safe and reliable maglev vehicle operations. Therefore, the daily operational checks as are used in the U.S. for conventional train control apparatus are appropriate. These checks should include devices or communication channels used for multiple redundancy.

Much of the operations control equipment used on a maglev system is likely to be provided with automatic condition-monitoring features, which will identify faulty components when the fault occurs. Since such faults will frequently reduce the level of redundancy available in the affected function, it will be essential to have strict requirements for the maximum time to repair, and for the repair procedure itself, to make sure the equipment is functional after repair, and any necessary requirements to restrict vehicle operations prior to completion of the repair. As indicated in the discussion of Functional Area 105, Computer Safety for Vehicle and Operations Control, it will be particularly important to develop proper procedures for repair and replacement of computers and software.

Overall, the German paper, Operational Fields of the New High Speed Rail Systems in the Federal Republic of Germany [20], provides a useful framework for developing condition monitoring, inspection, and maintenance requirements for maglev operational control systems. Specific procedures for maglev operational control equipment that differs from that used in conventional railroad signalling and train control systems are lacking, however, and need to be developed.

6.2.5 Findings

Proper inspection and maintenance procedures, diligently applied, will be essential to ensure the continuing safe performance of maglev operations control systems. Defective equipment, and in particular a failure to follow correct procedures while performing maintenance or component replacement can lead to an undetected dangerous fault and an accident.

Existing FRA safety regulations contained in 49 CFR, Part 236 for signal and train control systems are applicable to high speed maglev systems in the U.S., where similar devices and components are used for an equivalent purpose. The existing FRA regulations lack inspection and maintenance requirements for some components and subsystems used on a high-speed maglev system, and new safety requirements will be needed. The German paper [20], provides a good starting point for structuring maintenance and inspection requirements. In addition, the FRA is continuing to study the safety implications of new signal and train control systems. The results of these studies will further assist in the development of appropriate requirements.

Pending the results of ongoing research for U.S. maglev system applications, consideration should be given to the following safety requirements for operations control system inspection and maintenance.

- A daily operational check shall be made of all vehicle-borne safety critical operations-control equipment. This check shall take place prior to the first departure of the day, or shortly after departure where a running test is appropriate. Checks should be performed on at least the following systems:
  - Vehicle to guideway communications systems, including multiple redundant channels where used.
  - Vehicle location and speed sensors, including multiple redundant installations where used.
  - Critical functions of the on-board safety computer, including multiple redundant installations where used.
- A comprehensive condition monitoring, inspection, and maintenance manual should be prepared for the operations control systems used on the maglev system. The manual should reflect manufacturers recommendations, and other relevant knowledge regarding component failure modes and criticality.
- All system components where a failure would reduce the degree of redundancy in safety-critical systems should be constantly monitored for correct functioning, and a failure indication provided to the on-board vehicle operator and/or the operations controls center as appropriate.
- All systems, sub-systems and components newly installed during maintenance or modifications should receive suitable pre-service tests. With microprocessor systems, it will be particularly important to ensure that both the correct hardware <u>and</u> software has been installed for a specific function and/or location. A careful "configuration-management" process is required.
- Detailed records should be kept of all inspection results, maintenance, and replacements of operations control equipment. Records must be subject to continuing analysis and review so that problems can be identified and corrected.

- Staff performing maintenance on operations control systems shall be properly trained in their work, and have passed a suitable test of competency. Records shall be maintained of staff training and testing.

6.2.6 Further Studies

Insufficient information is available to make more detailed recommendations regarding inspection and maintenance procedures for safety-critical computer systems; further study in this area is desirable.

Studies of procedures to ensure against the inadvertent introduction of a fault into the system during maintenance are desirable. Improved knowledge of failure modes and failure frequency of all subsystems and components is highly desirable to support the development of inspection and monitoring procedures for all operations control equipment.

6.3 FUNCTIONAL AREA 403 - COMMUNICATIONS

6.3.1 Description of Functional Area

This functional area is concerned with all forms of communication used in managing and controlling maglev system operations. The types of safety-related communication likely to be used in a maglev system include wayside links between guideway installations (such as switches and power supply substations) and the control center using fiber-optic or copper wire, data communications by radio between vehicles and guideway for vehicle location and control data, and voice radio communication between the control center, vehicles, guideway maintenance crews, and other maglev system personnel in the field.

This functional area is closely related to other functional areas addressing vehicle movement control and guideway status:

Functional Area 101, System Safety, includes the role of communications in the overall safety performance of a maglev system.

Functional Area 103, Reliability and Availability, discusses definitions for these terms, and different techniques for achieving desired safety, reliability, and availability performance levels.

Functional Area 105, Computer Safety for Vehicle and Operations Control Systems, discusses the methods of ensuring adequate safety and reliability in maglev system functions controlled by computer.

Functional Area 207, Brake Installation and Performance, includes the brake control system and its interface with maglev system controls and communications.

Functional Area 303, Guideway Switch, covers the operation of the switch system and its interface with maglev system controls and communications.

Functional Area 401, Operations Control System Design, describes overall system control requirements including functions of communication systems linking the components of the control system.

Functional Area 405, Electromagnetic Compatibility and Electromagnetic Interference, describes requirements to ensure that communication systems are not unacceptably interfered with by other vehicle and guideway electrical and electronic systems.

Functional Areas 501, Qualifications and Training, and 502, Operating Rules and Practices, both address the use of radio, and particularly voice radio in maglev system operations from the point-of-view of employee skills and operating procedures.

Functional Areas 601, Emergency Plans and Procedures, and 602, Emergency Features and Equipment, address requirements for communication capabilities and procedures in an emergency situation.

6.3.2 Safety Baseline

The safe operation of a maglev system relies on the safe functioning of many types of communication systems. Although it is recognized that the loss of a communication link of any type cannot completely be ruled out, such losses must be rare to avoid frequent recourse to less safe back-up modes of operation. More importantly, communication systems must be structured so that there is an extremely low probability of errors introduced in transmission or as a result of a communications failure, leading to an unsafe condition. Examples of such errors could include errors in vehicle speed and location as transmitted from a vehicle to the control center, or an erroneous sensor signal indicating that a switch is properly locked when this is not the case. Like other components of the operations control system, communication systems must be either fail-safe, or fault-tolerant with an automatic indication of a failure.

In the specific case of safety-relevant voice communications used, for example, to provide instructions to a vehicle operator for slow-speed movements under manual control, or to communicate with guideway maintenance personnel, there is the risk that a misunderstood message may lead to an unsafe action. Good voice radio procedures are required to minimize the risk of such an occurrence.

6.3.3 Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6-4, and are described below by of origin under three headings: German, U.S., and other foreign and international.

6.3.3.1 German Requirements

Chapter 4 of the RW MSB, On-Board Control System, provides general requirements for the communication of safety-relevant information, either between on-board components or between the vehicle and fixed installations. Safety of such systems must be guaranteed by application of appropriate techniques such as anti-coincidence signal lines or secured telegrams. Either continuous monitoring or intermittent testing of these communication links is required to ensure that faults are detected in a timely way and appropriate safety action taken.

Section 8 of Chapter 4 requires that the transmission installation on the vehicle that receives, processes, and forwards safety relevant data must be a two-out-of-three voting system. In one installation that meets these safety requirements, the equipment is cyclically tested at 10-second intervals, and data telegrams are sent forward and reversed, and compared to check for transmission errors. Failure of one transmission channel is permitted, but safe programmed braking must be initiated if two channels fail.

TABLE 6-4. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 403 - COMMUNICATIONS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 4 Chapter 8 Chapter 9	On-Board Central System Guideway Switch Operational Control Equipment	Maglev
German Government	Draft MBO EBO	Section 2 Section 3 Section 16	Operating Installations Vehicles Railroad Installations: Communication Facilities	Maglev Railroad
DIN VDE	0800 Telecommunications: Erection and Operation of Facilities			General
DIN VDE	0816 External Cables for Telecommunications			General
DIN VDE	0845 Specification for the Protection of Tele-communication Systems Against Over-Voltages			General
DIN VDE	0888 Optical Waveguides for Telecommunication Systems			General
FRA	49 CFR, Transportation	Part 220 Part 236	Radio Standards and Procedures Rules, Standards and Instructions Governing the Installation, Inspection and Maintenance of Signal and Train, Control Systems	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 6-4. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 403 - COMMUNICATIONS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FCC	47 CFR, Federal Communications Commission	Part 2 Part 90	Frequency Allocations Private Land Mobile Radio Services	General
AAR	Manual of Recommended Practices - Communications			Railroad
UIC	738 Processing and Transmission of Safety Information			Railroad
	755 Laying of Telecommunication and Signalling Cables 781 Transmission Systems and Methods of Remote Control for Signalling Installations			

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

fail-safe manner to the on-board safety computer and the control center. The proper functioning of the communication systems used to transmit this signal must be cyclically monitored by the safety computer.

Chapter 8, Switch, of the RW MSB, Section 5, requires fail-safe reporting of switch usability to the operations control center and/or other operational points.

Chapter 9, Operational Control Equipment, of the RW MSB, Section 2.1.2, requires that any technical installations that record, transmit or process safety-relevant information must be fail-safe as defined in DIN-VDE 0831. The requirements of DIN-VDE 0831 are described in Functional Area 401, Operations Control Systems Design. Thus, any communication system must meet the requirement that failures or breakdowns must not have dangerous consequences. Where fail-safe behavior cannot be guaranteed, there must be two mutually independent systems, and provisions for condition monitoring and immediate reporting of failure. If the system lacks a safe state, a 2-out-of-3 fault-tolerant system must be used.

The draft MBO, Section 2.4 contains the general requirement that the train safety installations must be reliable and fail-safe.

The draft MBO, Section 3.4, Paragraph 16 requires that vehicles must be equipped with communication systems by means of which the vehicle can make contact with personnel in the operations control center, and vice versa. Section 3.7, Paragraph 3, of the same document requires systems that facilitate communications between the vehicle operator and the operations control center must be provided in the operator cab. These requirements refer to radio voice transmissions, separate from radio or other communications used for vehicle control data.

Section 16 of the EBO requires the key wayside control points to be linked by a telephone line.

DIN-VDE 0888, Optical Waveguides for Telecommunication Systems is a detailed specification for optical fibre communications cable, including definitions, dimensions and dimensional tolerances, optical properties, and protective covers for both outdoor and interior applications.

DIN-VDE 0800, Telecommunication: Erection and Operation of Facilities is a general industrial requirement for conventional telecommunication lines. Subjects covered include grounding, insulation protection from over-voltage, and the construction and installation of cables for both overhead and underground usage, and protection against environmental conditions such as heat, cold, moisture, and corrosive environments.

VDE 0816, External Cables for Telecommunication Systems provides a detailed specification for conventional "electrical conductor" communications cables for exterior use. Cables for special application such as underwater use are not included. Particular specifications are provided for railway signalling cables, including outer sheathing and armoring, and copper conductor sizes and arrangements.

VDE 0845, Specification for the Protection of Telecommunication Systems Against Over-Voltages provides general protection guidance against over-voltages caused by atmospheric conditions such as lightning and the proximity of conductors such as railroad rails. The application of recommended protective measures such as cable sheathing and various kinds of arrester devices are described for underground and overhead lines and equipment at the ends of communication lines. Specifications in terms of response times and voltage limits for different arrester types are given.

6.3.3.2 U.S. Requirements

The U.S. requirements for safety-relevant communications are contained in FRA, FAA, AAR, and Federal Communications Commission (FCC) requirements.

In 49 CFR, Part 220, the FRA specifies procedures for voice communication by radio. These procedures include requirements for designating radio channels in use, daily radio tests by radio users such as train operators and maintenance personnel, and procedures for transmitting train orders and similar train movement instructions.

The FRA regulations for signal systems contained in 49 CFR, Part 236 contains requirements for conventional wayside communications and track-to-train communications used in train control systems. These requirements include the tagging of wires for identification (Part 236.71-236.76), insulation tests for wires and cables (Part 236.108), and details of intermittent inductive systems used to transmit train control data from track-to-train (Parts 236.526-236.557).

The U.S. Federal Communications Commission (FCC) controls the use of radio frequencies in the United States as specified in 47 CFR Part 2, Frequency Allocations and Radio Treaty Matters. Also, all radio equipment used in the U.S. must be type-approved for the application for which it is used. Specific parts of the radio frequency spectrum have been allocated to railroad use, including some new frequency bands for Advanced Train Control Systems. These may be suitable for maglev system vital data communications, but are likely to differ from the 40 GHz range used for train control in Germany. Radios and communications equipment of all types must conform to technical standards and administrative requirements specified in 47 CFR Part 90 for private land mobile radio services.

The AAR Manual of Recommended Practices for Communications contains detailed requirements for all components of communication systems used in the conventional railroad industry, including copper wire and fiber-optic transmission lines, voice, radio, microwave links and data transmission.

6.3.3.3 Other Foreign and International Requirements

UIC Code 738, Processing and Transmission of Safety Information is the primary international requirement for safety-relevant communications, and is specifically referenced in the RW MSB. Section 5 of Code 738 covers the transmission of safety information, particularly emphasizing methods to protect against the transmission and acceptance of erroneous messages or data. The model used for a communication system is illustrated in Figure 6-1. Particular subjects addressed in Code 738 include:

- The classification and identification of error sources.
- Methods for protecting against errors such as information redundancy, and various transmission protocols such as returning the message for checking against the original message at source.
- Guidelines for selecting the most appropriate methods of error protection. These methods vary with the communications medium used.

Code 738 concludes with some detailed recommendations for communication system structure and performance. Two recommendations of particular interest are that any system must be able to respond to a total interruption of communications in a safe way, since such interruptions cannot be ruled-out, and that FMEA and quantitative failure risk analyses of a communication system should be carried out to confirm that safety performance is within acceptable bounds.

Two other UIC Codes provide recommendations for conventional railroad communications installations:

- Code 755, Laying of Telecommunication and Signalling Cables, and Their Protection Against Mechanical Damage specifies appropriate installation methods to avoid electrical and mechanical damage.
- Code 781, Transmission Systems and Methods of Remote Control for Signalling Installations provides good-practice guidelines for communication systems that form part of a CTC installation.

6.3.4 Comparison and Assessment

Communications safety requirements contained in the reviewed documents are of two types: system-level requirements that address the need for communication systems to perform in a fail-safe or fault-tolerant manner, and component-level requirements that provide details of individual equipment and materials used in telecommunication systems (such as cables), and their installation.

6.3.4.1 System-Level Requirements

The RW MSB and UIC Code 738 provide the most complete system-level require-ments. The principal requirements are that procedures and equipment must be such that there is a very low probability of errors in data communications, and that there must be a safe response

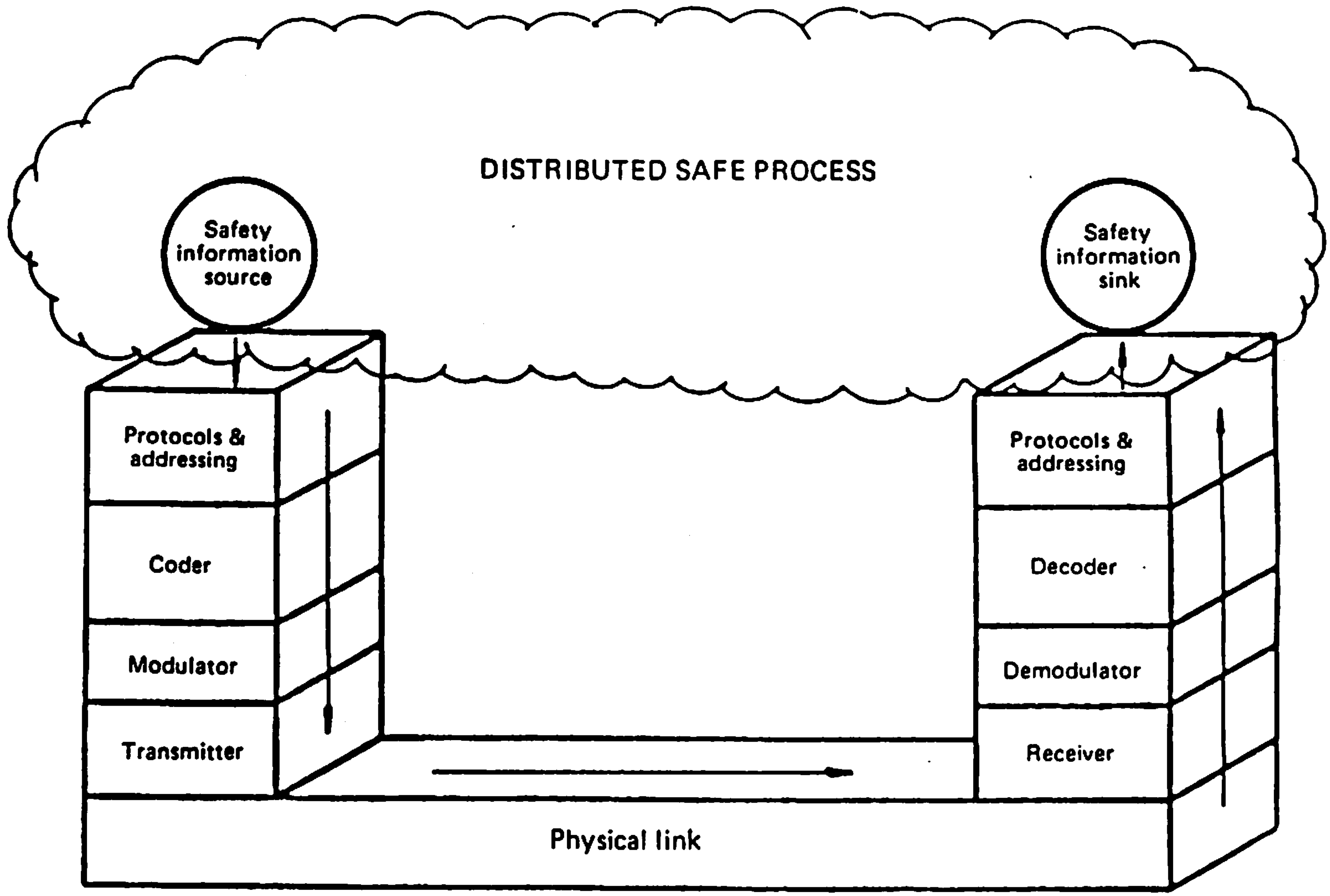


FIGURE 6-1. COMMUNICATION SYSTEM MODEL FROM UIC 738 - PROCESSING AND TRANSMISSION OF SAFETY INFORMATION

of the system to a loss of communication at any point in the maglev system communication network. Communications equipment used by conventional railroads for safety-relevant data (such as that covered in the AAR Manual) are designed to be fail-safe. If higher levels of availability are required, then redundant or fault-tolerant communication systems must be used. To confirm that such systems are adequately safe and reliable, UIC Code 738 recommends that FMEA and quantitative risk analyses should be performed to demonstrate that safety requirements can be met. A requirement for such analysis is also implicit in the MBO in the statement that all systems be adequately safe.

All radio communications equipment, and frequencies used are subject to approval by the FCC. Communication equipment and frequencies used by maglev systems in Germany may lack such approval, and thus may not be usable in the United States. Alternative transmission frequencies and equipment complying with FCC requirements will have to be substituted, or appropriate approvals obtained.

6.3.4.2 Component-Level Requirements

Component-level requirements are principally provided by the DIN-VDEs and by the AAR Manual. A few requirements are also included in the FRA signal system requirements, particularly with regard to insulation, grounding, and tagging to identify the purpose of individual wires to minimize the risk of erroneous connections. Component requirements appear to be broadly similar, but differ in details. Maglev installations in the United States would likely purchase conventional communications equipment from domestic U.S. suppliers, and use U.S. contractors for system design and installation. Therefore, it would probably be most appropriate to follow U.S. requirements for conventional fixed communications equipment for which applicable requirements exist in the AAR Manual or elsewhere.

Existing FRA requirements for voice radio procedures in 49 CFR, Part 220 appear to be equally applicable to maglev voice radio communications with minor changes in terminology.

6.3.5 Findings

Communications failures have the potential to cause unsafe situations in several ways. Radio or fixed communication links can be broken or lost. Where data is being transmitted, the data could be corrupted by an equipment fault or temporary interruption in transmission. Voice communications can be misunderstood. Adequate precautions are needed to ensure that such failures are either extremely rare, or that the system is designed so that the failures do not compromise safety.

The existing FRA safety requirements in 49 CFR, Part 220 for voice radio communications, and in 49 CFR, Part 236 for conventional wayside communications are applicable to maglev systems in the U.S.

In addition, all communication systems must comply with applicable FCC regulations. Radio communications must comply with 47 CFR, Part 2, Frequency Allocation, and Part 90, Private Land Radio Service.

There are no specific FRA regulations for data communications by radio or cable. The RW MSB and UIC Code 738 provide useful guidance regarding methods to ensure that there is a very low probability that erroneous data will be accepted.

In more detail, for U.S. maglev system applications, consideration should be given to the following safety requirements for safety-critical communications.

- Safety-critical communications systems should be fail-safe or fault-tolerant, so that loss of a communication channel or link does not result in an unsafe situation.

- Data transmission systems and procedures should be designed so that the probability of acceptance of erroneous data is extremely low.

- FMEA, Quantitative Risk Analysis and other types of safety analysis should be carried out, as recommended in Functional Area 101, System Safety, to demonstrate that an unsafe situation resulting from a communications failure or error is extremely improbable.

- A voice-radio link between vehicles and the control center should be provided, and should be completely independent of any other radio system used to communicate train control data to the vehicle, and should be provided with an independent power source. Voice radio procedures should comply with FRA requirements in 49 CFR, Part 220.

- All communication systems must comply with applicable FCC regulations.

- Conventional communication system components and cabling should conform to the FRA requirements in 49 CFR, Part 236 with regard to insulation, grounding and marking, and preferably with the requirements of the AAR Manual of Recommended Practices, Communications.

6.4 FUNCTIONAL AREA 404 - ELECTRICAL SAFETY AND POWER SUPPLY

6.4.1 Description of Functional Area

This functional area addresses all safety issues related to the electrical power supply and the electric power systems installed on the guideway or the vehicle. The power supply; transformers, rectifiers, switchgear and guideway power controllers in the wayside power substations, the guideway stator windings, and power electrical equipment on the vehicle, such as levitation and guidance magnets and eddy current brake windings are included. The primary safety concerns associated with electric power systems include avoidance of any situation that can cause electric shock, electrical overload and overheating of any equipment, and the electrical and fire performance of cable insulation. It is also important to ensure that all electrical equipment is highly reliable. Although a maglev system is designed so that the failure of electric power equipment does not immediately lead to a dangerous situation, a failure may mean loss of redundancy in certain systems or a disruption to service, and increase system vulnerability to a more serious failure. Therefore, the incidence of such failures must be low.

This functional area has an interface with the following functional areas:

- Functional Area 405, EMC and EMI, discusses requirements for electromagnetic compatibility between electric power systems and electronic and communication systems used by the maglev system.

- Functional Areas 301 and 302, Guideway Construction and Maintenance, covers the mechanical mounting of the stator on the guideway.

- Functional Areas 206 and 207, covers the mechanical engineering aspects of design and construction of the vehicle suspension and braking systems. These are the principal safety related "electric power" systems on the vehicle. The other main electric power systems on the vehicle are components of the heating, ventilation and air conditioning systems.

6.4.2 Safety Baseline

Electrical systems installed in the maglev vehicle, in wayside substations, and on the guideway must be both safe and reliable. Safety means adequate protection against electric shock, short circuits, overloads and proper consideration of fire safety in cabling and other electrical equipment. Reliability means a low failure rate of the principal electrical components of the system such as transformers, switchgear, rectifiers and motor and magnet windings. Safety and reliability in electrical equipment is attained by adherence to the relevant technical requirements as specified in nationally and internationally recognized design codes and standards, such as those issued by IEEE, ANSI, NFPA, IEC, DIN, and VDE. Appropriate requirements for the power range and operating environment found on a fixed guideway transportation system should be used.

6.4.3 Description of Existing Safety Requirements

Existing requirements in this functional area are listed in Table 6-5, and described below by origin under two headings: German and other foreign and international, and United States. This functional area covers a very broad range of electrical equipment and components. For improved clarity, these descriptions have been broken down into several sub-areas as follows:

- **Electrical Safety Requirements**
  - Protection against electric shock
  - Grounding system
  - Disconnection equipment
  - Equipment and cable insulation.
  - Overload and short circuit protection
- **Equipment Design Requirements**
  - Transformers
  - Switchgear
  - Rectifiers

The descriptions of German and other foreign and international requirements are combined in this functional area only because the RW MSB cites both German (DIN-VDE) and international (IEC) requirements in different instances, and many DIN-VDE and IEC requirements are interchangeable.

6.4.3.1 German Requirements

Chapter 2 of the RW MSB, Propulsion, including Energy Supply, describes the requirements of the maglev wayside propulsion and energy supply systems. The systems covered include the stator of the long stator linear motor mounted on the guideway, and the switchgear, propulsion control systems and transformers at the power supply locations. Electrical safety issues covered particularly include a requirement for total separation from each other of the electric power systems supplying the two linear motor stators mounted on the guideway, and ensuring a safe response to ground faults, short circuits, and other electrical malfunctions. Numerous DIN and VDE and other requirements documents are referenced.

Chapter 3 of the RW MSB, On Board Energy Systems, describes the on-board energy systems for the maglev vehicle. This chapter includes requirements for the power supply to the vehicle, energy storage on the vehicle, power controllers for on-board equipment such as

TABLE 6-5. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 404 - ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 2 Chapter 3	Propulsion, Including Energy Supply On-Board Energy Systems	Maglev
DIN VDE	0100 - Installation of Power Plant with Rated Voltages not Exceeding 1000V	Part 410		General Industrial
DIN VDE	0101 - Erection of Power Installations with Nominal Voltage Exceeding 1KV			General Industrial
VDE	0115 - Traction Systems: General Construction and Safety			Electric Railroad
DIN	40 050 - Degrees of Protection Provided by Enclosures			General Industrial
VDE	0141 - Grounding Systems for Power Installations with Rated Voltages Above 1KV			General Industrial
DIN VDE	0266 - Halogen-Free Cable with Improved Behavior During Fire			General Industrial
DIN VDE	0160 - Electronic Equipment for Use in Electric Power Installations and their Assembly into Electric Power Installations			General Industrial
DIN VDE	0532 - Transformers and Chokes			General Industrial
DIN VDE	0660 - Switchgear			General Industrial

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 6-5. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 404 - ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
DIN VDE	0558 - Provision for Semiconductor Rectifier			General Industrial
NFPA	70 - National Electrical Code (NEC)			General Industrial
ANSI	C2 - National Electrical Safety Code (NESC) Test Plans			General Industrial
NEMA	250 - Enclosures for Electrical Equipment (1000V maximum)			General Industrial
IEEE	142-1990 - Recommended Practice for Grounding of Industrial and Commercial Power Systems			General Industrial
ANSI/IEEE	C57 - Distribution, Power and Regulating Transformers			General Industrial
ANSI/IEEE	C37 - Circuit Breakers, Switchgear Relays, Substations and Fuses			General Industrial
ANSI/IEEE	C34 - Semi-Conductor Rectifiers (under revision)			General Industrial
AREA	Manual for Railway Engineering	Chapter 33	Electrical Energy Utilization	Railroad
AAR	Manual of Standards and Recommended Practices	Section F, Standard S501	Wiring and Cable Specification	Railroad
Amtrak	323 - High Performance Wire and Cable Used on Amtrak Passenger Vehicles			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

levitation magnets, and power distribution within the vehicle. As for wayside electrical power systems numerous DIN-VDE and other requirements are referenced.

The DIN and VDE requirements referenced in Chapters 2 and 3 of the RW MSB are described below by sub-area. It should be noted that an individual electrical systems requirements document might be published as DIN 57XXX, DIN-VDE 0XXX or VDE 0XXX. The only difference is the publication series: the contents are unchanged.

6.4.3.1.1 Protection Against Electric Shock

- VDE 0100 Part 410, Installation of Power Plant with Rated Voltages Not Exceeding 1000 V: Protective Measures. This requirement discusses protection against electric shock. Major topics are protection against direct contact, protection against indirect contact, and protection by barriers and enclosures. In general, this standard is not very relevant to maglev systems since the nominal propulsion voltages in the feeders subsystems and the long stator subsystem are in excess of the voltages discussed in this standard.

- VDE 0101, Erection of Power Installations with Nominal Voltage Exceeding 1 Kv. This requirement is similar to VDE 0100, except for higher voltages, and therefore applicable. However, there is notice in this requirement that it does not apply to railways and that VDE 0115 should be consulted for railway applications.

- VDE 0115, Traction Systems: General Construction and Safety. This requirement is not applicable to maglev systems, since it pertains to grounding and associated potential problems due to the use of running rails as the return circuit as well as overhead contact systems and contact rails. This requirement applies to the wheel-on-rail railway, and is not relevant for many maglev electrical systems for which VDE 0101 should be used.

- DIN 40 050, Degrees of Protection Provided by Enclosures defines seven classifications of enclosures pertaining to egress by foreign bodies and contact with live surfaces, and nine classifications for protection against water entering the enclosure.

6.4.3.1.2 Grounding

VDE 0141, Earthing Systems for Power Installations with Rated Voltages Above 1 Kv addresses the design and construction of systems grounding, equipment grounding, static grounding and lightning protection. Methods of measuring earth resistance and calculating grounding conductor sizes are included. *Touch* and *Pace (Step* in the U.S.) potentials are defined. Maximum limits for touch potentials are given, but not for step potentials.

6.4.3.1.3 Disconnection

DIN-VDE 0101, Erection of Power Installations with Nominal Voltage Exceeding 1 Kv, previously discussed under the subject of electric shock, also discusses the means of disconnecting power. Rather than being a requirement applicable to equipment, this is a functional requirement that describes minimum clearances, prevention of accidental reclosing and remote control of the disconnect means. It is noted that Chapter 2 of the RW MSB specifies 1.2 times the clearance specified in this standard.

6.4.3.1.4 Cable Insulation

Fire characteristics of cable insulation play an important role in a public transit environment. Chapter 2 of the RW MSB specifies VDE 0266, Halogen-Free Cable with Improved Behavior During Fire. Work in the U.S. as well as efforts of the UITP have made transit operators as well as cable manufacturers aware of the need for improved fire safety in the area of electrical insulation. Halogen-free, low smoke, flame retardant cables conforming to either U.S. or German requirements should be specified.

6.4.3.1.5 Overload and Short Circuit Protection

This area of protection includes ground fault protection. The content of the requirements documents are as follows:

- VDE 0101, Erection of Power Installations with Nominal Voltage Exceeding 1 Kv. This requirement, in a rather generic manner, provides that monitoring and protecting for short circuits, overload conditions, and ground fault conditions must be provided for safety of persons as well as for proper operation of equipment.

- VDE 0160, Electronic Equipment for Use in Electrical Power Installations and Their Assembly into Electrical Power Installations. VDE 0160 requires electronic equipment incorporated into power equipment and installations to be capable of functioning after involvement in a fault on the power system.

6.4.3.1.6 Transformers

Transformers built to the applicable VDEs have been used on US transit systems in the past. In general, the requirements of VDE 0532 are equivalent to the ANSI/IEEE standards. It should not be a problem, either safety-related or quality-wise to use a transformer manufactured in accordance with VDE for a U.S. maglev system.

6.4.3.1.7 Switchgear

The VDE 0660 requirements for switchgear do not include a category that compares to the ANSI C37 requirements for metal clad switchgear. The VDE requirements are more in line with the ANSI requirements for metal enclosed switchgear. Safety concerns should dictate the use of metal enclosed switchgear. This should not be an obstacle impeding the successful design and construction of a U.S. maglev system. German manufacturers in the past have manufactured switchgear for application in the United States that meets the requirements of metal clad switchgear.

6.4.3.1.8 Rectifiers

The major differences between ANSI/IEEE and VDE requirements pertain to elements of the electrical design that are not actually safety-related. A rectifier manufactured to VDE 0558 would not affect the safety of a maglev system.

6.4.3.2 U.S. Requirements

U.S. requirements that are equivalent to the German requirements described above in each of the functional sub-areas are described below:

6.4.3.2.1 Protection Against Electric Shock

- NFPA 70, National Electric Code (NEC), is the primary U.S. requirement for protection against electrical shock. Although this requirement states that it is not applicable to railroads, it is commonly cited in transit specifications. It is one of the most widely used requirements for the "...practical safeguarding of persons and property from hazards arising from the use of electricity," as stated in the Purpose of the NEC, Article 90-1. This requirement could be applied to all auxiliary equipment rated at 600 volts or less, lighting systems, industrial substations (propulsion substations) greater than 600 volts, and cable installations.

- ANSI C2, National Electrical Safety Code (NESC), covers rules for safeguarding persons during the installation, operation and maintenance of electric supply and communications lines and can be applied to maglev systems.

- NEMA, Standard 250 Enclosures for Electrical Equipment (1000 V Max.), classifies 13 categories of enclosures for protection against entering by water and foreign bodies.

6.4.3.2.2 Grounding

IEEE Standard 142-1990, Recommended Practice for Grounding of Industrial and Commercial Power Systems, is the primary work of reference in the U.S. for grounding practices. Many of the issues discussed in VDE 0141 are covered in a similar manner in IEEE Standard 142. An exception is the matter of step and touch potentials, which are covered in IEEE Standard 80.

6.4.3.2.3 Disconnection

ANSI C2, National Electrical Safety Code (NESC), is similar in intent to VDE 0101.

6.4.3.2.4 Cable Insulation

Amtrak Specification 323, High Performance Wire and Cable Used on Amtrak Passenger Vehicles, appears to be broadly similar to VDE 0266. One notable difference is that Amtrak requires low temperature performance to be demonstrated at -55°C (+5°F) , while the VDE standard requires only -15°C (-67°F), illustrating the importance of climatic factors in some U.S. applications.

6.4.3.2.5 Overload and Short Circuit Protection

Overload and short circuit protection schemes and design philosophies are similar and for the purpose of evaluating safety requirements. There is little need to be concerned that one system would be safer than another system.

6.4.3.2.6 Transformers

The ANSI/IEEE C57, Distribution, Power and Regulating Transformers, standards for transformers would not give any advantage over use of the VDE standards in the areas of safety or of a quality product.

6.4.3.2.7 Switchgear

ANSI/IEEE C37, Circuit Breakers, Switchgear Relays, Substations, and Fuses, provides requirements for metal clad switchgear appropriate for use in maglev power supply and distribution systems.

6.4.3.2.8 Rectifiers

ANSI/IEEE Standard C34, Semi-Conductor Rectifiers (under revision), is comparable to the VDE requirements for the safety aspects of semiconductor rectifiers.

6.4.3.2.9 Railroad-Specific Requirements

Railroad specific requirements for electric power systems are contained in the FRA regulations described in 49 CFR, Part 229, the AREA Manual for Railway Engineering and the AAR Manual of Recommended Standards and Recommended Practices.

Electrical safety requirements are described in the locomotive safety regulations contained in 49 CFR, Parts 229.77 to 229.91. Parts 229.77, 79 and 81 apply to conventional railroad power collection systems and are not relevant to maglev systems unless similar equipment is used. Part 229.83 requires that all unguarded metal parts subject to becoming charged must be grounded or thoroughly insulated. Part 229.85 requires that all doors and covers protecting high voltage equipment must be provided with an appropriate warning sign. Part 229.87 requires that manual switches for over 150 volts must be covered and be operated from outside the cover. Parts 229.89 and 91 require that jumpers, cable connections, motors, and generators must be free of significant defects such as damaged insulation, broken connectors, or short circuits.

The AREA Manual contains only requirements specific to conventional railroad third rail or overhead catenary electrification systems. There are no requirements that could be applied to a maglev system, unless the maglev system uses railroad power collecting methods to transfer power to the moving vehicle.

Except for cable and wiring requirements, the AAR Manual, Section F, Locomotive and Electrical Equipment only provides requirements specific to conventional railroad locomotives such as the layout of inter-locomotive control line receptacles. The wire and cable requirements are based on general industrial requirements, but add a number of additional requirements for tolerance of extreme temperatures, mechanical strength, and crushing and abrasion resistance to ensure good performance in the harsh locomotive environment.

6.4.4 Comparison and Assessment

6.4.4.1 Protection Against Electric Shock

The reviewed VDE requirements cover issues addressed by both the NEC and the NESC. In general, they could be used interchangeably without compromising the safety of the system. DIN 40 050 and NEMA Standard 250 are comparable. Both requirements reference their classifications to a common IEC standard.

6.4.4.2 Grounding

Conceptually, the German and U.S. requirements appear to be the same. It would be necessary to check some of the calculations to compare the results obtained by applying both standards, which would be beyond the scope of this study. In addition, IEEE Standard 80 was not available for use in comparing touch potential recommendations.

6.4.4.3 Disconnection

The German and U.S. requirements are similar and cover, among other things, the methods of disconnecting power from equipment. In this case, the requirements would be applied to the method of disconnecting power from the long stator. It should be noted that both of these requirements cover conceptual ideas rather than applications. For example, the concept that a disconnect means is required for maintenance is included but not how to accomplish this disconnect in a practical manner, such as by the application of a circuit breaker or load break switch. The spacing of isolating links and bus spacing is specified in the VDEs, and modified by RW MSB, Chapter 2. No similar U.S. requirement could be located. It is pointed out in some sources that this is a matter of design experience. In addition to recommendations in the NESC, methods of safe operation of disconnect devices are usually covered in standard operating practices established by the agency having jurisdiction, commonly the system operator.

6.4.4.4 Overload and Short Circuit Protection

General U.S. requirements could not be located which specify the incorporation of electronic assemblies into power systems and the degree of protection required. It is a common practice to specify functional standards such as those in VDE 0160, and this requirement should be included in any system such as the high-speed maglev train.

Since it is a less obviously safety-critical concern, a more limited review was carried out of requirements pertaining to major items of electrical equipment. Some comments on the requirements for U.S. applications are provided below.

6.4.4.5 Cable Insulation

It would seem practical to use U.S. manufactured cable on a maglev system in the U.S., except for some possible termination problems due to the use of metric or English unit sizes of conductors. The concern of smoke and fire characteristics of wire and cable, considered vital in US transit installations, have been addressed in the VDE standards (VDE 0250 Part 503) and in this matter, there should not be any safety concerns in the use of VDE cable requirements.

6.4.4.6 Transformers

German manufactured transformers have been employed in the U.S. transit industry with excellent success. This experience demonstrates that the safety of German manufactured transformers is equivalent to transformers from U.S. manufacturers with regard to meeting U.S. safety requirements.

6.4.4.7 Switchgear

Based on experience in the industry, the German requirements are not as stringent as the U.S. standards for metal-clad switchgear. Experience shows that the German manufacturing facilities can meet the U.S. standards, although it is not their standard product. The vacuum circuit breakers produced in Germany do meet the U.S. requirements. Use of SF6 switchgear may be a good alternative.

6.4.4.8 Rectifiers

Based on experience in the industry, German and U.S. requirements are similar in regard to designing rectifiers for safe operation. There are some differences in philosophy and means of achieving safe operation. However, significant differences do not exist.

6.4.4.9 General Observations

Requirements for installation, operation, and maintenance were not reviewed. For many reasons, it is not considered practical to adopt "foreign" methods of installation, operation, and maintenance. An important factor in safety is familiarity with the equipment being worked on. It would not be in the interest of safety to use unfamiliar methods. Therefore, U.S. standards for installation, operation, and maintenance should be followed.

6.4.5 Findings

The use of good electrical engineering practice in maglev system electric power installations on the vehicle, on the guideway, and in wayside equipment is essential to minimize risks from electrical hazards such as electric shock, fire, or unacceptably frequent failures.

The FRA regulations for electrical installations in conventional locomotives contained in 49 CFR, Part 229 are applicable to maglev vehicles, but are limited to requirements for grounding and enclosures to minimize the risk of electric shock, and a maintenance requirement to keep electrical equipment in good order. The only other railroad-related requirements applicable to maglev vehicles are the AAR requirements for wire and cable. Otherwise, there are no U.S. railroad-related requirements for electric systems that could be applied to maglev systems. General industrial requirements for electric power systems are customarily used in the U.S. for electric railroad and rail mass transit systems.

Based on this review, it does not appear that significant differences exist between the German and U.S. general industrial requirements applicable to the electrical systems of high-speed maglev systems. In some cases, further study of the requirements, such as those involving grounding, should be conducted to confirm that the design methods and calculations specified are, in fact, equal or if one set of requirements is more stringent than the other.

Thus, either U.S. or German requirements could be used in confidence that a satisfactory installation would result. However, electrical equipment installed in a U.S. maglev system would probably come from U.S. suppliers and be installed by U.S. workers. German requirements would be less familiar to these suppliers and workers, and closer supervision would be needed to obtain a satisfactory result. Therefore, it is preferable that all wayside heavy-current electrical equipment, including the guideway-mounted stator packs, should follow, whenever possible, United States industrial requirements as specified in IEEE, NESC and NEC documents. For the most part, these are identical to or very similar to the German requirements cited by RW MSB. The same preference applies to on-board heavy-current electrical equipment such as the linear generator for transferring power to the vehicle and the systems for supplying the support and guidance magnets, and to on-board electrical power systems. Although support and guidance magnets are safety-critical components, adequate safety is achieved by using multiple independent systems rather than special electrical technology.

In summary, for U.S. maglev system applications, consideration should be given to the following safety requirements for the safe construction of electric power systems:

- For most system components, equipment and components manufactured to either DIN-VDE or U.S. requirements (IEEE/ANSI, NEC, NESC) may be used without affecting either electrical safety or system performance. However, equipment manufactured to U.S. requirements is preferred because personnel responsible for installation and maintenance will be more familiar with such equipment, leading to lower risk of errors.

- Metal-clad switchgear to ANSI/IEEE C37 should be required in preference to the German requirement VDE 0660.

- Cabling on the vehicle should be of a halogen-free low-smoke type with improved fire resistance which meets Amtrak Specification 323 or equivalent. Cabling to the German requirements is not suitable because of a more limited operating temperature range.

- Electrical power system design and equipment specification for the vehicle, guideway, and power supply substations should be subjected to a thorough independent review by a qualified engineer to ensure that all electrical safety concerns have been properly addressed.

6.4.6 Further Studies

Electrical safety encompasses a very large number of individual subsystems and devices. There are a large number of German, U.S., and international technical requirements applicable to such systems which have a bearing on system safety and the safety of individual pieces of equipment. Only a very preliminary review has been possible in this study. Further study to investigate the whole subject of electrical safety in greater depth is suggested.

6.5 FUNCTIONAL AREA 405 - ELECTROMAGNETIC INTERFERENCE AND ELECTROMAGNETIC COMPATIBILITY (EMI and EMC)

6.5.1 Description of Functional Area

This functional area addresses requirement for controlling Electromagnetic Interference (EMI) and providing for Electromagnetic Compatibility (EMC) in maglev electronic and electrical systems.

Electromagnetic radiation given off by an electrical or electronic subsystem or device can potentially degrade the performance of another subsystem on device to unacceptable levels. Safety-critical communication and electronic systems are particularly vulnerable to such interference. For Electromagnetic Compatibility (EMC), electrical and electronic systems must be tolerant of the ambient level of EMI, and at the same time limit their output of EMI to levels which can be tolerated by other equipment. Radios, solid state invertor, electric motors, fluorescent lights and many other components produce significant electromagnetic radiation.

Possible health effects of electromagnetic radiation or magnetic fields are not covered in this study, but are being addressed in a separate series of FRA studies.

Functional areas that are closely related to this functional area are:

Functional Area 105, Computer Safety for Vehicle and Operative Control Systems, discusses safety requirements for computer hardware and software. Computers have to be able to function satisfactorily in the ambient levels of electromagnetic radiation.

Functional Area 401, Operations Control System Design, and Functional Area 403, Communications, discusses safety-relevant technical requirements for these systems, which have to be tolerant of ambient levels of electromagnetic radiation.

Functional Area 404, Electric Power Systems, discusses technical requirements for systems which are a major source of EMI.

6.5.2 Safety Baseline

To ensure safe operation of electronic and communications systems installed on the maglev vehicle, along the guideway, and in control and communications installations, it is necessary to ensure electromagnetic compatibility between all equipment that may produce electromagnetic radiation and equipment that could be adversely affected by such radiation. Such compatibility is best accomplished by preparing an EMC specification and plan. The specification should detail minimum EMI tolerance levels for equipment that could be adversely affected by EMI, and maximum permitted levels of electromagnetic radiation for each major element of the maglev system (control centers, vehicles, power supply substations). EMI maxima should also comply with any applicable national regulations such as those of the FCC. The EMC plan should include programs for testing maglev subsystems and devices for EMI and EMC performance to confirm that specified requirements have been met.

6.5.3 Description of Existing Requirements

Existing requirements are listed in Table 6-6, and described below by country of origin under three headings: German, United States, and other foreign and international.

6.5.3.1 German Requirements

Chapter 10, Lightning Protection/EMC/ESD, of the RW MSB requires an EMC plan to prevent impermissible breakdowns and failures of a safety-relevant system due to EMI. This plan must include the following information:

- An assessment of the electromagnetic emission environment under normal operating conditions including location-dependent emissions such as those from a power supply substation or electrical transmission line.
- Structural assessment of the electromagnetic interaction between safety relevant systems.
- Specified performance criteria for safety relevant systems or subsystems.
- EMC measures adopted.
- Effectiveness of EMC measures in all relevant operational states of the vehicle, wayside and signal and train control equipment.

Measurements and tests, as specified by the VDE requirements described below, are required to demonstrate that the EMI levels and the effectiveness of the EMC measures adopted are in compliance with the plan.

VDE 0228, Measures Against Interference in Telecommunications Systems by Electric Power Installations, provides a discussion of general principles, including how to analyze the performance of a given communications installation. Detailed specific recommendations are given for protective measures to be taken against interference from AC electric power distribution systems, and in Parts 3 and 4 against interference from AC and DC railroad electric traction systems.

VDE 0839 (Part 10), Electromagnetic Compatibility, Evaluation of Immunity from Conducted and Radiated Disturbances, provides methods to evaluate the immunity of a subsystem to interference from electric power equipment. Specific test conditions are prescribed for each type of interference-causing equipment.

TABLE 6-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 405 - ELECTROMAGNETIC INTERFERENCE AND ELECTROMAGNETIC COMPATIBILITY (EMI AND EMC)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 10	Lightning Protection, Electromagnetic Compatibility, Electrostatic Discharge	Maglev
DIN VDE	0228 - Measures Against Interference in Telecommunications Systems by Electric Power Installations			General Industrial
E DIN VDE	0839	Part 16	Electromagnetic Compatibility Evaluation of Immunity from Conducted and Radiated Disturbances	General Industrial
DIN VDE	0843 - Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment (equivalent to IEC 801)	Parts 1,2,3		General Industrial
DIN VDE	0847 - Measurement Methods for Electromagnetic Compatibility	Parts 2 and 4		General Industrial
DIN VDE	0870 - Electromagnetic Interference - Terms			General Industrial
DIN VDE	0873 - Measures Against Interference from Electric Utility Plants and Electrical Traction Systems			General Industrial
DIN VDE	0875 - Railroad Interference: Suppression of Electrical Appliances and Systems			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 6-6. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 405 - ELECTROMAGNETIC INTERFERENCE AND ELECTROMAGNETIC COMPATIBILITY (EMI AND EMC) (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FCC	47 CFR, Federal Communications Commission	Parts 15 and 17	Regulations Regarding Maximum Acceptable Levels of Electromagnetic Emissions	General
FTA (UMTA)	MA-06-0153-85-8 - Test Procedures for Rail Vehicle Inductive Emissions from the Electrical Power Subsystems	-		Rail Mass Transit
FTA (UMTA)	MA-06-0153-85-6 - Test Procedures for EMI from Power Supply Substations and Propulsion Equipment			Rail Mass Transit
FTA (UMTA)	MA-06-0153-85-11 - Test Procedures for Broadband Emissions of Rapid Transit Vehicle (140KH2 - 400MHZ)			Rail Mass Transit
U.S. Government	MIL STD 461B - Limits and Requirements for Electromagnetic Emissions			General/ Military
U.S. Government	MIL STD 462 - Measurement Techniques for Electromagnetic Emissions and Susceptibility			General/ Military
UIC	737-3 - Application of Thyristors in Railway Technology 737-4 - Measures for Limiting the Disturbance of Light Current Installations by Electric Traction			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

VDE 0843, Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment, is a comprehensive guide to the kinds of EMI that can be expected in different operating environments, and EMI test procedures.

VDE 0847, Procedures for the Measurement of Electromagnetic Compatibility, addresses both radiated (Part 4) and conducted (Part 2) disturbances. Detailed descriptions are provided of test apparatus and procedures.

VDE 0870, Electromagnetic Interference, Terms, provides definitions of terminology used in studying and analyzing EMI.

VDE 0873, Measures Against Radio Interference from Electric Utility Plants and Electric Traction Systems, Part 2 provides limits of high frequency interference with radio reception, and procedures to measure and assess the interference of traction and power supply systems. This requirement particularly concentrates actions to reduce the level of EMI at its source.

VDE 0875, Railroad Interference; Suppression of Electrical Appliances and Systems, Parts 1, 2, and 3 provide limits for high frequency interference with radio reception, and procedures to measure and assess the interference from electrical apparatus such as portable tools, small appliances and semiconductor devices. The limits given in this requirement correspond to legal limits for electromagnetic radiation from small power tools, household appliances and similar products.

6.5.3.2 U.S. Requirements

FCC regulations contained in 47 CFR, Parts 15 and 18 provide general requirements for maximum levels of radiation and testing procedures for equipment which may produce electromagnetic emissions. These mandatory regulations specify maximum acceptable levels of electromagnetic radiation from all kinds of equipment that may produce such radiation. Products and equipment must be certified as being in compliance with the regulations before sale or use.

Several studies of electromagnetic interference have been conducted on urban rail transit systems for the Federal Transit Administration (formerly UMTA) to develop measurement techniques for EMI:

- UMTA-MA-06-0153-85-8 (DOT-TSC-UMTA-86-6) provides test procedures to measure the inductive emissions of a rail vehicle's electrical power subsystem and the susceptibility of audio-frequency rate coded signaling systems to EMI. This and the other UMTA documents mentioned below are measurement techniques, and do not provide acceptability limits or recommendations.

- UMTA-MA-06-0153-85-6 (DOT-TSC-UMTA-86-7) provides test procedures to measure conducted EMI from electric rail transit system propulsion equipment and substations, as well as the susceptibility of audio frequency rate coded signaling systems to EMI.

- UMTA-MA-06-0153-85-11 (DOT-TSC-UMTA-87-4) provides test procedures to measure the radiated broadband emissions of rapid transit vehicles (140 KHZ TO 400 MHZ).

MIL-STD-461B provides limits and requirements for EMI emissions generally.

MIL-STD-462 provides measurement techniques for EMI emissions and susceptibility.

6.5.5.3 Other Foreign and International Requirements

The UIC Codes 737-3 and 737-4 provide some general guidelines regarding methods to reduce the level of interference from thyristor-controlled power systems (such as AC motor drives and DC choppers) by suitable filtering and other methods, and to shield communication cables and similar equipment from interference. Recommendations are provided for test programs to identify EMI problems on new or newly electrified railway lines. Neither document is very detailed, and specific numerical limits for EMI are not provided.

6.5.4 Comparison and Assessment

EMI clearly has the potential to affect the performance of safety-critical electronics and communications systems used in a maglev system. A maglev system relies on radio communication and many sensors and electric systems for safe and reliable operation. Maglev systems also use many power electrical systems such as for levitation and power supplies on the vehicle, the long-stator linear motor on the guideway, and power supply substations, which are potentially powerful sources of interference. Therefore, proper management and control of EMI will be essential, as required by the RW MSB.

The reviewed documents address two areas of concern in connection with electromagnetic interference: requirements providing limits on acceptable levels of EMI, and test methods to measure both the EMI environment, and the tolerance of different types of equipment for EMI.

The RW MSB specifies a process to be followed and references VDE requirements for detailed procedures and acceptability limits.

With regard to limits, compliance with the FCC limits is clearly mandatory for any maglev equipment operated in the United States. Since these requirements are relatively complex, a detailed comparison of the German and FCC requirements is beyond the scope of this study. However, a maglev system manufacturer will have to demonstrate compliance with FCC requirements.

Most of the testing methods described in the German requirements (such as VDE 0843, VDE 0847, and VDE 0873), as well as the MIL-STD requirements appear to be designed for static sources. Thus, they appear to be suitable for the assessment of mutual interference between different guideway installations and between different vehicle-borne systems. Only the

UMTA requirements address the effects of moving vehicles on their surroundings, and may be the most appropriate requirements for a US maglev system EMI/EMC assessment.

With regard to overall procedures, the RW MSB requirement for the development of an EMI/EMC plan, covering both the assessment of emissions from all maglev electrical and electronics systems and the sensitivity of sensor, communications, and computer systems to EMI is clearly highly appropriate. Remedial measures must be instituted if any lack of electromagnetic compatibility is identified in such an assessment program.

6.5.5 Findings

Given the reliance of a high speed maglev system on electronic and computer controls for many safety critical functions, proper attention to electromagnetic interference, and electromagnetic compatibility between the different electric power and electronic systems is clearly essential.

There are no FRA safety requirements for EMC and EMI, but maglev systems will be required to conform with FCC requirements for electromagnetic emissions, contained in 47 CFR, Parts 15 and 18.

Otherwise, the practice in the railroad and rail transit industries has been to define maximum acceptable levels of EMI and ensure that the emissions for all electrical equipment do not exceed the maxima. The RW MSB specifies an equivalent approach by requiring the preparation of an EMI/EMC plan for a maglev system. U.S. or German requirements for testing and assessment techniques provide useful guidance, but the testing procedures developed by the FTA for rail mass transit systems appear to be the most suitable for application to U.S. maglev systems.

For U.S. maglev system applications, consideration should be given to the following EMI/EMC safety requirements:

- Compliance with FCC regulations regarding electromagnetic emissions (47 CFR, Parts 15 and 18) is mandatory for maglev equipment to avoid unacceptable interference with radio communications.

- A detailed plan to ensure EMC in both wayside and vehicle-borne systems must be prepared. The plan should include expected sources and levels of EMI, identification of equipment that could be affected, test procedures, and proposed countermeasures where these are shown to be necessary.

- Both emission levels and susceptibility to interference of safety-critical systems should be tested to establish compatibility of vehicle-borne and wayside equipment. Tests should include those for both conducted and radiated emission, using established test techniques such as those given in the UMTA reports and MIL-STD-462.

6.5.6 <u>Further Studies</u>

It is recognized the EMI and EMC are complex subjects which have received extensive study in the guided transportation field and elsewhere. This assessment of available information has necessarily been limited. Further research is desirable to better understand the safety issues associated with high power electric propulsion and electromagnetic levitation systems situated in close proximity to safety critical electronics and communication systems, and the ways in which similar problems have been addressed by conventional electric railroads.

6.6 FUNCTIONAL AREA 406 - LIGHTNING PROTECTION

6.6.1 Description of Functional Area

The possibility exists of the maglev vehicle, the guideway, or other maglev installations such as buildings, electric power substations, or the control center being struck by lightning. This risk varies with the location of a maglev system in the United States, but can be significant in some parts of the country and higher than that normally experienced in Europe. A lightning strike could result in a fire, injury to people in maglev vehicles or installations, and electric power surges damaging to safety-critical equipment such as operations control systems. Thus, it is necessary for all maglev installations and vehicles to be equipped with suitable protection against the consequences of a lightning strike.

This functional area is closely related to other functional areas covering safety-related equipment that could be damaged by a lightning strike. The relevant functional areas are 105, Computer Safety for Vehicle and Operations Control Systems; 401, Operations Control System Design; 403, Communications; and 404, Electric Power Systems. All equipment covered by these functional areas could potentially be damaged by lightning, leading to at least a disruption in maglev operations, and possibly an unsafe vehicle or guideway condition.

6.6.2 Safety Baseline

Maglev vehicles and installations vulnerable to damage from lightning must be provided with adequate protection systems to minimize the risk of personal injury, fires, or equipment damage. The equipment and systems that require protection and the kinds of protection required are as follows:

- A fire or direct injury to vehicle occupants due to a direct strike, sideflash or step voltage. Provision of an appropriate electrical path to ground is the customary approach to protection.

- Appropriate insulation and surge protection devices are required to prevent damage to safety-critical vehicle control systems due to voltage surge, including those which control the following subsystems:

  - levitation and guidance system
  - emergency brake system
  - vehicle location system
  - vehicle to wayside communications
  - wayside switch controls

- Appropriate protection against damage to wayside operations control equipment or electric power supply installations either due to fire or an electrical overload.

6.6.3 Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6-7 and described below by origin under three headings: German, U.S., and other foreign and international.

6.6.3.1 German Requirements

Chapter 1 of the RW MSB, System Properties, Especially Safe Hovering, addresses the direct risk of personal injury from lightning strikes, and the risk of damage to vehicle-borne equipment that would impair hovering and emergency braking capabilities. Section 3.4.1 of Chapter 1 requires a low resistance path for lightning from the vehicle body to ground via the vehicle suspension, support skids, magnetic levitation or guidance units, the guideway long-stator motor or reaction rails and the guideway structure.

Chapter 10 of the RW MSB, Lightning Protection/EMC/ESD, provides lightning protection requirements for maglev systems in Germany. Section 2 of Chapter 10 identifies the specific equipment that is exposed to a lightning strike, and specified appropriate countermeasures which should be taken to prevent unacceptable risk to persons or equipment damage. The technical requirements documented in the DIN and VGs are referenced for the details of lightning protection, as described below.

VDE 0185, Lightning Protection Systems, is a general guide to lightning protection systems for buildings and electrical equipment. The guide covers building protection via external conductors to ground, methods to equalize metal structures and equipment within buildings, overvoltage protection of electric circuits and equipment, and testing methods. Part 2 of VDE 0185 provides specific recommendations for different types of structures, including bridges, telecommunications towers and buildings requiring a specially high standard of protection.

VG 96900 and 96901, Protection Against Nuclear Electromagnetic Pulse and Lightning Strike, provides specific recommendations for protection of electrical and electronic systems against an electromagnetic pulse, and a definition of the design-pulse strength to be used in design.

Two reports have been prepared by Thyssen-Henschel for the Transrapid system regarding lightning protection. These reports are summarized below:

- Analysis of Lightning Protection for the Transrapid Magnetic Railway (July 18, 1990) provides an analysis of the effects of a lightning strike on a maglev vehicle. The results showed no dangerous effects inside the vehicle body, but possible risk of damage to sensors adjacent to the guideway structure. Careful shielding of such sensors and their cables will be required.

- Evaluation of Lightning Protection Analyses for the TR 07 (Thyssen-Henschel, August 29, 1990) also draws attention to the need for careful specification and installation of under-vehicle sensors and equipment to minimize the risk of damage from lightning discharge.

TABLE 6-7. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 406 - LIGHTNING PROTECTION

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1 Chapter 10	System Properties, Especially Safe Hovering Lightning Protection/ Electromagnetic Compatibility/ Electrostatic Discharge	Maglev
Thyssen/Henschel	Doc No. GT-900830-0209 - Analysis of Lightning Protection for the Transrapid Magnetic Railway			Maglev
Thyssen/Henschel	486 DOC. TV 8341 1 - Evaluation of Lightning Protection Analyses for the TR 07			Maglev
DIN VDE	0185	Parts 1 and 2	Lightning Protection Systems	General Industrial
VG 96900 VG 96901			Protection Against Nuclear Electromagnetic Pulse and Lightning Strike	General Industrial
FAA	14 CFR, Aeronautics and Space Part 25, Airworthiness Standards Transport Category Airplane	Part 25.581	Lightning Protection	Commercial Aircraft
		Advisory Circular AC 20-136	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning	Aircraft

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 6-7. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 406 - LIGHTNING PROTECTION (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
ANSI/UL UL	96-1988, 96A - Lightning Protection for Buildings and Structures			General Industrial
AAR	Manual of Standards and Recommended Practices	Signals, Section 11.1	Grounding, Protection and Surge Protection Guidelines	Railroad
NFPA	78 - Component and Installation Requirements for Lightning Protection Systems			General Industrial
ANSI/IEEE	C3790-1 1974 - IEEE Guide for Surge Withstand Capability Tests			General Industrial

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

6.6.3.2 U.S. Requirements

FAA requirements for transport category airplanes contained in 14 CFR, Part 25.581 require that airplanes must be protected against the catastrophic consequences of a lightning strike by appropriate electrical bonding of metallic components, and provided with the means of minimizing the effects of a strike or diverting the resulting electrical current for non-metallic components.

The FAA Advisory Circular (AC) 20-136, Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning, requires a structured analysis and evaluation process to be followed to ensure that adequate precautions have been taken against lightning. The process involves analyzing likely lightning strike effects on airplane interior electrical circuits (voltage or current levels), comparing these with equipment sensitivity to the voltage or current levels, and taking protective action where levels are above those that can be tolerated by the equipment. Test methods to verify protection performance are described.

Underwriters Laboratories documents ANSI/UL 96 and 96A, Lightning Protection of Static Buildings and Structures, provides a comprehensive guidance but specifically excludes electrical power distribution installations.

National Fire Protection Association (NFPA) 78, Component and Installation Requirements for Lightning Protection Systems also provides comprehensive requirements for buildings, excluding electric power distribution installations.

The AAR Manual of Standards and Recommended Practices for Signal and Communications Systems, Section 11.1 specifies requirements for the grounding and surge protection of signal installations.

ANSI/IEEE C3790-1, 1974 IEEE, Guide for Surge-Withstand Capability Tests, is the basic requirement for the protection of electrical and electronic equipment, and for devices to provide this protection.

6.6.3.3 Other Foreign and International Requirements

No relevant requirements have been identified.

6.6.4 Comparison and Assessment

Available data indicates that there is a much higher incidence of and more powerful lightning strikes in parts of the United States relative to Germany. U.S. requirements have been developed for the U.S. environment and thus may provide more appropriate lightning protection than requirements developed in Europe. However, the general requirements for building protection contained in VDE 0185 and in the NFPA and UL requirements appear to be broadly similar.

Specific lightning protection requirements for buildings are developed by state and local government authorities and may form part of local building codes. These codes are often based on national requirements such as those published by UL or NFPA. Compliance with local codes is normally mandatory.

The requirements for lightning protection analysis for aircraft in FAA AC 20-136 are generally similar to the analyses performed by Thyssen-Henschel. Such analyses, and the tests specified in AC 20-136 are highly desirable to confirm that safety-critical equipment in the vehicle will survive a lightning strike without loss of safety-critical functions.

6.6.5 Findings

A significant risk exists in the United States of maglev system equipment damage due to a lightning strike, and adequate protection is required against this risk.

The lightning environment in the U.S. can be significantly more severe than in Germany. Therefore, it would be appropriate to apply U.S.-derived lightning protection requirements to maglev systems in the U.S.

There are no FRA safety regulations for lightning protection for conventional railroads. The FAA, AC 20-136 requires a lightning protection analysis for aircraft, which would be applicable to maglev systems in the U.S.

Specifically, consideration should be given to the following lightning protection requirements for U.S. maglev system applications:

- All maglev structures and buildings including the elevated guideway should be protected to ANSI/UL 96 and 96A-1988, and to the requirements of state and local building codes. The protection system should be installed and inspected annually to UL requirements.

- Wayside power supply and power control systems (for propulsion and braking) should be designed to withstand lightning surges based on ANSI/IEEE C3790.1-1974 IEEE, Guide for Surge-Withstand Capability Tests.

- Wayside operations control equipment should be designed to the requirements of the AAR Manual of Recommended Practice for Communications and Signalling Equipment, and in particular to the requirements of Section 11.1 for grounding and surge protection.

- The vehicle should be provided with multiple conducting paths to the guideway (at least four) via support or guidance magnets or support skids. When in motion, the vehicle is non-contacting, but it is expected that lightning discharges will easily travel across the air gap of the magnets.

- The effects of lightning strikes on vehicle electrical and electronic equipment should be analyzed and tested using the methods of FAA AC 20-136 to verify that all safety-critical functions can survive a lightning strike. The analysis should be carried out assuming that the vehicle is supported on its levitation magnets at a normal working air gap and that the discharge of lightning energy to ground is via the guideway structure.

6.6.6 Further Studies

The lack of contact with the guideway in normal operation of a maglev vehicle means that the effect of a lightning strike on a maglev vehicle coule be unlike that on other ground transportation vehicles. Some further study is suggested into how lightning energy will be conducted to ground via the air gap and the guideway structure to ensue that no safety threat exists.

7. PERSONNEL AND OPERATIONS

7.1 FUNCTIONAL AREA 501 - QUALIFICATIONS AND TRAINING

7.1.1 Description of Functional Area

This functional area addresses qualifications and training requirements for all personnel engaged in maglev system operations and maintenance activities that affect the safety of the system. Staff at stations, on-board the vehicle, in operations control centers, and those responsible for the inspection and maintenance of vehicles, guideway structures and installations, electric power supply systems, operations control equipment and communications equipment are included.

Other functional areas which are related to this functional area are:

Functional Area 104, Quality Assurance, the requirements for which can be equally applied to operations and maintenance activities as to the manufacture of hardware.

Functional Area 209, discusses technical maintenance and inspection requirements for vehicles.

Functional Area 302, discusses technical maintenance and inspection requirements for the guideway.

Functional Area 402, discusses technical maintenance and inspection requirements for operations control equipment.

Functional Area 502, Operating Rules and Practices, specifies procedures to be followed to ensure the safe operation of a maglev system, including staffing requirements for particular maglev operating functions.

Functional Area 602, Emergency Plans and Procedures, part of which addresses the training of staff with regard to emergency response.

7.1.2 Safety Baseline

All personnel engaged in maglev system operations and maintenance activities must be adequately qualified and trained so that they can carry out their duties properly, and in ways that do not create danger either for themselves or for co-workers, or for members of the public using the maglev system. To accomplish this objective, the maglev system operating organization should specify the qualifications needed for each safety-relevant occupation, and carry out appropriate training and testing of all personnel.

7.1.3 Description of Existing Safety Requirements

The existing requirements in this functional area are listed in Table 7-1 and described below by origin under three headings: German, United States, and other foreign and international.

7.1.3.1 German Requirements

The RW MSB is primarily concerned with safety requirements for maglev design and construction. Staffing and operating requirements are not addressed, except for a requirement in Chapter 9, Operational Control Equipment, (Section 2.1.1.1) that the Operations Control Center must be continually occupied by professionally trained, suitable and competent personnel.

The draft MBO addresses personnel qualifications and training requirements in two sections.

- Section 1.6 states that personnel directly concerned with maglev system operation must be:
  - 21 years old
  - Free of any disabilities that would affect their capabilities to perform their duties (e.g., in vision or hearing)
  - Qualified, trained and tested to ensure that they can satisfactorily perform their duties
- Section 4.2 contains requirements for vehicle on-board staff, and guideway and Operations Control Center staff:
  - Capabilities of the on-board operator must be consistent with the requirements of the operators duties, which in turn are a function of operating and train-control equipment and procedures.
  - A responsible person must be in charge of each guideway segment.
  - A responsible person must be in charge of the Operations Control Center whenever the system is operating.

The EBO, Section 5, Personnel, provides a broad set of requirements for personnel on conventional railroads.

- Paragraph 47 defines the categories of operating and maintenance staff to which the regulations apply. These include train crew, dispatchers, car and track inspectors, and supervisory personnel in charge of these functions.
- Paragraph 48 defines health requirements, and specifies physical examinations to confirm that employees meet these requirements.

TABLE 7-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 501 - QUALIFICATIONS AND TRAINING

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 9	Operations Control Equipment	Maglev
German Government	Draft MBO	Section 1.6 Section 4.2	General/Personnel Requirements of Railroad Operation - Preconditions for Personnel	Maglev
	EBO, Railroad Construction and Traffic Regulations	Section 5	Personnel	Railroad
FRA	49 CFR	Part 240 Part 217 Part 219 Parts 213, 215, 217, 220, 229	Qualifications for Locomotive Engineers Railroad Operating Rules Control of Alcohol and Drug Use Qualifications to Perform Track and Vehicle Inspections	Railroad
FAA	14 CFR	Part 67 Part 43 Part 61 Part 63 Part 65	Medical Standards and Certification Aircraft Maintenance and Alteration Pilot Qualifications Other Air Crew Qualifications Qualifications for Maintenance, Repair, and Air Traffic Control	Aviation

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

- Paragraphs 49 to 52 specify age, vision, and hearing requirements. Minimum age of operating staff is 18 years, except vehicle operators who must be 21.

- Paragraph 54 specifies that appropriate training and testing must be provided so that operating officers and administrative personnel have the knowledge and skills to enable them to perform their duties. Locomotive engineers must pass a test.

7.1.3.2 U.S. Requirements

The FRA railroad regulation contained in 49 CFR, Part 219 requires that all prospective railroad operating employees receive pre-employment screening tests for drug and alcohol use. Employees are also forbidden from reporting for duty under the influence of alcohol or any drug not prescribed by a doctor.

49 CFR, Part 240 requires that all locomotive engineers must undergo a training program which meets specified criteria, and must pass a test to obtain a federal license. Retesting every three years is required. A description of the engineer training program and associated tests must be filed with the FRA by the operating railroad.

49 CFR, Part 217.11 requires that railroads shall periodically instruct operating employees in operating rules in accordance with a training program filed with the FRA. The program shall describe the content of the training program for new and existing employees and the frequency of refresher training.

In addition, several other FRA regulations contained in 49 CFR require that persons who perform safety-critical duties have appropriate training and experience.

- Part 213.7 requires that suitably qualified persons perform track inspections and supervise maintenance.

- Part 215.11 requires that car inspectors demonstrate that they are qualified to perform the required inspections of freight cars.

- Part 220 requires instruction in radio procedures to be given to any employee using radio communications in his or her duties.

- Part 229.21 requires that qualified persons be designated to perform the locomotive inspections required by FRA regulations.

The FAA regulations contained in 14 CFR include the following requirements with respect to personnel concerned with the operation and maintenance of aircraft:

- Part 43 requires that only persons holding a mechanic or repairman certificate from the FAA may perform maintenance, repairs and alterations on aircraft.
- Part 61 provides detailed instructions for the qualification of pilots, and flight instructors, including training, and written and practical tests. Pilots licenses are issued by the FAA.
- Parts 63 and 65 specify requirements for flight crew other than the pilot (engineers and navigators, not cabin staff), and for ground personnel, including aircraft maintenance and air traffic control personnel. In each case, a set of skills is specified, which must be demonstrated in a written test and in a period of probationary practical experience.
- Part 67 provides medical standards and certification procedures. A commercial airline pilot is required to have a first-class medical classification, specifying very good vision, hearing, and the absence of any medical condition that could lead to a hazard.

7.1.3.3 Other Foreign and International Requirements

UIC Code 966, Measures Intended to Promote Safety-Consciousness in Staff, focuses on requirements for specialized training and other means of promoting safety awareness such as lectures, films, meetings and awards for periods of accident-free operation.

7.1.4 Comparison and Assessment

With regard to the qualifications and training of operating and maintenance personnel, the documents reviewed vary in the level of detail with which the requirements are specified, but are otherwise similar. Elements found in most of these requirements are:

- Definition of occupations for which training and formal qualifications are required.
- The content of training programs and tests for new personnel in each occupation.
- The content and frequency of refresher training for existing personnel.

With variation in detail, requirements covering these three points are contained in the draft MBO, EBO, 49 CFR, Parts 213, 215, 217, 220 and 229, and the FAA aviation regulations contained in 14 CFR. In the case of railroads, the exact content of training and tests are the responsibility of the railroad in both the U.S. and in Germany. In commercial aviation, however, the training and testing of airplane pilots and maintenance personnel are directly supervised by the FAA. The FAA also specifies a minimum number of supervised operating hours prior to granting pilots licenses.

Health requirements for operating personnel are addressed in the MBO, EBO, and in the aviation regulations for aircraft pilots. Except for the special case of alcohol and drug dependence, health requirements are not addressed in U.S. railroad regulations, although individual railroads may have such requirements.

Some maglev occupations require personnel to be in good physical condition. For example, vehicle on-board personnel may have to help passengers in an emergency. Vehicle operator and control center staff must have good vision. Therefore, personnel health requirements will be highly desirable.

Except for UIC Code 966, none of the regulations address training specifically for safety awareness although most railroads will normally undertake such training together with other safety awareness activities. This subject is further discussed in Functional Area 502, Operating Rules and Practices, since it is an on-going activity as much as a qualification and training requirement.

7.1.5 Findings

The overall safety of a maglev system depends critically on the competence of personnel performing operating and maintenance functions. It is essential that such personnel be properly qualified and trained to perform their duties. Therefore, maglev system qualifications and training safety requirements are required.

Existing FRA regulations regarding alcohol and drug abuse, contained in 49 CFR, Part 219 are applicable to maglev system personnel. The FRA requirements for locomotive engineer training and licensing contained in 49 CFR, Part 240, are applicable in principle, but cannot be directly applied to a maglev system. High speed maglev systems will likely be highly automated, and the functions of an engineer have been replaced by the automated system and operations control center personnel.

Existing FRA regulations concerning the qualifications and training of inspection and maintenance personnel are applicable to maglev employees in principle, but more specific requirements on qualifications and training are desired. In an automated system, inspection and maintenance personnel are particularly critical in ensuring that the automated systems function correctly.

The RW MSB, MBO, and other non-U.S. requirements reviewed contain little guidance regarding qualifications and training. These findings are, therefore, based on adaptations of existing U.S. requirements.

For U.S. maglev system applications, consideration should be given to establishing formal qualification and training requirements for all personnel engaged in safety-critical activities, including the following:

- On-board operating personnel

- Control center and dispatching personnel

- Inspection and maintenance personnel

  - Vehicles
  - Guideway structures
  - Electric power supply
  - Operations control installations

- Supervisors and managers of operating and maintenance personnel

At a minimum, the qualifications and training specifications for each distinct occupation should include the following information:

- Minimum academic qualifications and/or past experience needed to be considered for employment should be specified.

- The specific content and duration of training for new personnel, or existing personnel seeking to move to a different or more advanced skill level, should be specified.

- Qualification tests for new personnel (written and practical) in each skill area should be specified. Preferably, the tests will include simulated vehicle or system operations, including in emergencies.

- Specific content and frequency of refresher training and tests should be specified to ensure that existing skills are maintained.

- For direct "hands-on" operating personnel (such as on-board operators and control center personnel), a minimum period of supervised experience should be required before they can be permitted to perform duties alone.

Minimum personnel health requirements should be specified by the maglev system operator, related to the physical demands of each occupation in normal operation and emergency conditions.

All personnel should receive regular safety awareness training, in addition to occupational skills training, as part of an integrated safety management plan, as recommended in Functional Area 502, Operating Rules and Practices.

7.1.6 Further Studies

Only a limited review of qualification and training issues has been possible in this study. Further study is suggested into qualifications and training practices in comparable public transportation environments, such as airlines and automated mass transit systems, to develop suitable guidelines in this maglev system functional area.

7.2 FUNCTIONAL AREA 502 - OPERATING RULES AND PRACTICES

7.2.1 Description of Functional Area

Operating rules and practices comprise the formal requirements governing day-to-day operations of a maglev system and the conduct of personnel involved in vehicle operations. Rules and practices may be generally applicable systemwide or may be applicable to specific locations on a system. Operating rules and practices cover procedures for authorizing and controlling vehicle movements and any activity that affects the status of the guideway (such as maintenance and inspection work), procedures for responding to system malfunctions or emergencies of all types, routine pre-departure safety checks, permitted hours of work for operating personnel, and similar matters.

The functional areas related to or having an interface with this functional area are:

Functional Area 401, Operations Control Systems Design. Operating rules are part of the operating control process and have to be consistent with the design of the operations control system.

Functional Area 403, Communications, is also closely related to the operations control process both in normal operations and after an accident or malfunction, and operating rules should include communication procedures.

Functional Area 501 covers requirements for personnel qualifications and training.

Functional Area 602, discusses emergency plans and procedures.

7.2.2 Safety Baseline

Safe and efficient high-speed maglev operations will depend on adherence to appropriate operating rules and practices. Even though the operations of a high-speed maglev system will likely be highly automated, operations will be monitored by operators who will be responsible for responding to abnormal situations and emergencies. Rules and practices are required for such situations, and also for other operational activities that may not be fully controlled by automated systems. Activities that may not be fully controlled by automated systems include work on or near the guideway or on vehicles away from a maintenance workshop, maintenance work on safety-critical systems, pre-departure safety checks, and voice-radio communications. Rules and practices may also be required for minimum staffing on the vehicle and in a control center, and to govern the hours of work and rest of operating personnel. Overall, operating practices should be aimed at ensuring all operating activities are appropriately staffed by alert individuals, who are equipped with appropriate rules and practices to cover every eventuality.

7.2.3 Description of Existing Safety Requirements

Existing safety requirements in this functional area are listed in Table 7-2 and are described below by origin under three headings: German, United States, and other foreign and international.

7.2.3.1 German Requirements

The RW MSB is primarily concerned with the technical installations of a high-speed maglev system, and not with operations. However, Chapters 4 and 9 of the RW MSB contain relevant information on operating requirements that reflect the interface between the technical installations and operating procedures.

Chapter 4 of the RW MSB, On Board Control System, specifies that the operators console on the vehicle should display all safety relevant vehicle information, such as the status of the vehicle levitation and guidance system, and door systems. The operator is responsible for permanent or periodic monitoring of this information (Section 4), and can initiate an emergency stop if needed. The operator is also responsible for monitoring and responding to a passenger-initiated emergency alarm (Section 9).

Chapter 9 of the RW MSB, Operations Control System, specifies that a vehicle movement over a segment of guideway may be permitted only if all the following conditions are satisfied (Section 2.2.2):

- The segment of guideway is not occupied by another vehicle.
- If the segment of guideway is moveable, the segment must be set and secured in the correct position.
- Precautions have been taken to ensure that there are no intrusions into the clearance required for the vehicle to move safely along the guideway; for example, from vehicles on connecting guideways, or from other technical insrallations.
- No previous authorities have been issued for another vehicle to occupy the guideway segment, and
- No other condition exists to block, and thus prevent, safe movement over the guideway segment.

Chapter 9 of the RW MSB (Section 2.1.1.1) specifies that the operations control center (OCC) must be staffed by qualified persons and provided with equipment displaying the status of the maglev system. The OCC staff are responsible for controlling vehicle operations within the constraints of the automated safety systems, including ensuring that all such systems are functioning correctly before initiating a normal service vehicle movement.

TABLE 7-2. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 502 - OPERATING RULES AND PRACTICES

Issuing Organization	Title and or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 4, Section 4 Chapter 9	Operators Console Operational Control Equipment	Maglev
German Government	Draft MBO	Section 1, Paragraph 1.4 Section 4	Basic Rules Railroad Operations	Maglev
	EBO	Section 4	Railroad Operations	Railroad
FRA	49 CFR	Part 217 Part 218 Part 219 Part 220 Part 228 Part 232 Part 236	Railroad Operating Rules Railroad Operating Practices Control of Alcohol and Drug Use Radio Standards and Procedures Hours of Service Power Brakes Signal and Train Control Systems	Railroad
AAR	Standard Code of Operating Rules	-		Railroad
Amtrak	NORAC Operating Rules, 4th Edition 1993			Railroad
UIC Code	734 - Adaptation of Safety Installation to High-Speed Operations 966 - Measures to Promote Safety-Consciousness in Staff 965 - Instructions Governing the Behavior of Staff Working on the Track			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

Section 1.5 of Chapter 9 states that a "special operation" mode must be used in the event of system breakdowns, construction or maintenance work or operationally necessary tests. The requirements for such operations are (Section 3.1) that maximum speed is limited to 50 km/h (30 mph), and movement of vehicles with passengers is not allowed, except to move to the nearest stopping point in the event of breakdown. Movements must be controlled from the vehicle, or from the OCC only when the vehicle is in sight.

Chapter 1 of the draft MBO, Section 1.7, states that the operator must develop an overall safety concept governing infrastructure, vehicles and operations, and submit this to the competent authority.

Chapter 4 of the draft MBO contains a number of relevant operating rules. These are:

- The length, weight, sequence and design of vehicles intended for a run must be compatible with the segment of guideway over which it is to operate, with respect to length of platform, load-bearing capability of the structures, and stopping distances.

- The safety braking system, and other safety-critical vehicle equipment must be checked prior to a run.

- Special precautions must be taken for the transport of hazardous materials.

- The preconditions for permitting operation at speeds above 50 km/h are:

  - The guideway must be unoccupied, with all moveable elements secured, and no conflicts from other permitted movements.

  - Automatic protection systems must be used to monitor guideway status and vehicle speed.

  - Running speed must be controlled so that the vehicle can always reach a safe stopping point.

- Manual control of a maglev vehicle at speeds exceeding 50 km/h (30 mph) must be supervised by an automatic system, or by a second operator.

- Parked vehicles must be safeguarded against unintentional movement.

The EBO, Section 4, Railroad Operation, specifies the following operating procedures for conventional railroads.

- A test of the brake system must be performed before the train leaves the originating station.

- The operation ("sequencing") of trains must be assigned to a dispatcher or traffic controller. A block system of signalling must be used for speeds exceeding 30 km/h (19 mph) in normal operation. Alternative methods of operation are allowed in emergencies.

- Functioning train control (ATC) equipment must be available for speeds in excess of 160 km/h (100 mph).

- One person operation of tractive units is permitted up to 140 km/h (87 mph). Two persons are required for speeds exceeding 140 km/h.

- A conductor is not required on passenger trains when doors are automatically operated, train control (ATC) is available, and the power controls have a dead man's handle.

7.2.3.2 U.S. Requirements

The FRA railroad safety regulations in 49 CFR contain several requirements for operating rules, as described below:

- Part 217 requires each railroad to file a current set of operating rules and location-specific operating instructions (timetables) with the FRA. There are no specific requirements for the content of these rules and timetables, except as mentioned below. Part 217 also requires that the railroad shall conduct periodic tests and inspections to monitor compliance with the rules.

- Part 218 requires railroad equipment which is undergoing inspection, maintenance, or repair must be protected by a blue signal, indicating that such work is in progress and that the equipment must not be moved or disturbed. Alternative equivalent means of protection such as locking the turnouts on an approach track are also permitted. Part 218 also requires that adequate means of protection must be provided against following trains when trains are moving on lines without block signals. Flags and fusees are the principal approved means.

- Part 219 requires that any person engaged in railroad operations shall not possess or be under the influence of alcohol or specified drugs. Specific rules are provided for the administration of this regulation and related testing procedures.

- Part 220 specifies procedures for radio voice communications in railroad operations, including transmission train orders and other instructions for train and vehicle movements.

- Part 228 limits the maximum continuous hours of duty of specified railroad operating and maintenance personnel to 12 hours in most cases. Covered employees include train crew, dispatchers, and employees engaged in signal and train control equipment maintenance. Minimum off-duty time is 8 hours, increasing to 10 hours following a 12-hour shift.

- 49 CFR, Parts 232.12 to 232.16 specify terminal and running brake tests that must be performed to ensure that brakes have been properly connected and are operating throughout the train.

- 49 CFR, Part 236.0 specifies the maximum operating speed as a function of signal system type. A block system is required for speeds of 97 km/h (60 mph) and above, and an automatic cab signal or equivalent for speeds of 129 km/h (80 mph) and above.

The AAR Standard Code of Operating Rules provides a baseline for operating rules used by most freight railroads. These rules are primarily concerned with the management of train movements under train-order instructions, and under the control of block and interlocking signals. Additionally, all railroads provide location-specific operating requirements (maximum speeds, what equipment can operate where, etc.) in timetables and other instructions.

Amtrak and commuter railroads use the Northeast Operating Rules Advisory Committee (NORAC) rules and timetables for Northeast Corridor operations. These cover operations on high-speed cab-signal track.

7.2.3.3 Other Foreign and International Requirements

Three UIC codes cover specific aspects of operating safety:

- Code 734, Adaptation of Safety Installations to High-Speed Operations, recommends that automatic train control be used at speeds above 140/160 km/h (87-100 mph), and that cab signals and automatic train protection systems be used at speeds over 200 km/h (125 mph).

- Code 965, Instructions Governing the Behavior of Staff Working on the Track, requires the clear delineation of safety responsibility for staff working on the track, and that a proper look-out be maintained. The process of obtaining permission to work, and the interface with the train control systems are not discussed.

- Code 966, Research to Promote Safety-Consciousness in Staff, discusses the contents of safety programs designed to keep employees aware of safety matters, including training, testing and media presentations.

Documents of rules for high-speed and conventional operations on individual foreign railroads are not available at present.

7.2.4 Comparison and Assessment

The RW MSB, draft MBO, EBO, FRA and other operating requirements reviewed all have a somewhat different focus, but appear to be complementary and do not conflict with each other. The RW MSB requirements in Chapters 4 and 9 cover some technical requirements for the automated operations control system, and indicate the responsibilities of the on-board operator and operations control center staff. Requirements for emergency operations under manual control are also specified. The focus of the draft MBO is on conditions for safe operation: compatibility between vehicle and guideway with regard to braking, headways, etc., confirming that the vehicle is in safe operating condition, and that the guideway is clear of obstructions and other vehicles. The draft MBO also specifies that speeds over 50 km/h (30 mph) must be supervised by an automated system, or a second on-board operator must be provided.

Among conventional railroad requirements, the EBO requires pre-departure brake tests, but otherwise focuses on signal and train control requirements for different speeds of operation. UIC Code 734, and FRA 49 CFR, Part 236 also address signal and train control requirements by speed, as summarized in Table 7-3. Automatic train protection (ATP) is the basic requirement for high-speed operations, whether a vehicle is under manual or automatic control. An ATP system continuously monitors actual speed vs authorized speed, taking into account guideway conditions and vehicle braking capability, to ensure that safe speeds are not exceeded. More detailed discussion of the technical requirements for operational control systems is provided in functional area 401.

Table 7-3. COMPARISON OF SPEED AND SIGNAL SYSTEM REQUIREMENTS

Maximum Speed of Operation (km/h)					
Requirement Source	**Manual Control, no signals**	**Block Signalling**	**Cab Signals and/or ATC**	**Cab Signals and ATP**	**Full Automation**
FRA 49 CFR, Part 236	95	127	177	-	-
MBO	50	N/A	N/A	All speeds over 50	-
EBO	30	160	Over 160	-	-
UIC 734	-	140/160	200	All Speeds over 200	-

The FRA requirements are concerned with drug and alcohol abuse, protecting persons carrying out vehicle maintenance, radio communications, and hours on work, none of which are covered in other requirements documents, and all of which are relevant to maglev operations. The FRA requirements also require pre-departure and running brake tests, a requirement that is also found in the draft MBO and EBO.

As well as signal requirements, the UIC codes address the safety of working on the guideway. and in Code 966, the more general question of safety management. Although not strictly concerned with the management of vehicle movements, safety management should be included in a maglev systems' day-to-day practices. A structured procedure to identify and correct safety problems before they cause an accident is highly desirable.

Overall, the requirements identified include many individual elements that should be included in comprehensive maglev system operating rules, but do not constitute a complete set of operating rules.

7.2.5 Findings

Carefully formulated operating rules are essential to the safety of any HSGGT system, however highly automated. The automated systems cannot provide full protection at all times and for all activities. For example, proper procedures are necessary for staff working on or near the guideway, and to perform maintenance on safety critical installations. Manual operating procedures are needed in the event of a failure of the automated system, and for certain slow-speed movements.

Existing FRA regulations regarding drug and alcohol abuse (49 CFR, Part 218) and the requirement for filing operating rules and instructions with the FRA (49 CFR, Part 217) are applicable to maglev operations in the United States.

Other than these two requirements, the intent of existing railroad operating rule requirements from the FRA, AAR, Amtrak, and EBO are applicable to maglev operations, but adaptations are required because of the automated operations and the different functions of on-board and control center personnel. The German RW MSB, and draft MBO requirements are also applicable to U.S. maglev operations, but do not address all the safety issues normally covered by operating rules.

For U.S. maglev system applications, consideration should be given to requiring, at a minimum, that comprehensive rules and procedures be required for the activities, situations, and subject areas listed below:

- Terminology used in maglev operations should be defined.

- The maximum permitted speed of operation without a functioning ATP system should be specified.

- Detailed operating rules should be provided for maglev train movements under normal control, including pre-departure ATP and brake system tests and other actions by both on-board and control center staff.

- Operating procedures should be specified for maglev train movements under emergency manual control following a malfunction of train control or power supply systems.

- Procedures should be specified for the protection of staff working on or near the guideway and/or performing maintenance and inspection duties. In particular, procedures should be provided for disabling any portion of the power supply, signal or communication systems, and for physical occupation of the guideway by equipment or personnel.

- Procedures should be specified for the protection of a vehicle on which maintenance or inspection work is being performed outside the regular maintenance shop.

- Procedures should be provided for voice radio communication during normal operations, for manual operations, and in emergency situations. These procedures could be adapted from existing railroad radio communications requirements in 49 CFR, Part 220.

- Maximum hours of service and minimum rest periods between on-duty periods for operating staff should be specified, including vehicle operations and control center staff.

- A timetable should be prepared giving speed limits for all points on the network, and other location-specific operating requirements.

7.2.6 Further Studies

Further study to develop a model code of operating rules, which would be equivalent in function to the AAR code or the "NORAC" rules is suggested, using existing rules and the above recommendations as a starting point.

Consideration should also be given to developing safety management guidelines which incorporate the requirements of UIC Code 966. Good safety management involves ensuring that staff at all levels are aware of safety responsibilities, that a good reporting and follow-up system is in place for potentially unsafe conditions and events, and that periodic audits are made to ensure that the safety management program is being conducted properly.

8. EMERGENCY PREPAREDNESS

8.1 FUNCTIONAL AREA 601 - EMERGENCY PLANS AND PROCEDURES

8.1.1 Description of Functional Area

Procedures are needed for responding to any emergency that might develop on the high-speed maglev system that threatens the safety of passengers, employees or others, or which might cause significant property damage.

Emergencies include fires on the vehicle or guideway, a collision, injury or sudden illness of a vehicle occupant, or stranding of an occupied vehicle away from a station or designated stopping place. Inadequate plans and procedures can lead to a delayed response to an emergency and a higher number and severity of casualties. This functional area discusses the preparations and plans that are required for an effective response to these emergencies. Other functional areas provide information on system design features and equipment that address emergency response needs. Specifically, these are:

Functional Area 101, System Safety, describes the overall system safety approach applicable to high-speed maglev systems, including the roles of emergency plans and procedures.

Functional Area 205, Fire Safety, discusses the requirements to minimize the occurrence and severity of on-vehicle fires.

Functional Area 403, Communications, provides information and requirements for communication systems, including those for emergency communication.

Functional Area 602, Emergency Features and Equipment, Including Access and Egress, addresses emergency access to and egress from a disabled maglev vehicle, and other emergency features and equipment required to respond to on-board emergencies and malfunctions.

8.1.2 Safety Baseline

Emergency plans and procedures should address all preparations needed for an adequate emergency response, including:

- Identification of the types of emergencies for which the plans and procedures have been prepared.

- Content of plans and procedures for responding to the identified emergencies.

- Requirements for training, rehearsals and drills to familiarize maglev system personnel with the procedures and their responsibilities.

- Requirements for coordination with community emergency services such as fire, police and ambulance.

- Location and readiness requirements for emergency equipment and vehicles.

- Definition of the roles and responsibilities of vehicle crew, operations control center and other parties during an emergency, including lines of communication.

8.1.3 Description of Existing Safety Requirements

The existing safety requirements in this functional area are listed in Table 8-1 and described below under three headings: German, United States, and other foreign and international.

8.1.3.1 German Requirements

Chapter 1 of the RW MSB, System Properties, discusses the overall emergency response philosophy adopted for high-speed maglev in Germany. This philosophy is to ensure that the maglev vehicle is always capable of reaching a "designated stopping place" in an emergency. Once at a stopping place, occupants can leave the vehicle and move to safety, and emergency services can be provided. This philosophy, and the accompanying design and equipment requirements for maglev vehicles and facilities, are discussed in Functional Area 602, Emergency Features and Equipment, Including Access and Egress.

Chapter 12 of the RW MSB, Rescue Plan, provides some detailed requirements regarding emergency plans and procedures, the most important of which are as follows:

- Emergency planning should involve local rescue services, such as police, ambulance, and fire departments.

- The planning should take into account the proximity of hospitals, police and the availability of access roads for emergency vehicles.

- The rescue plan must be submitted to the competent supervisory authorities or to an expert commissioned by the authorities for inspection. Periodic rescue exercises must be conducted, especially of the stopping place plan for rescue operations between regular stations.

- On-board conductors are required to be trained to provide passenger safety in the event of an emergency. In particular, they are required to be trained in first aid, and in the use of rescue equipment.

TABLE 8-1. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 601 - EMERGENCY PLANS AND PROCEDURES

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1 Chapter 12	System Properties, Especially Safe Hovering Rescue Plan	Maglev
German Government	Draft MBO	Chapter 3	Vehicle Para 3.4 Vehicle Compartments Para 3.7 Operator's Cab	Maglev
FRA	Recommended Emergency Preparedness Guidelines for Passenger Trains	Chapter 3		Railroad
Amtrak	Emergency Evacuation from Amtrak Trains NPRC 1910			Railroad
FTA	Emergency Preparedness Guidelines for Rail Transit Systems Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers		Chapter 2 Chapter 3	Rail Mass Transit Rail Mass Transit
NFPA	130 Fixed Guideway Transit Systems	Chapter 3 Chapter 6	Trainway Emergency Procedures	Guided Ground Transportation
FAA	AC 150/5200-31 Airport Emergency Plan			
BSI	6853 Fire Precautions in the Design and Construction of Railway Passenger Rolling Stock			Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

Section 1.7 of the draft MBO requires that the operator establish measures that will prevent the occurrence of accidents, minimize the consequences of accidents, support self-rescue and facilitate outside rescue. Measures to be taken in individual areas (e.g., infrastructure, vehicles, operations, rescue operations) must be combined into an overall concept and submitted to the competent authorities.

8.1.3.2 U.S. Requirements

An Amtrak manual, NRPC 1910, Emergency Evacuation from Amtrak Trains, provides detailed instructions for emergency entry to and egress from Amtrak passenger cars through regular doors and through emergency exits. Instructions are given for all car types operated. Instructions are also provided for emergencies in tunnels, which emphasizes that emergency evacuation from a train in a tunnel should be used as a last resort. The preferred action is to move the train to a safe evacuation point out of the tunnel, unless movement is impossible, or there is reason to believe that a derailment or personal injury would result.

Amtrak NRPC 1910 also provides details of all major tunnels through which it operates, including the location of emergency exits or refuges, and emergency communications via telephone or train radio. Emergency procedures specific to individual locations are also provided.

Chapter 6 of NFPA 130, Fixed Guideway Systems, provides detailed requirements for emergency plans and procedures. An emergency procedures plan should be prepared designating responsibilities of system personnel in an emergency, communication systems to be used and their operation, and detailed instructions for each kind of emergency. Coordination arrangements with community emergency services should be included. All personnel should be trained in the emergency procedures, and exercises and drills to test the procedures should be held twice a year. Particular emphasis should be given to the overall coordination of the emergency response by an operations control center, and control of actions at the scene of the emergency by a command post.

Recommended Emergency Preparedness Guidelines for Rail Transit Systems, published by the FTA (formerly UMTA), includes requirements for emergency response procedures. The guidelines provide detailed recommendations for the preparation of emergency response plans, including the definition of responsibilities for carrying out emergency actions, and documentation of the emergency procedures.

The guidelines also contain recommendations for providing initial and refresher training of rail transit system personnel in emergency procedures. Training should include both classroom sessions, demonstrations on-site, visits and tours, and periodic drills of different types, as appropriate. Local community emergency services (fire, police, ambulance) should be invited to participate in training activities, and also participate in the development of emergency plans.

The FTA has also published Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers, which addresses the unique needs of elderly and disabled passengers. Recommendations are provided to assist rail transit and emergency response organizations in evaluating their emergency response plans in terms of the needs of the elderly and disabled. Reviews of the special needs of the elderly and disabled in terms of access and egress, visibility, graphics, ventilation and communications in both vehicles and facilities such as stations are included. In particular, procedures are developed for assisting in the evacuation of elderly and disabled passengers. Training requirements in elderly and disabled needs are also specified.

The FAA has published an Advisory Circular (AC 150/5200-31) Airport Emergency Plan. This AC discusses emergency plan development, testing and maintenance, and covers plan preparation, exercises, and training.

The FRA is in the process of developing emergency preparedness guidelines for intercity and commuter rail passenger trains. The guidelines are being developed using concepts described in the FTA guidelines and the FAA Advisory Circular. However, the guidelines are being tailored to consider the unique operational environment of intercity passenger and commuter trains.

8.1.3.3 Other Foreign and International Requirements

British Standard, BS6853, requires the vehicle crew to give emergency evacuation instructions to passengers in the event of an emergency such as a fire. Instructions are to be given over the public announcement system, if available, or verbally.

8.1.4 Comparison and Assessment

In general terms, there is no significant conflict between the emergency procedures specified by the RW MSB, NFPA 130, the FRA, and the FTA. All emphasize:

- The need for advance planning of emergency response, including procedures to be followed systemwide in an emergency, and procedures for specific types of emergency, and for specific locations on the system.
- The establishment of clear responsibilities and lines of communication between vehicle crews, systems operation personnel and local emergency services, and between control centers and the scene of the emergency.
- The need to provide training to all personnel who may be involved in an emergency response, and to carry out regular drills and exercises.

The most critical question with regard to specific emergency procedures on a high-speed maglev system is response to an emergency on an elevated guideway away from a station or a designated emergency stopping place. The approach specified in the RW MSB is to make the vehicle systems so reliable that the accidental immobilization of a vehicle away from a station or designated stopping place is a very rare event. Only minimal means of egress from the vehicle are specified, using ropes for decent to the ground, and there is no requirement for vehicular access to the guideway other than at designated stopping places. In contrast to NFPA recommendations for fixed guideway transit systems require egress to be possible at any point, whether the track is underground, at grade, or elevated. Vehicular access to elevated track is required by NFPA at intervals not exceeding 762 m (2500 ft). As discussed and recommended in Functional Area 601, Emergency Features and Equipment, Including Access and Egress, access for emergency vehicles to all points of the guideway is recommended. Such vehicles can be used to aid evacuation, if necessary, and to otherwise respond to the emergency.

8.1.5 Findings

A high-speed maglev system will need emergency plans and procedures to ensure that the potential consequences of an emergency are minimized. Recommended guidelines for emergency plans and procedures have been developed for rail and fixed guideway mass transit systems, and are in preparation for conventional passenger railroads. When completed, the FRA emergency preparedness guidelines will provide a resource which the maglev developer and operator should use in developing emergency plan and procedures.

The emergency response needs of high-speed maglev systems will differ from those of existing rail systems because of the likely use of a relatively inaccessible elevated guideway. Procedures for responding to an emergency on this elevated guideway need special consideration. The procedures should be developed in the light of an assessment of the risks of the maglev vehicle becoming immobilized on an elevated guideway, either at a safe stopping point or elsewhere.

The maglev system developer and system operator should be required to 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.

For U.S. maglev system applications, special consideration should be given to developing procedures for responding to an emergency on an elevated maglev guideway away from a safe stopping place.

8.2 FUNCTIONAL AREA 602 - EMERGENCY FEATURES AND EQUIPMENT, INCLUDING ACCESS AND EGRESS

8.2.1 Description of Functional Area

This functional area addresses needs for emergency features and equipment for the maglev vehicle and guideway, including requirements for emergency access and egress. Emergencies may include an on-board fire, or a significant malfunction in a major vehicle or guideway system such as propulsion, braking, levitation and guidance, or operations control. In such an emergency, essential on-board systems such as ventilation and lighting may be affected, and it may be necessary to evacuate the vehicle at the first opportunity. Appropriate maglev system design features and equipment are required to ensure that adequate provision has been made for the safety of passengers and crew in such emergencies.

Several other functional areas interface with this functional area, as follows:

Functional Area 101, System Safety, discusses emergency response issues as a component of the overall system safety philosophy.

Functional Area 202, On-Board Operator and Crew Compartments, discusses emergency equipment and egress and access for operator's compartments.

Functional Area 203, Passenger Compartment Interiors, addresses "passive" accident survivability aspects of the vehicle interior.

Functional Area 204, Passenger Vehicle Doors and Entryways, discusses door requirements for normal operations.

Functional Area 205, Fire Safety, provides detailed requirements for minimizing the incidence and severity of on-vehicle fires, including requirements for fire detection and the numbers, types, and locations of fire extinguishers. A fire is one of the most important types of emergencies that might lead to vehicle evacuation.

Functional Area 601, Emergency Response Plans, details operational and procedural aspects of responding to an emergency. This plan must be closely aligned with the vehicle emergency features and equipment.

8.2.2 Safety Baseline

Vehicle occupants must be provided with reasonable protection against adverse consequences of a fire or major maglev system malfunction, and with adequate means of egress from the vehicle should a life-threatening situation develop. Provision is also required for access into the vehicle by rescue services. Specific vehicle features and equipment are:

- Provision of an adequate number of suitably sized emergency exits, to allow occupants to leave the vehicle quickly in an emergency such as a fire.

- Means for occupants to retreat to a safe place after leaving the vehicle, including when the vehicle is on an elevated guideway.

- Adequate consideration of the use of emergency exits by elderly and disabled persons.

- The availability of emergency access to the vehicle by rescue services.

- Provision of emergency lighting as a back-up to normal vehicle lighting.

- Provision of emergency means of communication between vehicle crew, the maglev system operations control center, and rescue services that may respond to an emergency.

- Provision of suitable signs and instructions for the location and operation of emergency vehicle exits and other safety-related features and equipment.

8.2.3 Description of Existing Safety Requirements

Existing safety requirements in this functional area are listed in Table 8-2, and are described below by origin under three headings: German, United States, and other foreign and international.

8.2.3.1 German Requirements

Chapter 1 of the RW MSB, System Properties, describes the overall emergency access and egress philosophy developed for high-speed maglev systems in Germany, and the detailed safety requirements which follow from the philosophy. The overriding requirement of this philosophy is that maglev vehicles must have the following capabilities, so that it can reach and stop at a "designated stopping place" at all times.

- Maglev support and guidance systems must have very high reliability so that the probability of an unintended stop away from a designated stopping place is very low. This capability is termed "safe hover" in the RW MSB.

- Very high reliability is required of the braking systems and brake controls (regular service and emergency brakes in combination) so that the maglev vehicle can always be brought to rest at a designated stopping place. This capability is termed "safe programmed braking" by RW MSB.

- Controlling vehicle speeds so that vehicles are always operating at or above the minimum speed needed to reach the next designated stopping place without external power.

TABLE 8-2. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 602 - EMERGENCY FEATURES AND EQUIPMENT INCLUDING ACCESS AND EGRESS

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Maglev Safety Requirements	Chapter 1 Chapter 12	System Properties, Especially Safe Hovering Rescue Plan	Maglev
German Government	Draft MBO	Section 1.7 Sections 2.2 and 2.3 Section 3	Safety Measures Stopping Places Vehicles	Maglev
UIC	560 Doors, Entrance Platforms, Windows, etc., of Coaches and Luggage Vans 564-2 Fire Safety 651 Layout of Drivers Cabs			Railroad
FRA	Emergency Preparedness Guidelines for Passenger Trains	Chapter 5 Chapter 6	Trains Facilities	Railroad
FAA	14 CFR, Aeronautics and Space Part 25, Airworthiness Standards for Transport Category Airplanes	25.803 25.807 and 809 25.811 25.812 25.813 25.1307 25.1411 and 1423 25.1561	Cabin Evacuation Performance Emergency Exits Emergency Exit Marking Emergency Lighting Emergency Exit Access Safety Equipment Public Address System Marking of Safety Equipment	Commercial Aircraft

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

TABLE 8-2. SAFETY REQUIREMENTS FOR FUNCTIONAL AREA 602 - EMERGENCY FEATURES AND EQUIPMENT INCLUDING ACCESS AND EGRESS (cont.)

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FTA	Recommended Emergency Preparedness Guidelines for Rail Transit Systems	Chapter 4 Chapter 5	Facilities and Equipment. Vehicles	Rail Mass Transit
	Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers	Chapter 4 Chapter 5	Vehicles Facilities	Rail Mass Transit
NFPA	130 Fixed Guideway Transit Systems	Chapter 3 Chapter 4 Section 4.5	Trainways Vehicles Emergency Egress	Rail Mass Transit
AAR	Manual of Standards and Recommended Practices	Section A	Passenger Car Requirements	Railroad
Amtrak	NRPC 1910 Emergency Evacuation from Amtrak Trains	-		Railroad
British Standards Institution	BS 6853 Fire Precautions in the Design and Construction of Railway Passenger Rolling Stock	Section 12	Aiding Passenger and Crew Escape.	Railroad

Note: Titles have been abbreviated in some instances. See Appendix B for full citation.

The reason for adopting the designated stopping place philosophy for emergency evacuation is the difficulty of providing emergency access and egress for a vehicle on an elevated guideway. The RW MSB points out that the situation of a maglev vehicle on an elevated guideway is similar to an airplane, where emergency access and egress can only be provided at an airfield.

Chapter 12 of the RW MSB provides comprehensive requirements for emergency access and egress using designated stopping places.

Section 2 requires, that as far as possible, the development of all situations (such as fire) that would threaten vehicle occupants must be delayed for sufficient time for the vehicle to stop and occupants to escape.

Section 3 specifies vehicle requirements which can be summarized as follows:

- A passageway with a 30-minute capability fire door must be provided between vehicles or vehicle sections.

- Emergency lighting of escape routes and exits must be provided.

- One safety rope per exit must be provided for emergency egress away from a designated stopping point, to be used when the guideway top surface is less than 20m (66 ft) above ground. Rescue slides are an acceptable alternative, provided they can function adequately from the elevated guideway.

- Longitudinal egress onto the top of the guideway is not acceptable.

- A passenger emergency signal. easily reachable by all passengers, must be provided in each vehicle. The signal informs the conductor of an emergency situation, and the conductor will initiate further action as appropriate.

- All emergency equipment must have suitable signs indicating location and instructions for use.

- Two independent communication installations for voice contact between vehicle and the operational control center are required.

- One first-aid kit per vehicle must be provided.

Section 4 describes the requirements for designated stopping places.

- Stopping places must be located so that there is always one within coasting and braking distance, assuming that propulsion power can be lost at any time, and taking into account all relevant speed, braking, gradient and wind effects.

- Stopping places should consist of a platform which is as long as the longest train plus an allowance for braking control tolerances. Egress will normally be via the regular vehicle doors. Steps or a slide should be provided to reach the ground where the guideway is elevated.

- A continuous walkway must be provided on major bridges and in tunnels.

- Stopping places should be accessible by emergency services, but be protected from unauthorized access, and should be equipped with communications equipment for contacting the operations control center and emergency services.

Section 2.3 of the MBO requires that auxiliary stopping places must allow safe egress and access for rescue teams, as well as being protected from unauthorized access. Section 3.4 requires specific emergency features and equipment in the vehicles as follows:

- Paragraph 16 requires voice communication between the vehicle and a manned control center.

- Paragraph 17 requires vehicle to be equipped with first-aid supplies.

- Paragraph 18 states that emergency exits must be provided.

The EBO requires provision of first-aid equipment in Paragraph 37.

DIN 5510 Part 6, Section 2 requires that passenger-operated alarms alert the vehicle operator or control center, but do not automatically stop the vehicle, to prevent the vehicle from stopping at locations where rescue is difficult. Paragraph 3.2 requires that the passengers be kept informed of the situation during an emergency by the vehicle operator or control center.

8.2.3.2 U.S. Requirements

The FRA regulation contained in 49 CFR, Part 223.15 requires a minimum of four emergency exit windows in a passenger car. There are no other FRA requirements for passenger car emergency features or equipment.

The FRA is developing recommended emergency preparedness guidelines for passenger trains. These guidelines describe recommendations for train equipment and features for emergencies and emergency evacuation.

The NFPA 130 Standard, Fixed Guideway Transit Systems, specifies emergency features and equipment of the vehicle or guideway. Evacuation from the vehicle must be possible at any point along the guideway through emergency exits on the vehicle. Access to an elevated guideway for emergency services must be provided at minimum intervals of 762 m (2500 ft).

Emergency lighting, a public address system, and vehicle-to-control center communications must be available and provided with an emergency power source.

The AAR Manual of Standards and Recommended Practices, requires the following features and equipment on intercity and commuter passenger cars, in Section A, Passenger Car Requirements:

- Provision of four emergency escape sash units of a minimum size of 0.46 m (18 in) x 0.61 m (24 in) in each car at readily accessible location.

- Sliding interior and exterior vestibule doors or other types that do not open inwardly or outwardly must be used.

- One set of wrecking tools are required per car, comprising a 2.7 kg (6 lb) sledge and a 1.9 kg (4 1/4) axe.

- Provision of battery-powered emergency lighting which is automatically activated if the primary lighting fails.

Amtrak document 1910, Emergency Evacuation from Amtrak Trains, provides detailed instructions for emergency evacuation from Amtrak vehicles both through regular doors and through windows. The following general points summarize typical conventional U.S. intercity passenger car emergency access and egress requirements, as indicated by Amtrak document 1910.

- All doors should be openable manually from inside and outside the vehicle. However, Amtrak staff may be required to de-activate the locks on automatically locked doors for access.

- Emergency exits are normally through two removable sash windows on each side of the car, in compliance with the FRA regulation contained in 49 CFR, Part 233.15. These are normally openable from inside, and can be opened by rescue services from the outside by removing the rubber molding which holds the glazing in place.

- Except for tunnels and bridges, Amtrak does not specify requirements for emergency escape once occupants have left the vehicle. Evacuation from tunnels and bridges are specified on a site-specific basis, since evacuation arrangements usually reflect the existing features of these structures.

In 14 CFR, Part 25.807-811, the FAA specifies requirements for emergency exits for commercial aircraft. Approximately one exit is required for every 30-40 seats. Except for crew compartment exits, exits must be openable from both inside and outside the aircraft. Opening means must be simple and obvious, not require exceptional effort and not take more than 10 seconds. Automatic evacuation slides are required at each exit and must be fully deployed less than 10 seconds after opening the exit. Tests must be performed to demonstrate that a fully occupied aircraft can be evacuated in less than 90 seconds through half the available exits. Emergency exits should be marked with illuminated signs, and clear operating instructions should be posted.

Other miscellaneous FAA emergency requirements of note are as follows:

- Part 25.812 requires the installation of emergency lighting independent of the main lighting system. The minimum light intensity for each part of the cabin is specified.

- Parts 25.831 and 832 require that the ventilation system must be capable of controlling concentrations of undesirable gases as follows:

  - Maximum carbon monoxide concentration: 1 part in 20,000

  - Maximum ozone concentration: 0.25 parts per million

- Part 25.1307 requires certain miscellaneous equipment to be installed in the airplane. Equipment relevant to a maglev operation includes:

  - A seat for each occupant.

  - Two or more independent sources of electrical power.

  - Two independent two-way radio systems.

8.2.3.3 Other Foreign and International Requirements

The provisions of UIC codes regarding emergency access and egress are as follows:

- UIC 560, Doors, Entrance Platforms, Windows, etc. of Coaches and Luggage Vans, requires that power-operated doors be manually operable from inside and outside the vehicle, including means to de-activate automatic locks. More details are provided in Functional Area 206, Passenger Vehicle Doors.

- UIC 564-1, Coaches-Windows Made from Safety Glass, requires two windows to be designated emergency escape windows in each car, one on each side. Emergency escape is achieved either by removing the whole window, or by breaking the window with a special purpose hammer. UIC accepts the use of safety glass that can be broken in this way.

- UIC 651, Layout of Drivers' Cabs, requires that an escape door and passage to the opposite end of a locomotive or cab-car be provided. Side exit from the cab through a removable or breakable window must also be possible.

The British requirements for rail vehicle fire safety, BS6853, address emergency egress in Section 12. The principal requirements are that all trains should have doors that can be used for emergency exits in the vehicle sides, or through the ends where side exit is not possible. Power doors must be manually openable from inside. Means of escape through fixed windows must be provided, such as hammers with hardened points that can be used to break safety glass. At least two such hammers should be provided in each car. Clear instructions for use of doors and other emergency features and equipment must be displayed.

8.2.4 Comparison and Assessment

The RW MSB emergency egress and access arrangements depend critically on the ability of a vehicle to reach a designated stopping place in an emergency. The designated stopping place must be either a regular station or an auxiliary stopping point equipped with a vehicle floor-level walkway parallel to the guideway and stairs to ground level.

The risk of a maglev vehicle stopping at a location other than a designated stopping place is considered to be very low. Therefore, only very limited means are recommended in the RW MSB for emergency egress in these circumstances - one "safety rope" per vehicle, which can be used when guideway elevation is less than 20 m (66 ft).

This approach requires a high operating reliability of vehicle levitation, guidance, speed supervision and braking systems. The vehicle must always have enough speed to coast to the next stopping place. The guideway must be undamaged and all the subsystems needed to control the emergency or service braking system must be functioning.

The primary concern with the "designated stopping place" approach to emergency egress from a maglev vehicle is that the continuing operation of several complex vehicle systems which could potentially be damaged by the same emergency (such as a fire) which led to the need for vehicle evacuation. A damaged or obstructed guideway could result in a stop, away from a designated stopping place. The vehicle may not be damaged, and occupants could await rescue without immediate risk, but they would eventually have to leave the stranded vehicle. A backup means of escape or rescue away from a stopping place that is more useable than the ropes appears to be desirable for maglev operations in the U.S., at least until system reliability has been demonstrated in service. Specific recommendations are made in Section 8.1.5 below.

While the designated stopping place approach may be acceptable if adequate system reliability can be demonstrated, it is not the only way of escaping from a vehicle on an elevated guideway. Other possibilities include:

- Use of aircraft-style escape chutes, mentioned in the RW MSB, as a possible alternative to a designated stopping place.

- Exiting onto the top of the guideway, provided some provision is made to safely walk there. The top surface is 2.7 m (9 ft) wide and the center portion does not have any propulsion, support, or guidance installations. However, this option is ruled out in the RW MSB.

- A continuous walkway alongside the guideway, required by the RW MSB for tunnels and long bridges.

Multiple approaches could be used depending on the configuration of the guideway at different points along the route.

The RW MSB specifies that emergency egress is through the regular vehicle doors. Separate emergency exits are not required. Detailed requirements regarding the operability of the doors in emergency conditions are not specified, for example, in case of loss of power.

Complete reliance on regular vehicle doors for emergency egress is also a concern. Requirements for conventional railroad vehicles (e.g., FRA 49 CFR 223.15, and UIC 564.1) provide for emergency exits through windows if doors are inaccessible or inoperable. UIC 560 and the FRA emergency preparedness guidelines also indicate the provision of manual means of opening power-operated doors from inside and outside the vehicle, both for use in an emergency and in the case of failure of the door-operating mechanism.

With regard to emergency features and equipment other than emergency egress, there is reasonable consistency between the requirements in the RW MSB, FAA regulations, NFPA 130, and the FRA emergency preparedness guidelines. The common ground covered by these requirements includes emergency signals for passenger operation, emergency lighting, signage, public address systems, and vehicle-to-operations control center communications. All of these requirements apply to existing transportation systems in the U.S. and appear to be suitable for application to high-speed maglev systems.

8.2.5 Findings

Maglev systems must be provided with adequate emergency features and equipment, especially to enable the safe evacuation or rescue of occupants from a damaged, on-fire or otherwise disabled vehicle.

Present FRA regulations specify only that conventional rail passenger vehicles should have four emergency exits through removable windows. This requirement is applicable in principle to a maglev vehicle, but should preferably be expressed in a way that can reflect the likely differences in vehicle size and seating arrangements between maglev and conventional rail vehicles. Other emergency requirements such as means of moving away from a disabled vehicle, and provision of emergency lighting, communications and public address systems are not covered by FRA regulations, but are addressed in other requirements discussed in this section.

The German RW MSB and the draft MBO requirements address the problem of emergency evacuation from a disabled vehicle on an elevated guideway by ensuring that the vehicle can always reach a safe stopping place. It is not clear that the safe stopping place will be adequate in all possible emergencies, and it may be necessary to consider alternative approaches, or at least carefully evaluate the risk of combinations of events that would prevent a vehicle reaching a safe stopping place.

For U.S. maglev system applications, consideration should be given to safety requirements for emergency features and equipment and emergency access and egress, as described below. in the RW MSB, and similar or equivalent requirements in NFPA 130, the AAR Manual, FAA Airworthiness Standards. ·When completed, the FRA emergency preparedness guidelines should provide a useful resource to the maglev developer and operator, relative to emergency features and equipment.

Adequate means must be provided for people to move away from a stranded vehicle in an emergency. Alternative approaches applicable to an elevated guideway include:

- Use of designated stopping points as specified by the RW MSB, provided the integrity of essential vehicle levitation, guidance and braking systems has been demonstrated.

- Aircraft-style emergency evacuation slides, provided they are compatible with elevated guideway height.

- A continuous walkway at vehicle floor height parallel to the guideway.

- Provision of permanently available mobile rescue platforms and stairs that could be brought to a disabled vehicle anywhere on the guideway, using an access roadway parallel to the guideway.

For U.S. maglev system applications, special consideration must be given to ensure that passenger egress from and response organization access to a vehicle is located on an elevated guideway.

Ideally, the guideway should be accessible to emergency rescue services at all locations via a roadway alongside the guideway or an adjacent public highway. Walkway access should be provided where a road is not possible (for example, where the guideway crosses a major waterway or in a tunnel).

9. SUMMARY OF RESULTS

This chapter presents a brief summary of the results of the comparisons of U.S. and foreign safety requirements having potential application to high-speed maglev systems in the United States. The summary first discusses why new safety requirements must be developed for high-speed maglev systems, and what sources exist for such safety requirements. Second, the summary discusses how the need for new maglev system safety requirements has been addressed in Germany, as presented in the RW MSB document and the draft MBO. Third, the summary discusses the results of this review regarding the applicability of RW MSB requirements, existing U.S. regulations and requirements, and other existing international requirements to high-speed maglev systems in the U.S.

9.1 RATIONALE FOR NEW SAFETY REQUIREMENTS

Existing safety requirements developed in the U.S. for conventional railroads and rail mass transit systems do not fully cover the safety assurance needs of high-speed maglev systems. High-speed maglev systems employ a number of technologies not found in conventional railroad or rail mass transit systems, or use existing technologies in a distinctly different operating environment. Existing safety requirements for guided ground transportation systems of all types are predominantly design-oriented, typically specifying loads, dimensions or materials to be used for a specific component or subsystem. Although the intent of such requirements may be applicable to high-speed maglev systems, the details cannot be applied. For example, the existing FRA safety regulations for locomotives contained in 49 CFR, Part 229 specify a variety of wear limits and condition requirements for trucks and wheelsets. The intent of these regulations - to ensure the structural integrity and proper functioning of the suspension system - is generally applicable to all guided ground transportation systems (railroads, rail mass transit, maglev), but the specific dimensional requirements are applicable in full only to a conventional U.S. railroad locomotive operating at conventional speed.

Particular technical features of a high-speed maglev system for which new safety requirements may be necessary include the following:

- Use of sensors and a microprocessor control system for the maintenance of the air-gap between the guideway and the levitation and guidance magnets.

- Use of full automatic operation at high-speed. Such operation in the past has been confined to relatively low speed mass transit systems.

- Reliance on electric braking systems such as linear motor reversal and an eddy-current brake for both service and emergency braking.

- Extensive use of an elevated guideway affecting the ease of rescue in an emergency.

Given that new safety requirements are necessary for high-speed maglev systems, there are a number of potential sources that can be used to provide these requirements. The sources used to develop the German safety requirements described in the RW MSB and the MBO, and the recommendations for U.S. requirements provided in this report are as follows:

- Use of existing railroad safety requirements, e.g., those specified in the FRA railroad safety regulations, industry requirements such as those of the UIC or AAR, or requirements issued by a major operator of railroad services such as DB or Amtrak. This approach is appropriate where there is little difference in the safety concerns and technology between the maglev system and a conventional railroad.

- Use of general industrial requirements developed by recognized organizations such as DIN or VDE in Germany, or ASTM, ANSI, and IEEE in the United States. Military Standards (MIL-STD) in the U.S. are also used outside defense applications as general industrial requirements. This approach is appropriate where the safety concern in a maglev system is similar to safety concerns arising when similar technologies are used in a number of different applications. A good example is the safety requirement for use of computer controls in safety-critical applications. Such requirements can be applied to a nuclear power plant and an industrial process as well as a maglev system.

- Adoption of requirements developed for another form of transportation such as commercial aviation or rail mass transit. This approach is applicable where the safety concerns arising in a high-speed maglev system are similar to those arising in the other form of transportation.

- Development of entirely new safety requirements, specifically for high-speed maglev systems. This approach must be used when none of the other approaches described can be used to address a recognized safety concern. Often, the new requirements may express the intent of an existing railroad-oriented requirement in a way that is applicable to a maglev system.

The following sections summarize which of the above approaches have been used in the German maglev system safety requirements described in the RW MSB, and how the requirements might be revised or enhanced for U.S. maglev system applications.

9.2 SUMMARY OF GERMAN MAGLEV SYSTEM SAFETY REQUIREMENTS IN THE RW MSB AND DRAFT MBO

The RW MSB uses many source documents to develop safety requirements for the different maglev system functional areas. Often, more than one approach is used for a functional area. Furthermore, the RW MSB does not address all functional areas to the same level of detail. Some areas are addressed extensively, and some are addressed partially or in limited detail. The noise functional area is not addressed.

Table 9-1 summarizes both the level of detail in the RW MSB and MBO requirements for each functional area, and the principal and supporting sources used for the safety requirements - railroad requirements, general industrial requirements, requirements from other forms of transportation and new maglev system-specific requirements.

With regard to the level of detail in the RW MSB and the MBO, all functional areas are addressed at some level of detail. Two vehicle-related functional areas, 202 - Operator Compartments, and 208 - Vehicle Guideway Interaction are partially addressed, in that some aspects of the functional area are addressed in detail, and other aspects are not addressed. In Functional Area 202, windshields and operator controls are covered but there is no mention of interior crashworthiness aspects: avoiding sharp corners and hard surfaces, attachment strength of seats and equipment and similar matters. In Functional Area 208, Vehicle-Guideway Interaction, there is an extensive discussion of static and dynamic loads at the vehicle-guideway interface, but no discussion of dynamic stability and dynamic vehicle-guideway interaction effects.

Several functional areas receive limited discussion in that safety requirements are mentioned, but only slight detail is provided. Functional areas where the discussion provides limited detail in the RW MSB include all three "Maintenance and Inspection" areas (209, 302 and 402), and the personnel and operations areas (501 and 502), reflecting the RW MSB focus on maglev system design and construction rather than operations and maintenance. Other functional areas where limited detail is provided in the RW MSB and the draft MBO are 203 - Passenger Vehicle Interiors, 204 - Doors, and 304 - Right-of-Way Security. All remaining functional areas are discussed in substantial detail.

With regard to the approach or source of safety requirements, new maglev-specific requirements are used most extensively as the primary or supporting approach. General Industrial requirements such as the DIN and VDE requirements are the next most commonly used, but are heavily concentrated in a few specific functional areas. These functional areas particularly include Guideway Structures (301), Electrical and Communication Systems (403, 404, 405 and 406) and the System Safety Area (101 through 105), particularly with regard to computer safety.

Railroad-specific requirements are used to a limited extent in selected areas. Most notable are 205 - Fire Safety, and 401 - Operations Control Systems where the MUe 8004 and DIN 0831 railway signalling requirements are referenced. Non-rail transportation requirements are cited in only one instance, aviation fire safety requirements in Functional Area 205.

TABLE 9-1. SUMMARY OF RW MSB AND DRAFT MBO REQUIREMENTS

Functional Area	Abbreviated Title	Level of Detail	Type of Requirements Used*			
			Railroad	General Industrial	Other Transportation	Maglev Specific
101	System Safety	Full		S		P
102	Reliability and Availability	Full		P		S
103	Quality Assurance	Full		P		
104	Certification	Full				P
105	Computer Safety	Full	S	P		S
201	Vehicle Structural Integrity	Full	S	S		P
202	Vehicle Operator Compartments	Partial	S	S		
203	Passenger Compartment Interior	Limited				S
204	Passenger Vehicle Doors	Limited				S
205	Fire Safety	Full	P	S	S	
206	Suspension	Full		S		P
207	Brakes	Full				P
208	Vehicle-Guideway Interaction	Partial				S
209	Inspection and Maintenance	Very Limited				S
210	Interior Vehicle Noise	None				
301	Design and Construction	Full	S	P		S
302	Inspection and Maintenance	Limited				S
303	Guideway Switch	Full	S	S		P
304	Right-of-Way Security	Limited				S
401	Control System Design	Full	P			S
402	Control System Inspection, etc.	Limited	S			P
403	Communication Systems	Full		P		S
404	Electric Power Systems	Full		P		S
405	EMC and EMI	Full		P		S
406	Lightning Protection	Full		P		S

*P = Principal S = Supporting

TABLE 9-1. SUMMARY OF RW MSB AND DRAFT MBO REQUIREMENTS (cont.)

Functional Area	Abbreviated Title	Level of Detail	Type of Requirements Used*			
			Railroad	General Industrial	Other Transportation	Maglev Specific
501	Qualifications and Training	Very Limited	S			S
502	Operating Rules and Practices	Limited				S
601	Emergency Features and Equipment	Full				P
602	Emergency Plans and Procedures	Full				P

*P = Principal S = Supporting

9.3 RECOMMENDED SAFETY REQUIREMENTS FOR HIGH-SPEED MAGLEV SYSTEMS IN THE U.S.

The safety requirements developed for high-speed maglev systems in Germany, as detailed in the RW MSB and the draft MBO requirements do not fully meet the needs for safety requirements for such systems in the United States. There are four primary reasons underlying the proposed, modified or additional safety requirements for U.S. maglev system application.

- The RW MSB requirements vary in emphasis and completeness among the different safety-critical functional areas, and do not address the noise functional area.

- Environmental conditions in the U.S. may be more severe than in Germany with regard to temperature range, high winds, snowfall, and earthquake risk.

- Use of foreign technical requirements may be inappropriate because personnel who will have to install and maintain safety-critical equipment will be familiar only with U.S. requirements.

- Institutional arrangements for developing and administering safety requirements, and for operating maglev system services will likely differ between Germany and the U.S., and will also differ from the arrangements that have evolved for the conventional U.S. railroad industry. In particular, there are differences in the roles played by government regulators, industry associations, and national requirements: publishing organizations such as DIN, ASTM, between the U.S. and Germany, and between U.S. railroads and a future U.S. maglev system.

The bulk of this report has been concerned with reviewing the German safety requirements for high-speed maglev systems, comparing the German requirements with equivalent U.S. and other foreign and international requirements, and developing recommendations for high-speed maglev safety requirements in the United States. Table 9-2 summarizes the results of the review for each functional area, indicating the recommended source of high-speed maglev system safety requirements for U.S. applications.

The sources of the proposed recommended U.S. requirements are as follows:

- The German requirements in the RW MSB and the draft MBO, including DIN and VDE requirements referenced in the RW MSB.

- Existing U.S. railroad safety requirements including FRA regulations and guidelines, and AAR and AREA requirements.

- Existing foreign and international railroad safety requirements <u>not</u> referenced in the RW MSB, primarily UIC codes.

TABLE 9-2. PROPOSED SOURCES FOR RECOMMENDED SAFETY REQUIREMENTS FOR U.S. MAGLEV SYSTEMS

Functional Area	Abbreviated Title	Principal (P) and Supporting (S) Sources of Safety Requirements					
		German RW MSB/MBO	Existing RR U.S.	Existing RR UIC/Int'l	U.S. General Industrial	U.S. Other Transportation	New U.S. Maglev
101	System Safety	S			S	S	P
102	Reliability and Availability	S			P	S	
103	Quality Assurance	P					
104	Certification	P					
105	Computer Safety	S		S	P	S	
201	Vehicle Structural Integrity	S	S				P
202	Vehicle Operator Compartments	P	S	S		S	
203	Passenger Compartment Interior		P	S		S	
204	Passenger Vehicle Doors			P			
205	Fire Safety	S	P	S	S		
206	Suspension	S	S	S			P
207	Brakes	P					S
208	Vehicle-Guideway Interaction	S					P
209	Inspection and Maintenance		S			P	S
210	Interior Vehicle Noise					P	
301	Design and Construction	P	S		S	S	
302	Inspection and Maintenance		P			S	
303	Guideway Switch	P			S		
304	Right-of-Way Security			S		P	S
401	Control System Design	P	S	S			
402	Control System Inspection, etc.	S	P	S			
403	Communication Systems	P	S				
404	Electric Power Systems	S			P		
405	EMC and EMI	P					
406	Lightning Protection	S			S	P	

TABLE 9-2. PROPOSED SOURCES FOR RECOMMENDED SAFETY REQUIREMENTS FOR U.S. MAGLEV SYSTEMS (cont.)

Functional Area	Abbreviated Title	Principal (P) and Supporting (S) Sources of Safety Requirements					
		German RW MSB/MBO	Existing RR U.S.	Existing RR UIC/Int'l	U.S. General Industrial	U.S. Other Transportation	New U.S. Maglev
501	Qualifications and Training		P			S	
502	Operating Rules and Practices		P	S			
601	Emergency Features and Equipment	P				S	
602	Emergency Plans and Procedures	S	S			P	

- U.S. general industrial requirements such as those published by the ASTM, ANSI, IEEE and similar organizations.

- U.S. safety requirements for other forms of transportation, primarily commercial aviation and mass transit rail systems.

- New maglev safety requirements developed specifically for U.S. application.

Following the logic described in Chapter 2, the application of RW MSB and draft MBO requirements to U.S. maglev systems is recommended where there are no conflicting applicable existing FRA regulations or guidelines, and where none of the four reasons for departing from the German requirements are applicable. If the German requirements are not applicable, a logical selection is made among other existing requirements. Where appropriate safety requirements cannot be found among existing requirements, new maglev-specific requirements are recommended.

Table 9-2 indicates which of the six sources have been referenced in the recommended U.S. maglev system safety requirements. The primary source (P) is the leading source for the suggestions in each functional areas, and the secondary sources (S) are sources that were also used, but less extensively than the primary sources. The table is intended to be a general indication of sources, and the individual functional area discussions should be read for details on the application of each safety requirement.

The RW MSB requirements are a source for two-thirds of the functional areas (21 out of 29), and the primary source for ten functional areas. Generally, RW MSB requirements are not suggested as a source only where the functional area is not addressed in sufficient detail in the RW MSB. Reliance was placed on the RW MSB itself, and requirements referenced in the RW MSB, particularly in 101 - System Safety , 400 - Operations Control, Communications, and Electric Power, and 800 - Emergency Preparedness functional areas.

U.S. railroad-related safety requirements were the primary source in six functional areas and a supporting source in eight functional areas. The primary source functional areas were 203 - Passenger Car Interiors, 205 - Fire Safety (FRA), 302 - Guideway Inspection and Maintenance (AREA), 402 - Control Systems Inspection and Maintenance (FRA and AAR), and 700 - Personnel and Operations functional areas.

Other foreign and international railroad safety requirements were used as the primary source in one functional area 204 - Doors, and as a supporting source in eight other functional areas, including 105 - Computer Safety, 203 - Vehicle Interiors, 205 - Vehicle Fire Safety, 207 - Brakes, 401 - Control System Design, 209 - Inspection and Maintenance, and 502 - Operating Rules.

U.S. general industrial requirements, including military standards, are the primary source of maglev system safety requirements in three functional areas, 102 - Reliability and Availability (mainly MIL-STDs), 105 - Computer Safety, and 404 - Electric Power Systems, and a supporting source in five other functional areas.

U.S. requirements for modes of transportation other than for conventional railroads provided the primary source of maglev system safety requirements for five functional areas. Requirements derived from mass transit practice are Functional Areas 210 - Interior Noise, 304 - Right-of-Way Security, and 602 - Emergency Plans and Procedures. Aviation requirements are the source for safety requirements for Functional Areas 209 - Vehicle Inspection and Maintenance, and 406 - Lightning Protection. U.S. requirements for mass transit highway bridges and commercial aviation also are a supporting source in nine other functional areas, particularly in general/system safety, vehicle interiors, guideway structures, personnel matters and emergency response.

Finally, new U.S. requirements specifically for maglev systems are the primary source in four functional areas. For system safety and vehicle structures, the requirements are derived from recently completed research on collision safety [9]. In the two other areas, 206 - Vehicle Suspension, and 208 - Vehicle Guideway Interaction, existing requirements including those cited in the RW MSB did not fully meet the needs of maglev system safety assurance in the U.S.; new requirements and further study are suggested.

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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. (Note, the text in this chapter originally appeared in the Volpe Center Report, No. DOT/FRA/ORD-92/02.)

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
BIBLIOGRAPHY OF TECHNICAL REQUIREMENTS

INTRODUCTION

The bibliography lists technical requirements documents referenced in the document High Speed Maglev Trains: Safety Requirements (RW MSB), and U.S. and international technical requirements cited in the reviews of individual functional areas in this report. The referenced documents consist of standards, rules, regulations, specification guidelines or codes issued by government departments, national and international standard-setting organizations, and industry associations in the United States and elsewhere. References to general technical literature are provided separately a the end of the report.

The bibliography contains the following information about each document:

- Issuing Organization
- Reference number, part, etc.
- Full title
- Date of Issue
- Where cited by RW MSB (if applicable)
- Applicable maglev Functional Areas of Areas, as reviewed in this report

This bibliography is organized as a series of tables, grouping documents issued by a specific organization or that otherwise are related to each other. Within each table, the documents are listed in alphabetical order by publisher or issuer, and then in numerical order by reference number.

The abbreviations used can be found in the list of abbreviations given at the beginning of this report.

Documents were obtained both from the publisher and from alternative sources specializing in the distribution or translation of international technical requirements documents. The principal sources used other than the original publisher or issuing organization were:

- Global Engineering Services, a commercial service that distributes technical requirements documents in the United States including many German DIN and DIN-VDE standards.

- Information Handling Services, which is affiliated with Global Engineering Services, and provides microfilm libraries of documents and periodic updates on a subscription basis.

- British Standards Institution, which provides English language translations of documents originally issued in languages other than English, including many DIN and DIN-VDE standards.

- Beuth Verlag, a publisher and distributor of technical requirements documents in Germany.

TABLE B1: REQUIREMENTS ISSUED BY GERMAN INSTITUTE OF STANDARDS (DIN)

Ref. Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
DIN 0109	Sheet 2	Driving Elements, Centre Distances for V-belt Drives	01-Jan-60	2.7	404
DIN 1045		Structural Use of Concrete; Design and Construction	01-Jul-88	6.4.3, 7.2.2.1	301
DIN 1055	Part 1	Design Loads for Buildings; Stored Materials, Building Materials and Structural Members; Dead Load and Angle of Friction	01-Jul-78	6.2.1	201,301
DIN 1055	Part 2	Design Loads for Buildings; Soil Characteristics; Specific Weight, Angle of Friction, Cohesion, Angle of Wall Friction	01-Feb-76	6.2.1	301
DIN 1055	Part 3	Design Loads for Buildings; Live Loads	01-Jun-71	6.2.1	301
DIN 1055	Part 4	Design Loads for Buildings; Imposed Loads; Wind Loads on Structures Unsusceptible to Vibration	01-Aug-86	6.2.1	301
DIN 1055	Part 6	Design Loads for Buildings; Loads in Silo Bins	01-May-87	6.2.1	301
DIN 1072		Road and Foot Bridges; Design Loads	01-Dec-85	5.5.0	301
DIN 1075		Concrete Bridges; Dimensioning and Execution	01-Apr-81	7.2.2.1, 7.4.0	201,301
DIN 1079*		Steel Road Bridges, Principles for Structural Design	01-Sep-70	7.4.0	101,301
DIN 1084		Quality Supervision in Concrete and Concrete Reinforced Construction		7.3.2, 7.4.0	103,301,302
DIN 4102	Part 2	Fire Behavior of Building Materials and Building Components	01-Sep-77	11.3.0	205

*Referenced in RW MSB, but out of print and superseded by DIN 18800 and DIN 18809

TABLE B1: REQUIREMENTS ISSUED BY GERMAN INSTITUTE OF STANDARDS (DIN) (cont.)

Ref. Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
DIN 4102	Part 4	Fire Behavior of Building Materials and Building Components; Summary and Use of Classified Building Materials; Building Components and Special Building Components	01-Mar-81	11.6.0	205
DIN 4102	Part 5	Fire Behavior of Building Materials and Building Components; Fire Barriers, Barriers in Lift Wheels and Glazings Resistant Against Fire; Definitions, Requirements and Tests	01-Sep-77	11.6.0	205
DIN 4102	Part 6	Fire Behavior of Building Materials and Building Components; Ventilation Ducts; Definitions, Requirements and Tests	01-Sep-77	11.6.0	205
DIN 4149	Part 1	Buildings in German Earthquake Zones; Design Loads, Dimensioning, Design and Construction of Conventional Buildings	01-Apr-81	6.3.2	301
DIN 4227	Part 2	Prestressed Concrete; Partially Prestressed Structural Members	01-May-84	6.4.3, 7.2.2.1	301
DIN 4227	Part 3	Prestressed Concrete, Segmental Type Structural Components, Design and Workmanship of Joints	01-Dec-83	6.4.3, 7.2.2.1	301
DIN 4227	Part 4	Prestressed Concrete; Prestressed Lightweight Concrete Structural Components	01-Feb-86	6.4.3, 7.2.2.1	301
DIN 4227	Part 5	Prestressed Concrete; Injection of Cement Mortar into Prestressing Concrete Ducts	01-Dec-79	6.4.3, 7.2.2.1	301

*Referenced in RW MSB, but out of print and superseded by DIN 18800 and DIN 18809

TABLE B1: REQUIREMENTS ISSUED BY GERMAN INSTITUTE OF STANDARDS (DIN) (cont.)

Ref. Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
DIN 4227	Part 6	Prestressed Concrete; Structural Components With Unbonded Prestressing	01-May-82	6.4.3, 7.2.2.1	301
DIN 5510	Part 1	Preventative Fire Protection in Railway Vehicles; Levels of Protection, Fire Preventative Measures and Certification	10-Jan-91	11.2, 11.6.0	205,603,604
DIN 5510	Part 4	Preventative Fire Protection in Railway Vehicles; Structural Design of the Vehicles; Safety Requirements	01-Oct-88	11.4.4, 11.6.0	205
DIN 5510	Part 5	Preventative Fire Protection in Railway Vehicles; Electrical Operating Means; Safety Requirements	01-Oct-88	11.4.6, 11.6.0	205,404
DIN 5510	Part 6	Preventative Fire Protection in Railway Vehicles; Auxiliary Measures, Function of the Emergency Brake Equipment, Information Systems, Fire Alarm Systems, Fire Fighting Equipment, Safety Requirements	01-Oct-88	11.4.7, 11.4.8, 11.6.0	205,603,604
DIN 18200		Inspection of Construction Materials, Structural Members and Types of Construction; General Principles	01-Dec-86	11.6.0	103,201
DIN 18800	Part 1	Steel Structures; Design and Construction	01-Mar-81	6.4.1, 6.4.3	301
DIN 18800	Part 7	Steel Structures; Fabrication, Verification of Suitability for Welding	01-May-83	6.4.1, 6.4.3	103,301
DIN 18809		Steel Road Bridges and Footbridges Design and Construction	01-Sept-87	-	301
DIN 24343		Hydraulic Fluid Power Systems and Components; List for Attendance and Inspection of Hydraulic Equipments (in German)	01-Feb-82	8.7.0	207,302,303

*Referenced in RW MSB, but out of print and superseded by DIN 18800 and DIN 18809

TABLE B1: REQUIREMENTS ISSUED BY GERMAN INSTITUTE OF STANDARDS (DIN) (cont.)

Ref. Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
DIN 24346		Hydraulic Fluid Power; Hydraulic Systems; General Rules for Application	01-Dec-86	9.7.0	207,302,303
DIN 29591		Aerospace; Examination of Welders; Welding of Metallic Components (in German)	01-Oct-86	7.3.1.1, 3.1, 7.4	103,201,301
DIN 31000		General Guide for Designing Technical Equipment to Satisfy Requirements - Safety Technology Concepts; Basic Concepts Safety	01-Dec-87	3.6.0	101,102
DIN 33400		Ergonomic Principles in the Design of Work Systems; Terminology and General Guiding Principles	01-Oct-83	4.4.0	202,204
DIN 33401		Control Elements: Terms and Definitions, Suitability, Design Recommendation	01-Jul-77	4.4.0	202
DIN 33402	Part 4	Human Body Dimensions; Principles of Dimensioning Passages and Accesses	01-Oct-86	4.4.0	202
DIN 33403	Part 1	Climate at Workplaces and in Working Environments; Basic Principles for Determining Climates	01-Apr-84	4.4.0	202,203
DIN 33413	Part 1	Ergonomic Aspects of Indicating Devices; Types, Observation Tasks, Suitability	01-Jun-84	4.4.0	202,401
DIN 33414	Part 1	Ergonomic Design of Control Rooms; Seated Work Stations; Terms and Definitions, Principles, Dimensions	01-Apr-85	4.4.0	202,401
DIN 40041		Reliability in Electrical Engineering; Terms and Definitions; General (in German)	01-Dec-90	0.5	101,102,103
DIN 40046		Environmental Tests for Electrical Technology		2.7.0	401,404

*Referenced in RW MSB, but out of print and superseded by DIN 18800 and DIN 18809

TABLE B1: REQUIREMENTS ISSUED BY GERMAN INSTITUTE OF STANDARDS (DIN) (cont.)

Ref. Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
DIN 40050		Degrees of Protection Provided by Enclosures; Protection of Electrical Equipment Against Contact, Foreign Bodies and Water	01-Jul-80	3.6.0	301
DIN 50060		Testing of Burning Behavior of Materials and Products; Terms and Definitions (in German)	01-Aug-85	11.3.0	205
DIN 54345	Part 1	Testing of Textiles; Electrostatic Behavior; Determination of Electrical Resistances	01-Jul-85	10.4.1	203,205
DIN 54345	Part 2	Testing of Textiles; Testing of the Electrostatic Propensity; Testing of Textile Floor Coverings by the Week Test	01-Oct-76	10.4.3	203,205
DIN 54345	Part 3	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Floor Coverings by Machine	01-Jul-85	10.4.3	203,205
DIN 54345	Part 4	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Fabrics	01-Jul-85	10.4.1	203,205
DIN 54345	Part 5	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Fabrics	01-Jul-85	10.4.3	203,205
DIN 65118	Part 1	Aerospace: Welded Metallic Component Parts Indications on Drawings (in German)	01-Mar-91	7.4	201
DIN 65118	Part 2	Aerospace: Welded Metallic Components Directives for Design (in German)	01-Jun-87	7.4	201

*Referenced in RW MSB, but out of print and superseded by DIN 18800 and DIN 18809

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0100	410	Installation of Power Plant with Rated Voltages Not Exceeding 1000 V; Protective Measures; Protection Against Electric Shock (VDE Specifications)	01-Nov-83	2.3.1,3.3.1, 3.6,2.3.3, 2.7	404
VDE 0100	430	Installation of Power Plant with Rated Voltages Up to 1000V; Protection of Cables and Cords Against Undue Temperature Rise	01-Jun-81	2.7, 3.3.1.14, 3.6	404
VDE 0100	520	The Erection of Power Installations with Rated Voltages of Up to 1000V; Selection and Erection of Electrical Apparatus; Cables, Conductors and Bushbars	01-Nov-85	2.7	404
VDE 0100	523	Installation of Power Plant with Rated Voltages Up to 1000V; Dimensioning of Cables and Cords; Mechanical Strength, Voltage Drop and Current Carrying Capacity	01-Jun-81	2.7	404
VDE 0100	540	Erection of Power Installations with Nominal Voltages Up to 1000V; Selection and Erection of Equipment; Earthing Arrangements, Protective Conductors, Equipotential Bonding Conductors	01-May-86	2.5.4.3	404
VDE 0101		Erection of Power Installations with Nominal Voltage Exceeding 1 kV	01-May-89	2.3.2,2.7	404
VDE 0105	V1	Operation of Electrical Power Installations; General Requirements	01-Jul-83	2.7.0	404
VDE 0106	100	Protection Against Electric Shock; Location of Control Elements in the Vicinity of Shock-Hazard Parts	01-Mar-83	2.7.0	404

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 108	Part 1	Power Installations and Safety: Power Supply in Communal Buildings: General	01-10-89	2.3.2	401,404
VDE 108	Amend-ment A1	Erection and Operation of Electrical Power Installations in Communal Buildings and of Emergency Lighting in Working and Business Premises	01-Dec-79	2.3.2	401,404
VDE 0109 =IEC 664	A1	Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment	01-Mar-89	2.7.0	401,404
VDE 0109 =IEC 664	10	Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment	01-Sep-90	2.7.0	401,404
VDE 0110	1	Insulation Coordination Within Low-Voltage Systems; Fundamental Requirements	01-Jan-89	2.5.3	401,404
VDE 0115	1	Traction Systems; General Construction and Safety	01-Jun-82	2.3.1.1	404
VDE 0115	2	Traction Systems; Particular Requirements for Vehicles and Their Equipment	01-Jun-82	2.7.0	404
VDE 0115	3	Traction Systems; Particular Requirements for Stationary Installations	01-Jun-82	2.7.0	404
VDE 0122		Electrical Equipment of Electrical Electrical Road Vehicles (in German)	01-Aug-86	3.4.2	404
VDE 0141		Earthing Systems for Power Installations with Rates Voltages Above 1 kV	01-Jul-89	2.5.4.2.4.1	404

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0160		Electronic Equipment for Use in Electrical Power Installations and Their Assembly into Electrical Power Installations	01-May-88	2.3,2.70, 3.3.1,3.4.2	401,403,404
VDE 0160	A1	Electronic Equipment for Use in Electrical Power Installations and Their Assembly into Electrical Power Installations; Amendment 1	01-Apr-89	2.3,2.70, 3.3.1,3.4.2	401,403,404
VDE 0165	A1	Installation of Electrical Equipment in Potentially Explosive Atmospheres	01-Sep-86	3.4.2	205,404
VDE 0185	1	Lightning Protection System; General with Regard to Installation (VDE Guide)	01-Jan-83	10.2.2.1	404,406
VDE 0185	2	Lightning Protection System; Installation of Special Structures (VDE Guide)	01-Jan-83	10.2.2.1	404,406
VDE 0228	1	Measures Against Interference in Telecommunication Systems by Electric Power Installations; General Principles	01-Oct-82	2.7.0	403,404,405
VDE 0228	2	Measures to be Taken Against Interference With Telecommunication Systems by Electric Power Installations; Interference by Three-Phase Systems	01-Dec-87*	2.7.0	403,404,405
VDE 0228	3	Measures to be Taken Against Interference With Telecommunication Systems by Electric Power Installations; Interference by Alternating Current Traction Systems	01-Sep-88	2.7.0	403,404,405

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0228	4	Measures to be Taken Against Interference With Telecommunication Systems by Electric Power Installations; Interference by Direct Current Railway Installations	01-Dec-87	2.7.0	403,404,405
VDE 0250	503	Cables, Wires and Flexible Cords for Power Installations; Halogen-Free Single-Core Non-Sheathed Cable With Improved Characteristics in Case of Fire; Nominal Voltages U_o/U 450/750 V	01-Mar-89	2.7.0	205,404
VDE 0266		Halogen-Free Cables With Improved Characteristics in Case of Fire; Nominal Voltages U_o/U 0/6/1 kV	01-Feb-85	2.7.6,3.6	205,404
VDE 0278	1	Power Cable Accessories with Rated Voltages U Up to 30 kV; General	01-Jun-80	2.7	404
VDE 0278	4	Power Cable Accessories with Rated Voltages U Up to 30 kV; Scaling Ends for Indoor U_o/U above 0.6/1 kV	01-Oct-84	2.7	404
VDE 0278	5	Power Cable Accessories with Rated Voltages U Up to 30 kV; Scaling Ends for Outdoor Installations U_o/U above 0.6/1 kV	01-Jun-82	2.7	404
VDE 0278	6	Power Cable Accessories with Rated Voltages U Up to 30 kV; Plug-In Type or Screw Type Enclosed Cable Connections U_o/U above 0.6/1 kV	01-Aug-88	2.7	404
VDE 0282	1	Rubber Cables, Wires & Flexible Cords for Power Installation	01-Apr-85	3.3.1	404

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0287		Technical Procedures for Determining the Conformity of Harmonized Cables and Cords	01-Apr-85	3.3.3.1	404
VDE 0298	2	Application of Cables and Flexible Cords in Power Installations; Recommended Values for the Current Carrying of Cables with Rated Voltages U_o/U up to 18/30 kV; VDE Specification	01-Nov-79	2.7.0,3.6	404
VDE 0298	3	Application of Cables and Flexible Cords in Power Installations; General Information on Cables	01-Aug-83	2.7.0,3.6	404
VDE 0298	4	Application of Cable and Insulated Conductors in Power Plant; Recommended Values for Current Carrying Capacity of Cables	01-May-85	2.7.0,3.6	404
VDE 0472	1b	Recommendations for Testing Insulated Cables and Flexible Cords	01-Jan-74	2.7.0	404
VDE 0510	2	Accumulators and Battery Installations; Stationary Batteries	01-Jul-86	3.4.2	206,404
VDE 0532	1	Regulations for Transformers and Chokes; Transformers	01-Dec-78	3.4.2	404
VDE 0532	1 Annex M	List of Important Deviations of VDE 532 Part 1 from IEC Publications 76 (1967)	01-Nov-71	3.4.2	404
VDE 0532	2	Transformers and Chokes; Temperature Rise	01-Mar-82	2.7.0	404
VDE 0558	1	Semiconductor Convertors; General Specifications and Particular Specifications for Line-Commutated Converters	01-Jul-87	2.7.0	401,404

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0558	5	Semiconductor Convertors; Uninterruptible Power Systems (UPS); Deviations from IEC 146-4	01-Sep-88	2.4.0	401
VDE 0660	103	Switch Gear and Control Gear; High Voltage Alternating Current Contractors (Deviations to IEC 470)	01-Mar-84	2.7.0	404
VDE 0660	Supp 1	Switch Gear and Control Gear; Index of the Standards of the Series DIN 57 660/VDE 0660	01-Sep-82	2.7.0	404
VDE 0660	Supp 2	Switch Gear and Control Gear; Quoted and Further Standards in the Series of DIN VDE 0660	01-Dec-85	2.7.0	404
VDE 0670	3	AC Switch Gear and Control Gear for Voltage Above 1 kV	01-Sep-81	2.3.2,2.5.3, 2.7.0	404
VDE 0675	1	Guidelines for Over-Voltage Protection Appliances; Valve Type Lighting Arresters for AC Circuits	01-May-72	2.7.0	404,406
VDE 0800	1	Telecommunications; Erection and Operation of Facilities	01-Apr-84	2.7.0	403
VDE 0800	2	Telecommunications; Earthing and Equipotential Bonding	01-Jul-85	2.3.1	403
VDE 0801		Principles for Computers in Safety-Related Systems	01-Jan-90	4.1.1	105
VDE 0816		External Cables for Telecommunications Systems	01-Feb-79	2.7.0	403
VDE 0831		Electrical Equipment for Railway Signalling (VDE Specification)	01-Jun-83	1.5.1,2.7.0	105,401

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0839	10	Electromagnetic Compatibility; Evaluation of Immunity from Conducted and Radiated Disturbances	01-Oct-87	10.1.0	401,404,405
VDE 0843 =IEC 801-1	1	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; General Introduction	01-Jan-84	10.2.0	401,404,405
VDE 0843 =IEC 801-2	2	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; Electrostatic Discharge Requirements	01-Apr-91	10.2.0	401,404,405
VDE 0843 =IEC 801-3	3	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; Radiated Electromagnetic Field Requirements	01-Jan-84	10.2.0	401,404,405
VDE 0845		VDE Specification for the Protection of Telecommunications Systems Against Overvoltages	*01-Apr-76	2.7.0	401,403,404
VDE 0847	2	Measuring Method for Evaluation of Electromagnetic Compatibility; Immunity from Conducted Disturbances	01-Oct-87	10.2.0	401,404,405
VDE 0847	4	Procedures for Measurement of Electromagnetic Compatibility; Immunity Against Radiated Interference Variables	01-Jan-87	10.2.0	401,404,405
VDE 0848	1	Hazards for Electromagnetic Fields Methods for Measurement and Calculation	01-Feb-82	10.3.3	403,404,405
VDE 0848	4	Safety at Electromagnetic Fields: Limits of Field Strength for the Protection of Persons in the Frequency Range from 0 to 30 kHz	01-Oct-89	10.3.3	403,404,405

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0870	1	Electromagnetic Interference (EMI) Terms	01-Jul-84		405
VDE 0871		Radio Interference Suppression of Radio Frequency Equipment	01-Jun-78	10.3.3	403,404,405
VDE 0873	1	Measures Against Radio Interference from Electric Utility Plants and Electrical Traction Systems; Radio Interference from Systems Below 10 kV and from Electric Trains (in German)	01-May-82	10.3.3	401,403, 404,405
VDE 0873	2	Measures Against Radio Interference from Electric Utility Plants and Electrical Traction Systems; Radio Interference from Systems Below 10 kV and from Electric Trains (in German)	01-Oct-88	10.3.3	401,403, 404,405
VDE 0875	1	Radio Interference Suppression of Electrical Appliances and Systems; Radio Interference Suppression of Household Electrical Appliances and Similar Apparatus; Radio Interference Suppression Order, 28 August 1984	01-Nov-84	10.3.3	401,403, 404,405
VDE 0875	2	Radio Interference Suppression of Electrical Appliances and Systems; Radio Interference Suppression by Luminaries with Discharge Lamps	01-Nov-84	10.3.3	401,403, 404,405
VDE 0875	3	Radio Interference Suppression of Electrical Appliances and Systems; Radio Interference Suppression of Electrical Systems and Special Electrical Appliances (VDE Specification)	01-Nov-84	10.3.3	401,403, 404,405

TABLE B2: ASSOCIATION OF GERMAN ELECTRICAL ENGINEERS (VDE AND DIN VDE) (cont.)*

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDE 0888	1	Optical Waveguides for Telecommunication System; Definitions (in German)	01-Jun-88	2.7.0	401,403
VDE 0888	2	Optical Waveguides for Telecommunication and Data Processing Systems; Fibres and Buffered Fibres (in German)	01-Aug-87	2.7.0	401,403
VDE 0888	3	Optical Waveguides for Telecommunication and Data Processing Systems; Outdoor Cables (in German)	01-Oct-89	2.7.0	401,403
VDE 0888	4	Optical Waveguides for Telecommunication and Data Processing Systems; Indoor Cable with One Optical Fibre (in German)	01-Aug-87	2.7.0	401,403
VDE 0888	5	Optical Waveguides for Telecommunication and Data Processing Systems; Outdoor Fan-Out Cables (in German)	01-Dec-87	2.7.0	401,403
VDE 31000	2	General Guide for Designing Technical Equipment to Satisfy Safety Requirements; Safety Technology Concepts; Basic Concepts	01-Dec-87	1.3.3.2	101,102

***Note: Many VDE documents are also published as DIN VDE with the same reference numbers.**

TABLE B3: REQUIREMENTS ISSUED BY GERMAN ASSOCIATION OF ENGINEERS (VDI)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
VDI 2230	Part 1	Systematic Calculation of High Duty Bolted Joints	Oct-88	3.1.1.3.2	201
VDI 2244	Part 1	Design of Safe Equipment and Machinery Qualitative Terms and Definitions (in German)	May-88	0.5.2	101, 102
VDI 3542	Part 1	Safety Terms for Automation Equipment (in German)	19-Dec-88	0.5.2	101, 102
VDI 3542	Part 2	Safety Terms for Automation System Quantitative Terms and Definitions (in German)	Dec-88		101, 102
VDI 3542	Part 3	Safety Terms for Automation Systems Application Hints and Examples (in German)	Jun-91		101, 102
VDI 4005	Part 1	Effect of Environmental Conditions on the Reliability of Technical Products - Fundamental Considerations (in German)	Aug-81	2.7	102
VDI 4005	Part 2	Effect of Environmental Conditions on the Reliability of Technical Products - Mechanical Influences of Environmental Factors (in German)	Nov-83	2.7	102
VDI 4005	Part 3	Effect of Environmental Conditions on the Reliability of Technical Products - Thermal and Climatic Influences of Environmental Factors (in German)	Nov-83	2.7	102
VDI 4005	Part 4	Effect of Environmental Conditions on the Reliability of Technical Products - Chemical and Biological Influences of Environmental Factors (in German)	Nov-83	2.7	102
VDI 4005	Part 5	Effect of Environmental Conditions on the Reliability of Technical Products - Electromagnetic Influences of Environmental Factors (in German)	Nov-83	2.7	102

TABLE B4: GERMAN WELDING ASSOCIATION CODE OF TECHNICAL STANDARDS (DVS SERIES)

Reference Number	Part	Title	Date of Issue	RW MSB	Functional Areas
DVS 1603		Spot Welding of Steel in Railroad Rolling Stock Construction (in German)	01-Nov-64	7.3.1.1.3.1	103,201,301
DVS 1604		Spot Welding of Aluminum and its Alloys in Railroad Rolling Stock Construction (in German)	01-Oct-66	7.3.1.1.3.1	103,201,301
DVS 1608		Welding of Aluminum in Railroad Rolling Stock Construction (in German)	01-May-83	7.3.1.1.3.1	103,201,301
DVS 1609		Spot Welding of Alloy Steel in Railroad Rolling Stock Construction (in German)	01-Feb-75	7.3.1.1.3.1	103,201,301
DVS 1610		General Guidelines for Planning Molded Structure in Railroad Rolling Stock Construction (in German)	01-Jun-88	7.3.1.1.3.1	103,201,301
DVS 1611		Radiographic Testing of Aluminum and Aluminum Alloy Molded Joints in Railroad Rolling Stock Construction (in German)	01-Apr-79	7.3.1.1.3.1	103,201,301

TABLE B5: GERMAN RAILWAYS CODE OF TECHNICAL STANDARDS

Reference Number	Part	Title	Date of Issue	RW MSB	Functional Areas
DS 804		Regulations for Railroad Bridges and Other Engineering Constructions (VEI) (in German)	01-Jan-83	3.4.4,5.5.0, 6.3.2	201,301
DS 899/35		Code of Practice for Testing the Burning Behavior of Solids (in German)	01-Dec-72	11.4.4,11.6.0	205
DS 899/59		Special Provisions for Railroad Bridges on New Lines (in German)	01-Jan-85	5.5.0	201,301
Mü 8004		Signal and Train Control Standards (in German)	01-Jan-91	4.2	401,402, 403,405

TABLE B6: MISCELLANEOUS GERMAN REQUIREMENTS

Issuing Organization and Ref. Number	Part	Title	Date of Issue	RW MSB	Functional Areas
BOSTRAB		Federal Gazette I, 1987 Directive for the Construction and Operation of Streetcars (in German)	01-Jan-87	1.3.4.2	207
BOSTRAB		Guidelines for Preventive Fire Protection for Passenger Vehicles in Accordance with Bostrab	15-Mar-85	-	205
EBO		Railroad Construction and Traffic Regulations	01-Jan-82	1.3.4,8.7	101
ESBO		Railroad Construction and Operation Ordinance for Narrow Gauge Railroads (in German)	21-Nov-83	8.7.0	101
ESO		Railroad Signalling Ordinance (in German)		8.7.0	401,402
Draft MBO		Construction and Operating Code for Magnetic Levitation Rail Systems (draft)	12-Dec-88	1.5,8.7,11.2	207,404,101, 201,301
Pehla		Test Guidelines for High Voltage Systems (in German)	01-Jan-77	2.7	101,401,404
TRB		Technical Regulations for Pressurized Containers -- Index (in German)	Various	8.6,8.7	302,303
TRGL		Technical Regulations for High Pressure Gas Conduits (in German)	Various	8.6,8.7	302,303
VG 96900		Standard, Protect Against Electromagnetic Pulse NEMP & Light Standards; Survey		10.2.5	406
VG 96901		Standard, Protect Against Electromagnetic Pulse NEMP & Light Standards; Survey		10.2.5	406

TABLE B6: MISCELLANEOUS GERMAN REQUIREMENTS (cont.)

Issuing Organization and Ref. Number	Part	Title	Date of Issue	RW MSB	Functional Areas
VDMA 24169		Technical Guidelines for Explosion Protection in Fans Transporting Air Containing Combustible EPS, Steam, or Mist (in German)	01-Dec-83	3.4.2	207,211
VNPI	967	Long Stator Cable	01-June-84	2.5,2.2	400,404
ZHI	153	Code of Practice for Selection and Installation of Force Opening Position Switches with Safety Function		8.7.0	101,301,303
ZHI	200	Guidelines for Avoiding Detonation Hazards due to Electrostatic		10.4.1,10.4.3	401,404,405

TABLE B7: U.S. GOVERNMENT REGULATIONS AND OTHER PUBLICATIONS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
14 CFR (FAA)	Part 21	Certification Procedures for Products and Parts	1993 (current)	-	104
	Part 25	Airworthiness Standards for Transport Category Airplanes	1993 (current)	-	102, 105, 201-4, 206, 406, 602
	Part 43	Maintenance, Preventative Maintenance, Rebuilding and Alterations	1993 (current)	-	209, 501
	Part 61	Certification: Pilots and Flight Instructions	1993 (current)		501
	Part 63	Certification: Flight Crew Members Other than Pilots	1993 (current)		501
	Part 65	Certification: Airmen Other than Flight Crew Members	1993 (current)		501
	Part 67	Medical Standards and Certifications	1993 (current)		501
	Part 121	Responsibility of Commercial Air Carriers - Subpart L, Inspection and Maintenance	1993 (current)	-	209
47 CFR (FCC)	Part 2	Frequency Allocations and Radio Treaty Matters: General Rules and Regulations	1993 (current)	-	403
	Part 15	Radio Frequency Devices	1993 (current)	-	405
	Part 18	Industrial, Scientific and Medical Equipment	1993 (current)		405

TABLE B7: U.S. GOVERNMENT REGULATIONS AND OTHER PUBLICATIONS (cont.)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
47 CFR (FCC)	Part 90	Private Land Mobile Radio Services	1993 (current)	-	403
49 CFR (FRA)	Parts 200-240	Railroad Safety Regulations	1992 (current)	-	104, 105, 201-210, 301-304, 307 312, 403-404, 501-502
FRA/Federal Register	Volume 54, Number 10	Rail Passenger Equipment, Reissuance of Guidelines for Selecting Materials to Improve Their Fire Safety Characteristics	Jan. 17, 1989	-	205
FRA/Federal Register		Recommended Emergency Preparedness Guidelines for Passenger Trains (Draft)			
FTA/Federal Register	Volume 49, Number 158	Recommended Fire Safety Practices for Rail Transit Materials Selection	Aug. 14, 1984	-	205
AC 20136 (FAA)	-	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning	March 1990	-	406
AC 25.1309-1A (FAA)	-	System Design and Analysis	June 1988	-	102, 105
RCTA/DO0178A	-	Software Considerations in Airborne Systems and Equipment Certification	March 1985	-	105
FDA		Review Guidance for Computer Controlled Medical Devices		-	105

TABLE B7: U.S. GOVERNMENT REGULATIONS AND OTHER PUBLICATIONS (cont.)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
UMTA (FTA)-MA-06-0152-85-1	-	Recommended Emergency Preparedness Guidelines for Rail Transit Systems	1985	-	601, 602
UMTA (FTA)-MA-06-0186-89-1	-	Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers	1989	-	601, 602
UMTA (FTA)-MA-06-0153-85-5	-	Conductive Interference in Rapid Transit Signalling Systems	1985		405
UMTA (FTA)-MA-06-0153-85-6	-	Test Procedures for EMI from Power Supply Substations and Propulsion Equipment	1985	-	405
UMTA (FTA)-MA-06-0153-85-8	-	Test Procedures for Rail Vehicle Inductive Emissions from the Electrical Power Subsystems	1985	-	405
UMTA (FTA)-MA-06-0153-85-11	-	Test Procedures for Broadband Emissions of Rapid Transit Vehicle (140 kHz - 400 MHz)	1985	-	405

TABLE B8: U.S. MILITARY AND AEROSPACE STANDARDS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
MIL-STD 461B	-	Limits and Requirements for Electromagnetic Emissions	-	-	405
MIL-STD 462	-	Measurement Techniques for Electromagnetic Emissions and Susceptibility	-	-	405
MIL-STD 721C	-	Definitions of Terms for Reliability and Maintainability	June 1981		102
MIL-STD 756B	-	Reliability Modelling and Prediction	Nov 1981		102
MIL-STD 781D	-	Reliability Testing for Engineering Development, Qualifications and Production	Oct 1986		102
MIL-STD 785B	-	Reliability Program Systems and Equipment Development and Production	Sept 1980		102
MIL-STD 882C	-	System Safety Program Requirements	1993		101, 105
MIL-STD 1543B	-	Reliability Program Requirements for Space and Launch Vehicles	Oct 1988		102
MIL-STD 1629A	-	Procedures for Performing a Failure Modes, Effects and Criticality Analysis	Nov 1980		101
MIL-STD 2167A	-	Defense System Software Development			105
MIL-STD 2168	-	Defense System Software Quality Programs	-	-	105
DOD H108		Quality Control and Reliability Handbook (Interim)	April 1960		102, 105
NASA JSC 30244	-	Space Station Software Standards	-	-	105
NASA NPC 250-1	-	Reliability Program Provisions for Space System Contractors	July 1963		102
NASA NHB 1700.1	-	Basic Safety Manual	Jan 1983		101

TABLE B9: REQUIREMENTS ISSUED BY AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
ANSI STD 730	-	IEEE Standard for Software Quality Assurance Plans	1984	-	105
ANSI STD 829	-	IEEE Standard for Software Tool Documentation	1983	-	105
ANSI STD 830	-	IEEE Standard for Software Requirements Specifications	1984	-	105
ANSI STD 1008	-	IEEE Standard for Software Unit Testing	1987	-	105
ANSI STD 1012	-	IEEE Standard for Software Verification, Validation and Test Plans	1986	-	105
ANSI/ASQC Q90-Q94	-	Quality Management and Quality Assurance Standards [Identical to ISO 9000-9004]	1992	-	103
ANSI/IEEE C2	-	National Electrical Safety Code (NESC)	1990	-	404
ANSI/IEEE C34	-	Semi-Conductor Rectifiers (under revision)		-	404
ANSI/IEEE C37	-	Circuit Breakers, Switchgear Relays, Substations, and Fuses	1979	-	404
ANSI/IEEE C57	-	Distribution, Power and Regulating Transformers		-	404
ANSI/IEEE C3790-1, 1974	-	IEEE Guide for Surge Withstand Capability Tests	1974		406
ANSI/UL 96-1988, 96A-1988	-	Lightning Protection for Building and Structures	1988	-	406

TABLE B10: MISCELLANEOUS U.S. TECHNICAL REQUIREMENTS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
ACI	318-89	Building Code Requirements for Reinforced Concrete	1989	-	301
AISC	-	Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, Ninth Edition	1989	-	301
ASCE	73	Manual of Engineering Practice - Quality in the Construction Project	1990	-	103, 301
ASME	-	Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels	Current	-	303
IEEE 142-1990	-	Recommended Practice for Grounding of Industrial and Commercial Power Systems	1990		404
MBTA	Reg 48	Technical Provisions for No. 2 Red Line Rapid Transit Cars	Oct 1983	-	210
National Fluid Power Association	-	Recommendations	Various	-	303
NFPA	70	National Electrical Code (NEC)	1990	-	404
NFPA	78	Components and Installation Requirements for Lightning Protection Systems	1990	-	406
NFPA	130	Fixed Guideway Transit Systems	1990	-	205, 601, 602
NEMA	250	Enclosures for Electrical Equipment: 1000 v maximum		-	404
Prestressed Concrete Institute	-	Design Handbook		-	301

TABLE B10: MISCELLANEOUS U.S. TECHNICAL REQUIREMENTS (cont.)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
SAE	-	Handbook	Various	-	303
NSBIR 82-2532		Further Development of a Test Method for the Assessment of the Acute Inhalation Toxicity of Combustion Products	June 1982	-	205

TABLE B11: REQUIREMENTS ISSUED BY U.S. TRANSPORTATION INDUSTRY ASSOCIATIONS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
AASHTO	-	Standard Specifications for Highway Bridges, 15th Edition	1992	-	301
AASHTO	-	Manual for Maintenance Inspection of Bridges	1983	-	302
AAR Manual of Standards and Recommended Practices	Section A Part 3	Passenger Car Requirements	Various	-	201, 204, 602
	Section C Part 2 M1001	Specifications for the Design, Fabrication and Construction of Freight Cars	Various	-	104, 201, 206, 208
	Section D	Trucks and Truck Details	Various	-	206
	Section E	Brakes and Brake Equipment	Various	-	207
	Section F	Locomotives and Electrical Equipment	Various	-	202, 205, 404
	Section G	Wheels and Axles	Various	-	206
	Section J	Specification for Quality Assurance	Various	-	103
AAR	-	Field Manual of Interchange Rules	1988	-	209
AAR	-	Manual of Recommended Practices, Communications and Signals	Various	-	401, 402, 403, 406
AAR	-	Standard Code of Operating Rules	1986	-	502

TABLE B11: REQUIREMENTS ISSUED BY U.S. TRANSPORTATION INDUSTRY ASSOCIATIONS (cont.)

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
APTA	-	Manual for the Development of a System Safety Program Plan	1989	-	101
		Glossary of Reliability, Availability and Maintainability Terminology for Rail Rapid Transit	Feb 1978	-	102
		Guideline for Rail Rapid Transit Reliability, Availability and Maintainability Specifications	Feb 1978	-	102
		Guidelines for Design of Rail Rapid Transit Facilities	June 1981		207, 210, 304
AREA Manual	Chapters 1-5	Track and Track Components	Various	-	208, 302-304
	Chapter 8	Concrete Structures	Various	-	301, 302
	Chapter 15	Steel Structures	Various	-	301-303
	Chapter 27	Hydraulic Systems	Various	-	303
	Chapter 33	Electrical Energy Utilization	Various	-	404

TABLE B12: AMTRAK PUBLICATIONS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
495	-	Specifications for Coach Seats - Revision C, 12-12-91	1986	-	203
352	-	Specification for Flammability, Smoke Emission and Toxicity - Revision A, 4-29-91	Jan 1990	-	205
323	-	High Performance Wire and Cable Used on Amtrak Passenger Vehicles	Mar 1990	-	404, 205
307	-	Smoke Alarm System for Passenger Rail Cars - Revision C, 11-1-91	Sept 1991	-	205
-	-	NORAC Operating Rules, Fourth Edition	1993	-	502
NRPC 1910	-	Emergency Evacuation from Amtrak Trains	Jul 1989	-	601, 602
SAFE 015	-	Tunnel and Evacuation Emergencies on Amtrak Trains: Non-Amtrak Employee Orientation Pilot Program, Instructor's Guide	Dec 1990	-	601, 601

TABLE B13: INTERNATIONAL STANDARDS ORGANIZATION (ISO) CODE OF TECHNICAL STANDARDS

Reference Number	Part	Title	Date of Issue	RW MSB	Functional Areas
ISO 9000		Quality Management and Quality Assurance Standards — Guidelines for Selection and Use	01-Jan-87	7.3.1.1	103,104
ISO 9001		Quality Systems — Model for Quality Assurance in Design/Development, Production, Installation and Servicing	01-Jan-87	7.3.1.1	103,104
ISO 9002		Quality Systems — Model for Quality Assurance in Production and Installation	01-Jan-87	7.3.1.1	103,104
ISO 9003		Quality Systems — Model for Quality Assurance in Final Inspection and Test	01-Jan-87	7.3.1.1	103,104
ISO 9004		Quality Management and Quality Systems Elements — Guidelines	01-Jan-87	7.3.1.1	103,104
ISO 286-2		System of Limits and Fits, Tables of Standard Tolerance Graphs and Limit Deviations for Holes and Shafts	01-Jun-88	7.3.1.12	103,201,301

Note: ISO 9000-9004 are also published as DIN 9000-9004, EN 29000-29004, ANSI/ASQC Q90-94, and BS5750.

TABLE B14: INTERNATIONAL UNION OF RAILWAYS (UIC) CODE OF TECHNICAL STANDARDS

Reference Number	Title	Date of Issue	RW MSB	Functional Areas
515	Coaches - Running gear (with amendments)			206
533	Protection by the earthing (grounding) of metal parts of vehicles (with amendments)			404
540	Brakes - Air brakes for freight and passenger trains	01-Jan-82		207
541	Brakes - Regulations concerning the construction of the various brake components	01-Jan-84		207
541	Brakes, Disc brakes and linings, Amendment 6	01-Jul-91		207
543	Brakes - Regulations relative to the equipment and use of vehicles (with amendments)	01-Jan-84		207
544	Brakes - Braking power (with amendments)	01-Jul-85		207
546	Brakes - High power brakes for passenger trains. New edition of 1-80 (with amendments)	01-Jan-80		207
560	Doors, entrance platforms, windows, steps, handles and handrails of coaches and luggage vans	01-Jan-88		204
564-1	Coaches - Windows made from safety glass	01-Jan-79		203
564-2	Regulations relating to fire protection and fire-fighting measures in passenger-carrying railway vehicles or assimilated vehicles used on international services	01-Jul-82	11.6.0	205
566	Coaches - Load cases	01-Jan-84		201
610	Rules for the testing of electric rolling stock on completion of construction and before entry into service	1-Nov-78		103,104,209, 404
617-4	Position of front and side windows and of other window situations in the driving compartments of electric powered stock (with amendments)	01-Jun-82		202

TABLE B14: INTERNATIONAL UNION OF RAILWAYS (UIC) CODE OF TECHNICAL STANDARDS (cont.)

Reference Number	Title	Date of Issue	RW MSB	Functional Areas
642	Special provisions concerning fire precautions and fire-fighting measures on motive power units and driving trailers in international traffic	01-Jan-83		205
651	Layout of drivers' cabs in locomotive railcars, multiple unit trains and driving trailers	01-Jan-86	5.5.0	201,202
711	Geometry of points and crossings with UIC rails permitting speeds of 100 km/h or more on the diverging track	01-Dec-84		301
720	Laying and maintenance of track made up of continuous welded rails	01-Jan-86		301,302
730-3	Automatic warning of track maintenance gangs	01-Jan-85		302,502
731	Inspection of signalling installations	01-Jul-71		402
734	Adaptation of railway signalling systems to meet the requirements of high speeds	01-Jul-86		401
737-3	Use of thyristors in railway technology: measures for the prevention of functional disturbance in signalling installations	01-Jul-85		401,404,405
737-4	Measures for limiting the disturbance of light current installations	01-Jul-86		405
738	The more important safety conditions to be observed in the use of electronic components in railway signalling techniques	01-Jan-90		401
965	Instructions governing the behavior and safety of staff working on the track	01-Jan-80		302,502
966	Measures intended to promote safety-consciousness in staff	01-Jan-80		301,502

TABLE B15: MISCELLANEOUS FOREIGN (NON-GERMAN) REQUIREMENTS

Reference Number	Part	Title	Date of Issue	RW MSB Reference	Functional Areas
Airbus Industrie ATS 1000.001	-	Fire-Smoke-Toxicity (FST) Test Specifications	Nov 1989	11.6	205
BSI 89/33005	-	Draft Standard: Functional Safety of Programmable Electronic Systems	Nov 1989	-	105
BS 6853	-	Fire Precautions for Railway Passenger Rolling Stock	1987	-	205, 601, 602
BSI/89/33006 IEC 65A	-	Draft Standard: Software for Computers in the Application of Industrial Safety-Related Systems	Dec 1989	-	105
Canadian Government	-	Draft Railway Passenger Car Standards Part I - General, Safety Inspection Part II - Inspection Safety Standards		-	209
		Draft Passenger Car Design Safety Standards	-	-	201, 203-4, 206-7
IRSE	-	Safety System Validation with Regard to Cross-Acceptance of Signalling Systems by the Railways	Jan 1992	-	105

*U.S. G.P.O.:1993-301-717:80453

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