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A Comparison of U.S. and Foreign Safety Regulations for Potential Application to Maglev Systems

Revised Draft Final Report to the Volpe National Transportation Systems Center

October 1992

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Reference 63057

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Acknowledgements

The authors wish to thank Ms. Stephanie Markos, the Technical Monitor for this task, Robert Dorer, William Hathaway, other staff of the Volpe National Transportation Systems Center, and Arne Bang of the Federal Railroad Administration for their support and assistance during this project.

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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 Volpe National Transportation Systems Center (VNTSC), 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. These may be existing domestic U.S. regulations, standards or guidelines or foreign equivalents considered suitable for application in the U.S. operating environment. Where no suitable regulation exists, the FRA may consider the introduction of new regulations or guidelines.

This report presents the results of a systematic review of the safety requirements selected for maglev systems in Germany, to determine their applicability and completeness with respect to the construction and operation of maglev systems in the United States.

German safety requirements for high-speed maglev systems are documented in the High Speed Maglev Trains Safety Requirements, Regelwork Magnetschnellbahn -- Sicherheitstechnische Anforderungen (RW MSB), Railroad Construction and Traffic Regulations (EBO) and the draft Maglev Construction and Operation Regulation (draft MBO). 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. Generally its work, and the content of the safety requirements has concentrated on maglev technology-specific safety issues, and does 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 includes involvement in field tests at the Emsland maglev test track (TVE) of maglev systems and subsystems. The end objective of these activities is the certification of maglev systems as being in compliance with the requirements, and acceptable for public passenger service in Germany.

Germany has been the leader in developing safety requirements for high speed maglev systems, and the first maglev systems that may be installed in the United States are likely to be of German design. For these reasons, the RW MSB safety requirements are being studied by VNTSC on behalf of the FRA, for their applicability to high speed maglev systems in the United States.

Two projects to analyze the applicability of German maglev safety requirements for US maglev operations have been undertaken by or on behalf of VNTSC. The first was a review of the RW MSB safety requirements and requirements contained in the EBO and draft MBO for applicability in the United States. These have been documented in the report German High Speed Maglev Train Safety Requirements -- Potential for Application in the United States, Ref. 2. This report documents the second effort, which concentrates on reviewing safety-related technical requirements referenced in the RW MSB, and other international and U.S. safety requirements that are potentially applicable to high-speed maglev installations and operations in the United States.

In more detail, the scope of the review presented in this report is as follows:

- A review of safety requirements applicable to high-speed maglev systems in Germany, as cited in the most recent safety requirements developed by RW MSB.

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

- A comparison and assessment of the safety requirements identified in each functional area regarding their applicability to a high speed maglev system operating in the United States. This included identification of similarities and differences, the impact of the U.S. operating environment and identification of needs for further research and study.

- Presentation of recommendations for safety requirements for the construction and operation of high-speed maglev systems in the United States. These recommendations support FRA's efforts to establish safety requirements for high speed maglev in the United States.

1.2 Organization of This Report

This report comprises thirty detailed reviews of safety requirements applicable to 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 7 present the individual reviews in each of the twenty-eight maglev system functional areas. These reviews present the following information:

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

B. Definition of a safety baseline: What safety requirements should accomplish.

C. A description of the relevant safety requirements identified.

D. A comparison and assessment of the requirements applicability to a high-speed maglev system in the U.S.

E. Recommendations for FRA consideration regarding high-speed maglev safety requirements.

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 electronic power systems

Chapter 7. Personnel, operations and emergency preparedness

Chapter 8 provides a summary of the principal recommendations regarding the need for and content of safety requirements for high-speed maglev systems and services in the United States.

The Bibliography provides a listing of the technical standards, rules, regulations, codes and guidelines referenced in this report, indicating the maglev functional area to which they apply, and where applicable, where they were referenced in the RW MSB requirements. A separate list of technical reports referenced is also provided.

Note that the term "requirements" is used throughout this report to mean all applicable rules, regulations, standards, practices, and codes.

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, and the procedure for carrying out the reviews of safety requirements, and the content of the reviews.

For the purpose of this effort, 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 "High-Speed Maglev Trains Safety Requirements," prepared by the German maglev safety working group (RW MSB). 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 requirements" in this report.

This analysis of requirements is based on the version of the RW MSB requirements dated March 1, 1991 published in English translation as FRA Report DOT/FRA/ORD-92/01 (Ref. 3).

The second source of German safety requirements for evaluation and review was approximately 250 German technical requirements documents referenced in the RW MSB as being applicable to specific functional areas of a maglev system. These German requirements fall 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 requirements publishers referenced by RW MSB are briefly described below:

- Deutsches Institute fur Normung (DIN)(German National 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 ANSI and ASTM in the U.S. The DIN-Standards cited in the RW MSB are mostly in mechanical engineering and civil engineering. Most are not transportation industry specific, but there are a few that are rail vehicle specific such as DIN 5510 Preventable Fire Protection in Railway Vehicle.

- Verbands Deutscher Electrotechniker (VDE)(German Association of Electrical Engineers) publishes a wide range of general technical standards for electrical engineering.

Table 2.1

High Speed Maglev Functional Area Reviews

Reference	Title
	General Safety
101	System Safety
102	Safety, 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	Vehicle Operator and Crew Compartments
203	Passenger Compartment Interior Fittings and Components
204	Passenger Vehicle Doors and Entryways
205	Fire Safety-Materials and Devices
206	Suspension Design and Construction
207	Brake Installation and Performance
208	Vehicle-Guideway Interaction
209	Inspection and Maintenance
210	Interior and Exterior 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 Power Systems
405	EMC and EMI
406	Lightning Protection
	Personnel, Operations and Emergency Preparedness
501	Qualifications and Training
502	Operating Rules and Practices
503	Emergency Features and Equipment, including Access and Egress
504	Emergency Plans and Procedures

Many VDE requirements are published jointly with DIN (designated DIN-VDE), or are published separately by DIN and/or the International Electrotechnical Commission (IEC). The document itself is unchanged in these cases of multiple publishers. VDE requirements are usually equivalent to IEEE, ANSI and 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 DIN's, 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 the MVe 8004 signal system specification. The purpose of these requirements is similar to requirements contained in the railroad manuals for rolling stock, signal systems and railroad fixed facilities issued by the AAR and AREA. The railroad-specific requirements among DIN, VDE and DVS requirements 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. All these appear to be requirements developed by professional or industry associations and have general industrial applications.

A third source of safety requirements for review was the UIC Code. This code applies 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 requirements, the 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.

All the safety requirements referenced in the RW MSB, UIC Codes, and the other international safety requirements were acquired for review. A full listing of these documents is provided in the Bibliography, referenced to functional areas, and if from the RW MSB, the chapter and paragraph 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 DIN-VDE publications of the German Institute for Standards. The firms used the microfilm library of DIN and DIN-VDE published by Information Handling Services, Global Engineering Services and the British Standards Institute. In all about 250 individual requirement documents were obtained. Every effort was made to ensure that the requirements reviewed were the current issue at the time of acquisition in mid 1991.

When the requirements document became available, the content received a brief initial review, to enable identification of the U.S. equivalents. U.S. equivalents included the relevant portions of the existing FRA rail safety regulations (as listed in Table 2.2), as well as relevant regulations of the 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. and foreign safety requirements having relevance to the functional area, such as UIC Codes.
- Any other relevant documents.

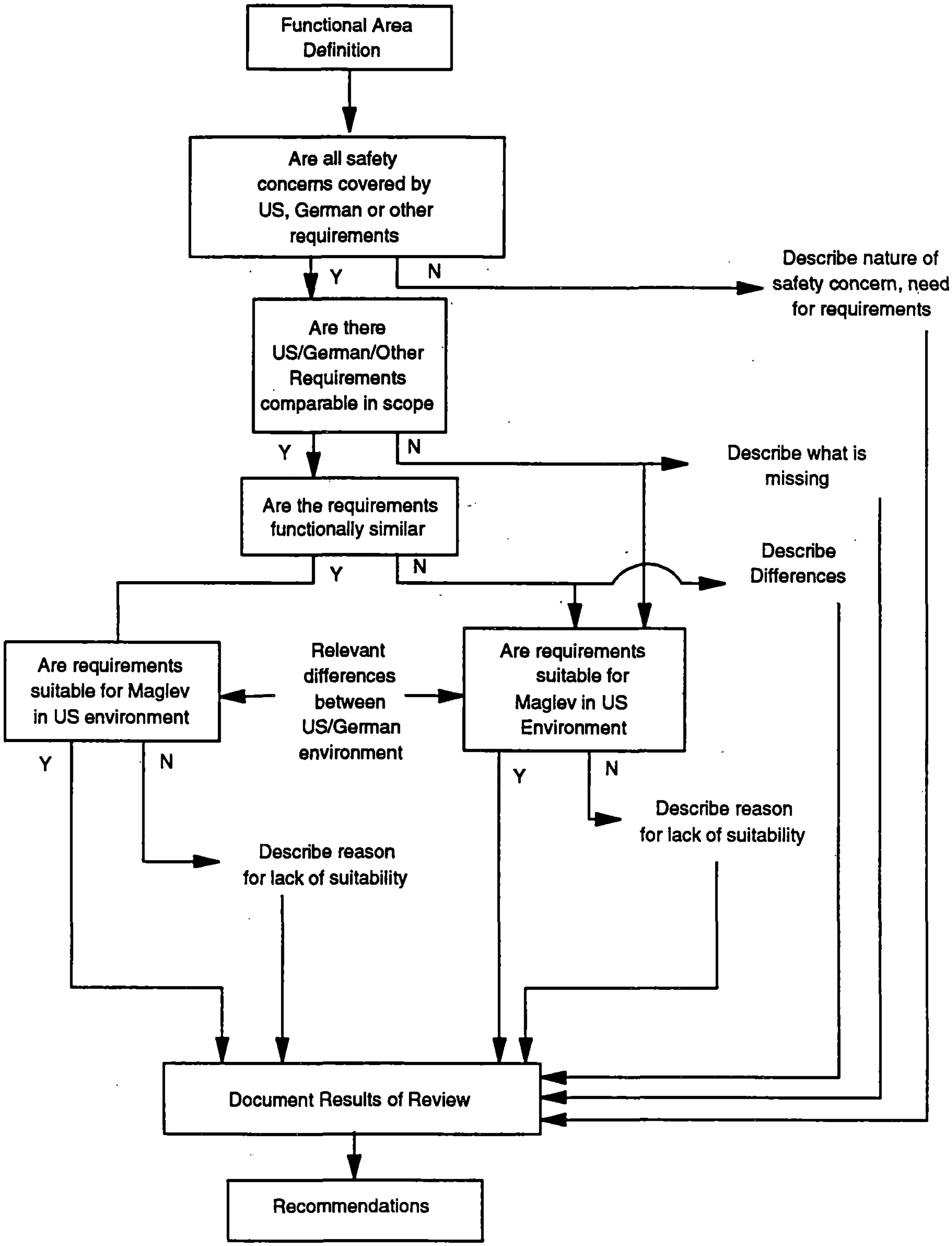
The documents were reviewed to answer the following series of questions:

- **What are the safety concerns associated with each functional area?** These include aspects of maglev system design, construction or operation that have a potential impact on the risk of adverse events in maglev operation that could lead to casualties or property damage. The answers were expressed as areas where safety requirements appear to be warranted to protect against a potential hazard. Useful sources of the answer to this question were two previous reports on HSGGT safety prepared for the

Table 2.2. Potentially Applicable FRA Regulations (49 CFR)

209	Railroad Safety Enforcement Procedures
210	Railroad Noise Emission Compliance Regulations
211	Rules of Practice
213	Track Safety Standards
215	Railroad Freight Car Safety Standards
216	Special Notice and Emergency Order Procedures: Railroad, Track, Locomotive, and Equipment
217	Railroad Operating Rules
218	Railroad Operating Practices
219	Control of Alcohol and Drug Use
220	Radio Standards and Procedures
221	Rear End Marking Device - Passenger, Computer, and Freight Trans
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: Approach to Review of Requirements



U.S. Department of Transportation.

- VNTSC, "Preliminary Safety Review of the Transrapid Maglev System" DOT/FRA/ORD 90-09, Nov. 1990 (Reference 1).

- ADL, "An Assessment of High-Speed Rail Safety Issues and Research Needs," DOT/FRA/ORD 90-04, December 1990 (Reference 2).

- **What are the relevant requirements in the U.S. and German documents, and how do they compare?** This involved listing, tabulating or illustrating the relevant requirements from each source, and identifying significant differences. It was also important to identify where safety concerns did not appear to be fully addressed by the RW MSB and other requirements. 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 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 adaptable to maglev applications.

- **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. These differences can include:

  - More severe weather environment
  - Greater risk of malicious damage by vandals
  - Less experienced or educated operating employees
  - More stringent expectations on the part of passengers of the degree of protection from hazards

  This means that safety requirements developed elsewhere may not be appropriate for direct application in the U.S., without revision. 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 will indicate which existing safety requirements are potentially applicable to maglev systems in the U.S., and which will need to be strengthened or revised to adequately address safety concerns.

The final step in the review is to develop suggestions and recommendations regarding the need for safety requirements for high-speed maglev systems in the United States to address the significant safety concerns in each functional area.

The suggestions or recommendations 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, for example, from conventional railroad or aviation regulations, to maglev systems, with or without some adaptations. This would apply when such existing regulations adequately address the safety concerns in a specific subject area.

- Adoption of German or other safety requirements, with or without adaptations. This would apply when these regulations 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. This is only suggested when the options described above are unable to address significant safety concerns in a functional area.

A standard five-point format has been developed to document the results of the reviews, which are provided in Chapter 3 to 7 of this report. This is as follows:

A. **Definition and Description of the Functional Area.** This 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. Such associated functional areas are also briefly described.

B. **Description of a Safety Baseline.** This 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.

C. **Description of Existing Safety Requirements** This provides a detailed description of the relevant content of all safety requirements identified. The safety requirements are described by country of 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, the requirements may have been developed for a specific transportation purpose or be general industrial requirements applicable to a wide variety of industries or products. Most DIN and DIN VDE requirements and similar requirements published by ANSI, ASTM and IEEE are for general industrial application and are not transportation-specific.

D. **Comparison and Assessment.** The requirements identified and described in Step C above, are assessed for similarities and differences with each other, their applicability and completeness in addressing the hazards identified in the safety Baseline, (Step B), and the extent to which their applicability is affected by differences in the U.S. and foreign operating environments.

E. **Recommendations.** Based on all the preceding information, recommendations or suggestions regarding the need for and content of safety-related requirements within each functional area are developed for the consideration of the Federal Railroad Administration. Generally, such requirements will be warranted if there are important safety concerns associated with the functional area, such as if a malfunction of a component or subsystem leads to a significant hazard to passengers, employees or the public at large, or if a component or subsystem plays a significant role in mitigating the consequences of such a failure.

One or more of the following actions are usually recommended:

1. Application of existing U.S. requirements, with or without modification.

2. Adoption of German or other foreign or international requirements.

3. Development of new requirements.

4. Carry out further research.

3. General Safety

3.1 Functional Area 101 System Safety

A. 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, it concerns the basic approaches adopted by a maglev system to control known guided transportation accident risks, such as collisions between vehicles and vehicles and objects on the guideway, fires, loss of levitation or guidance, etc. The risk of occurrence and severity of consequences from such adverse events have to be managed so that overall safety targets are met.

This Functional Area provides an overall framework for evaluating maglev safety. Therefore, it relates to all the other functional areas. The relationship is particularly close with the following:

Functional Area 102 - Safety, Reliability, and Availability provides guidance on how to achieve the required safety performance levels.

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.

B. Safety Baseline

A high-speed maglev system operating in the United States must be, and be shown to be, at least as safe as other intercity public transportation modes. This means that the risk of a passenger, employee or bystander becoming a casualty as result of maglev operations must be at least as low as with the other modes.

To demonstrate that this has been achieved, investigations are required to identify all possible safety threats, and assess the likelihood of occurrence and severity of consequences in light of maglev system, subsystem and component design. Systems must be modified to achieve acceptability whenever risks exceed acceptable levels.

C. Description of Existing Requirements

The existing requirements are listed in Table 3.1 and described below by country of origin: Germany, United States, and International.

German Requirements

Chapter 0 of the RW MSB provides definitions used in the German maglev requirements.

Chapter 1 of the RW MSB 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 states the following events must be ruled out with "adequate probability."

- Loss of levitation/guidance function
- "Racing" or magnet sticking
- Failure of 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 performance requirements of 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.

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

Section 1.7, Safety Measures, states that the operator must specify measures that 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

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	MBO	Section 1.4 Section 1.7 Section 2	Basic Rules Safety Measures General Requirements	maglev
	EBO	Section 2	General Requirements	Railroad
Institute for Railway Technology, Germany	Report 90/501 100/130 Technical readiness-Transrapid magnetic high-speed railway	-		maglev
Bassler 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

Table 3.1 Safety Requirements for Functional Area 101 (continued)

System Safety

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
VDI/VDE	3540 Safety terms for automation equipment			General/Industrial
Department of Defense	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

Table 3.1 Safety Requirements for Functional Area 101 (continued)

System Safety

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
APTA	Manual for the development of system safety program plan	-		Mass Transit

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

structured so that vehicles can always reach the auxiliary stopping points.

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. It introduces the concept that nothing is risk-free, and technical products must 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, and provides in Part 3 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 in which failure frequency thresholds are related to the consequences of failure, as shown in the table below:

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

A report by Bassler and Hofmann, titled "Safety Concept for the Maglev Train" is a comprehensive risk analysis for a German Transrapid maglev route between Bonn and Essen. A fault tree and quantitative risk model was developed, and used to select Maglev system features that would result in meeting defined safety goals.

A report by the Institute for Railway Technology, "Technical Readiness; Transrapid High Magnetic High-speed Railway," provides a qualitative Preliminary Hazard Analysis (PHA) of each safety-critical subsystem or aspect of operations.

U.S. Requirements

MIL STD 882B System Safety Program Requirements is a manual for managing system safety in new equipment. The primary safety assessment technique embodied in MIL STD 882B 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 exceed acceptable thresholds. These actions can be in one of four categories, in order of preference.

- 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 Regulations for Transport Category Airplanes 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 amplifies 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 of Part 25.1309. 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)

- 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, 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 882B. The principal steps in performing a system safety analysis are:

- Hazard Identification
- Hazard Characteristics (severity and probability)
- Hazard Mitigation
- Development of procedures for accident/incident reporting and investigation
- Development of safety audit process to identify and resolve problems with implementation of a system safety plan

D. Comparison and Assessment

The reviewed documents cover three distinct subjects.

1. Methods for system safety assessment, and of achieving safety goals which can be applied to any type of equipment.

2. Specific system features appropriate to a high-speed maglev system operating over an elevated guideway.

3. Examples of safety assessments applied to the German Transrapid maglev system.

1. System Safety Assessment and Design Techniques

In the first area, the German and U.S. documents use 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 is indicating 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 Failure Modes, Effects and Criticality Analysis, Fault Tree Analysis, and Quantitative Risk Analysis are appropriate.

The question of system safety goals was considered in the parallel project for VNTSC titled Collision Avoidance and Accident Survivability (CA/AS). The safety goal specified by FRA for any new high-speed guided ground transportation system is that it must provide a level of safety equivalent to existing intercity public transportation systems. In the CA/AS project, this goal was expressed by two requirements.

1. The rate of passenger fatalities in accidents should not exceed 0.2 per 10^9 passenger-km.

2. The incidence of accidents at different severity levels shall not exceed the risk profile shown in Figure 3.1.

2. Maglev-Specific System Safety Requirements

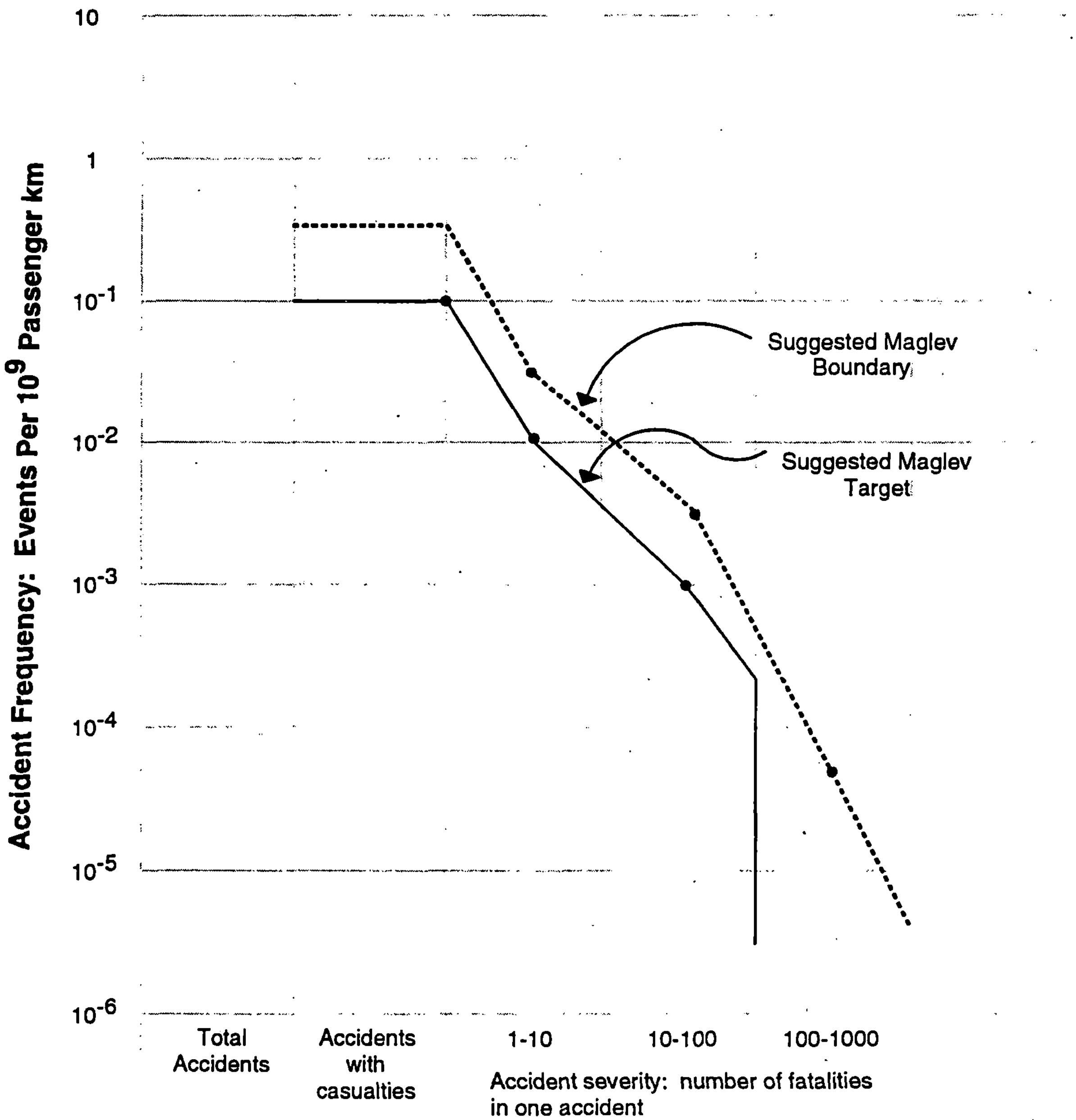
The RW MSB and MBO contain requirements specific to high-speed maglev systems. These requirements, and their underlying premise, are as follows:

- 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 MBO permits manual operation at high speed (with two operators) but 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" principal. This means that the levitation and guidance systems must be able to operate for 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.

Figure 3.1 Suggested Risk Profiles for Maglev Systems



All these requirements are system configuration choices, and alternative choices providing an adequate safety level may, in principal, 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 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 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 capabilities 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.

Transrapid System Safety Analyses

The examples of safety assessment applied specifically to the Transrapid maglev system provide partial assurance that the Transrapid system is able to meet overall safety goals, and also provide useful material and guidance for performing equivalent studies for other maglev systems and route variants. However, they are not in themselves safety requirements.

E. Recommendations

Consideration should be given to the following system safety requirements for high-speed maglev systems operating in the United States. These requirements are identical to those developed in the VNTSC's Collision Avoidance and Accident Survivability project.

Overall Risk to Occupants

The overall risk to occupants of a maglev vehicle or train of becoming a casualty in any kind of train accident shall not be greater than the general level of risk experienced in travelling by other public intercity modes of transportation in the United States, such as intercity rail or scheduled commercial airlines. An estimated rate of occupant fatalities in accidents below 0.2 per 10^9 passenger-km will satisfy this requirement.

Incidence of Accidents

The incidence of accidents of different levels of severity shall not exceed the general level of accident risk in other intercity public transportation systems operating in the United States. Estimated accident rates that do not exceed the suggested maglev safety boundary shown in Figure 3.1 shall not be considered as complying with this requirement. Additionally, every effort shall be made to achieve the safety levels represented by the suggested maglev target performance level also shown in Figure 3.1

Compliance with Requirements

Compliance with these requirements must be shown by analysis, supported as necessary by test and historical performance data. The analysis must consider:

- All accident scenarios to which the maglev system may be exposed in a particular application.

- All modes of failure of maglev subsystems and components.

- The effectiveness of warning and monitoring systems designed to detect failures, loss of redundancy or other adverse events that might threaten safety.

A system safety program must be initiated by the operator of a proposed maglev service to ensure that overall system safety goals are reached.

Specific types of analysis that can be used to determine compliance with these goals may include:

- Preliminary Hazard Analysis (PHA)

- Fault Tree Analysis (FTA)

- Failure Modes, Effects and Criticality Analysis

- Quantitative Risk Analysis

Subsequent to the system being put into operation, the operator must maintain records of all component and subsystem malfunctions that may affect safety and compare these with the estimates used in system safety assessments. Remedial action must be taken if failure rates of any safety-critical component or subsystem significantly exceed that assumed in system safety assessment.

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 Safety, Reliability, and Availability

A. 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, which addresses overall system safety goals and techniques for system safety assessment.
>
> Functional Area 105 - Computer Safety for Vehicle and Operation Control System, which 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, which is also a major area for the application of redundancy and fault tolerant design techniques.

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

B. Safety Baseline

Meeting overall system safety goals, as discussed under Functional Area 101 means that each safety-critical component and subsystem must be designed to meet individual safety goals. The goals can be defined as a minimum mean time between hazardous failures or a similar measure of safety performance. To do this, each component or subsystem has to be designed using an appropriate approach to achieving the desired safety performance. Whichever approach is used, fail-safe, safe-life, redundancy or fault tolerance, the design of a subsystem or component has to 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.

C. Description of Existing Requirements

The requirements identified are listed in Table 3.2, and are described below by country of origin: Germany, United States, and International and Other.

German Requirements

Chapter 0 of the RW MSB provides formal definitions of safe-life, fail-safe, and redundancy, as given 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).

There is no definition of fault-tolerance as distinct from redundancy.

Chapter 1 of the RW MSB, System Properties, Especially Safe Hovering, 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

Table 3.2 Safety Requirements for Functional Area 102

Safety, 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			

Table 3.2. Safety Requirements for Functional Area 102 (continued)

Safety, Reliability and Availability

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 bibliography for full citation.

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 principals.

Numerous fail-safe and safe-life requirements for individual systems are discussed elsewhere in this report.

Three German requirements documents referenced in the RW MSB contain reliability, availability and related definitions, and guidance regarding reliability and availability analysis. These are as follows:

- DIN 40 041, Dependability Concepts
- VDI/VDE 3542, Safety Terms for Automation Systems Safety Requirements
- VDI 2244, Design of Safe Equipment and Machinery

There is considerable overlap between these documents.

DIN 40.041 contains only definition of reliability terminology, including the definitions quoted above from RW MSB Chapter 0.

VDI/VDE 3542 contains similar definitions and also terms used for types of failure and in the statistical quantification of failure or defect rates. Part 3 of VDI/VDE 3542 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 is primarily concerned with safety assessment techniques, but as part of the discussion of this subject describes various ways of achieving desired safety performance. The definition of "safe-life" 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

Then appropriate methods of quantifying the environment are specified and corresponding test and analysis procedures are identified for each, usually by reference to other technical requirements document. These include general 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.

U.S. Requirements

The FAA Airworthiness Standards for Transport Category Airplanes, 14 CFR Part 25 Paragraph 25.1309, specifies that airplane systems and associated components must be designed to ensure that they perform their functions under all foreseeable operating conditions, and so 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.

An FAA Advisory Circular 25.1309-1A provides guidance regarding the interpretation of paragraph 25.1309. This document states the fail-safe design concept as applied by the FAA is defined 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, adequate design safety margins to allow for unforseen 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. No definitions are provided for fail-safe or safe-life.

The definitions are:

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. (Item state at start of a mission includes the combined effects of the readiness-related system R&M parameters, but excludes mission time; see dependability.)

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. (Item state during a mission includes the combined effects of the mission-related system R&M parameters but excludes non-mission time; see availability.)

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 redundance 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. Table 3.3 lists the tasks that make up the reliability 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.).

Table 3.3

Application Guidance for Implementation of Reliability Program Requirements

TASK	TITLE	TASK TYPE	PROGRAM PHASE			
			CONCEPT	VALID	FSED	PROD
101	RELIABILITY PROGRAM PLAN	MGT	S	S	G	G
102	MONITOR/CONTROL OF SUBCONTRACTORS AND SUPPLIERS	MGT	S	S	G	G
103	PROGRAM REVIEWS	MGT	S	S(2)	G(2)	G(2)
104	FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION SYSTEM (FRACAS)	ENG	NA	S	G	G
105	FAILURE REVIEW BOARD (FRB)	MGT	NA	S(2)	G	G
201	RELIABILITY MODELING	ENG	S	S(2)	G(2)	GC(2)
202	RELIABILITY ALLOCATIONS	ACC	S	G	G	GC
203	RELIABILITY PREDICTIONS	ACC	S	S(2)	G(2)	GC(2)
204	FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)	ENG	S	S (1)(2)	G (1)(2)	GC (1)(2)
205	SNEAK CIRCUIT ANALYSIS (SCA)	ENG	NA	NA	G(1)	GC(1)
206	ELECTRONIC PARTS/CIRCUITS TOLERANCE ANALYSIS	ENG	NA	NA	G	GC
207	PARTS PROGRAM	ENG	S	S(2)(3)	G(2)	G(2)
208	RELIABILITY CRITICAL ITEMS	MGT	S(1)	S(1)	G	G
209	EFFECTS OF FUNCTIONAL TESTING, STORAGE, HANDLING, PACKAGING, TRANSPORTATION, AND MAINTENANCE	ENG	NA	S(1)	G	GC
301	ENVIRONMENTAL STRESS SCREENING (ESS)	ENG	NA	S	G	G
302	RELIABILITY DEVELOPMENT/GROWTH TESTING	ENG	NA	S(2)	G(2)	NA
303	RELIABILITY QUALIFICATION TEST (RQT) PROGRAM	ACC	NA	S(2)	G(2)	G(2)
304	PRODUCTION RELIABILITY ACCEPTANCE ACCEPTANCE TEST (PRAT) PROGRAM	ACC	NA	NA	S	G(2)(3)

CODE DEFINITIONS

TASK TYPE:

ACC - RELIABILITY ACCOUNTING

ENG - RELIABILITY ENGINEERING

MGT - MANAGEMENT

PROGRAM PHASE

S - SELECTIVELY APPLICABLE

G - GENERALLY APPLICABLE

GC - GENERALLY APPLICABLE TO DESIGN CHANGES ONLY

NA - NOT APPLICABLE

(1) - REQUIRES CONSIDERABLE INTERPRETATION OF INTENT TO BE COST EFFECTIVE

(2) - MIL-STD-785 IS NOT THE PRIMARY IMPLEMENTATION REQUIREMENT. OTHER MIL-STDS OR STATEMENT OF WORK REQUIREMENTS MUST BE INCLUDED TO DEFINE THE REQUIREMENTS.

[Source: MIL-STD 785]

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 second like failure results in the system remaining safe, but non-operational.

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

D. Comparison and Assessment

The reviewed documents cover three areas within the overall subject of reliability and availability as follows:

1. Definition of terms.

2. Design philosophies or techniques for achieving desired reliability and availability levels consistent with overall safety goals.

3. Reliability and availability assessment techniques.

With regard to the definitions of terms, these reviewed documents are generally in agreement with each other, although there are some minor differences in some of the definitions. For example, the FAA in Advisory Circular AC 1309 defines fail-safe to include any failure which still leaves the airplane operational. In rail transit, fail-safe means the equipments fails to 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 Advisory Circular 25.1309-1A and some material in the APTA guidelines.

The third area, reliability and availability assessment techniques, is very closely related to the safety assessment techniques discussed in Functional Area 101. The techniques are essentially the same, 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 due to proximity to salt water may exist. Therefore, the extent to which reliability of individual components, and therefore overall availability and safety performance is influenced by these environmental factors should 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.

Actual reliability data has been developed for components of the German Transrapid maglev system. This data is used in the Bassler and Hofmann safety study described under Functional Area 101, and in a Thyssen-Henschel study, ref. 14.

E. Recommendations

Consideration should be given to the following reliability and availability safety requirements for high-speed maglev systems operating in the United States.

- A thorough reliability and availability analysis must be performed on all safety-critical subsystems of any maglev system, and of the system as a whole. This effort is closely related to the safety analyses required by the recommendation to Functional Area 101, and might be appropriately carried out at the same time.

- The principle used to obtain the required reliability/availability performance of each subsystem analyzed shall be clearly stated.

- Reliability data used in analysis shall be derived from direct testing or operational experience in a comparable environment, or taken from a generally accepted reference source.

- The overall reliability program should conform to a generally accepted technical requirement such as MIL STD 785B.

Further study of this subject is recommended, leading to safety, reliability and availability guidelines for maglev and other HSGGT systems, as recommended in Functional Area 101. The reviewed documents are either relatively inaccessible to

U.S. readers as they are not available in English translation, and none have 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 safety and reliability together with guidance on how such methods should be applied to guided transportation, and guidance on reliability analysis.

3.3. Functional Area 103 - Quality Assurance

A. 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, and manufactured so that their performance will fully meet all expectations of the eventual operators, passengers, and other interested parties, 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 concepts can also be extended to ensure that all ongoing maintenance and operational activities are carried out correctly. Here, also, the QA process is independent of specific technical requirements for an activity.

The safety concern is that a significant lack of quality in design, manufacture, construction operations or maintenance could result in a seriously substandard subsystem or component, which could contribute to an accident.

QA concepts and procedures are applicable to all activities involved in designing, building and operating a maglev system. They can, therefore, be applied to all the functional areas discussed in this report.

B. Safety Baseline

Comprehensive Quality Assurance procedures are required in any project as complex as a high-speed maglev system. 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 procedures adopted are internationally known and accepted.

C. Description of Existing Requirements

This description is divided into two groups. The first, German and International, describes the international QA requirements identified in the RW MSB. The second describes QA requirements developed in the United States. The requirements reviewed are listed in Table 3.4.

German and International

The RW MSB specifies a series of requirements Euronorm (EN) 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," have been adopted by several individual country and international

Table 3.4 Safety Requirement 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	
ANSI/ASQC	Q90-Q94		Identical to EN 29000-29004 above	General Industrial
AAR	Manual of Standards and Recommended Practices	Section J M1003	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 bibliography for full citation.

standards-setting organizations. Direct equivalents include:

- British Standard BS 5750
- German DIN 9000 to DIN 9004 inclusive
- International Standards Organisation ISO 9000 to ISO 9004 inclusive
- American National Standards Institute/American Society for Quality Control ANSI/ASQC Q90-94 inclusive

The only differences between these documents are in the language used, including variations between English and American usage of English.

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

The principal requirements embodied in EN 29000-29004 are 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 described in EN 29004, an organization has to design a set of procedures which should be embodied in a manual and implemented throughout the organization. These procedures should themselves by 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.

  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 are 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.

The other three documents EN 29001, EN 29002 and EN 29003 provide a detailed specification for quality management in a format that can be incorporated in contracts between a purchaser and supplier of goods and services, and following the principals described in EN 29004. The specific 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.

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) publish a guide to "Quality in the Construction Project" in 1990. Unfortunately, the title is misleading. 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 specifically to quality matters and this is mainly 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.

D. Comparison and Assessment

The traditional way of ensuring quality in manufacturing, construction, maintenance and operations is through thorough post-manufacturing or construction measurement 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 this traditional approach are that it identifies quality deficiencies relatively late in the manufacturing or other process. This means that the delay and additional costs caused by deficiencies can be heavy. Also the traditional approach typically fails to give employees sufficient incentive for considering quality in their work—often rate of production is the only measure that matters, 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 and their equivalents are a TQM process designed primarily for manufacturing industry, although they can be applied in principal to construction projects and 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 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 lags significantly behind Europe in the application of these QA processes, and EN 29000-29004 and similar processes (such as the AAR Manual, Section J) are just starting to be used. These processes are largely confined to manufacturing, and 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 that all employees are empowered to consider safety in their day-to-day work, and feedback mechanisms are established to ensure that safety problems are observed and identified and fixed.

There are clearly good reasons for applying TQM principals as embodied in EN 2900-29004 and equivalent 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 deficiencies in this activity, a properly structured TQM program has the potential to reduce costs, delivery delays and operational delays.

E. Recommendations

Consideration should be given to developing a Total Quality Management (TQM)-style QA program for any maglev system implemented in the United States. The elements of such a program could be as follows:

- The manufacturers of the vehicle and other maglev system components should implement QA procedures as specified in EN 29000-EN 29004, and have these procedures certified by an independent auditor.

- Consideration should be given to extending TQM-QA procedures to non-manufacturing areas of activity performed by or for the maglev system. These include construction services, operating and maintenance activities, and safety management.

However, because of the limited experience with TQM QA procedures in the U.S. guided ground transportation industry, a study of how to apply these procedures to this industry is desirable, especially operating and maintenance activities, leading to a manual of recommended practices. This study could use the quality assurance requirements discussed in this Function Area as a starting point.

3.4 Functional Area 104 Certification

A. 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 most of the other functional areas addressed in this chapter.

> Functional Area 101, System Safety, discussed system safety analyses, which are an essential part of confirming that a maglev system is adequately safe.
>
> Functional Area 102, Safety Reliability and Availability, addresses the definitions of reliability and availability concepts and the techniques used to achieve adequate reliability and availability of safety-critical systems. A careful testing and analysis of the techniques used will necessarily form part of a certification process.
>
> Quality Assurance (QA) Processes as described in Functional Area 103 are also an integral part of any certification process. Adequate QA has to be in place to ensure that structures and systems as built meet 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.

B. Safety Baseline

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

This means that 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 needs to 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, suitable documentation of testing, quality standards and analyses have to be kept on file.

C. Description of Existing Requirements

The existing requirements reviewed in this Functional Area are listed in Table 3.5 and described below by country of origin: Germany and the U.S.

German Requirements

The RW MSB Chapter 1, Section 7, states that it is necessary to prove compliance with the safety requirements of the RW MSB. This should be achieved first 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, these tests or certification must include:

- Manufacture or test certificates 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.

A report by the Institute for Bahntechnik, Technical Readiness, Transrapid Magnetic High-speed Railway, is understood to have been prepared to meet the requirement for an independent review of the completeness and correctness of the safety approach of the Transrapid maglev system. This report is further discussed in Functional Area 101 as an example of a safety assessment methodology.

The MBO, Paragraph 1.4, Basic Rules, 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 MBO say that the required tests should comprise a complete examination of compliance with the regulations of this 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

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	MBO EBO	Section 1.4 Paragraph 32	Basic Rules Vehicle Acceptance and Inspection	maglev Railroad
TÜV Rheinland	-	-	Florida Maglev High-Speed Transportation System - Safety/Reliability for Certification of Transrapid Maglev Technology	maglev
Institute for Bahntechnik	Technical Readiness: Transrapid Magnetic High-Speed Railway	-		maglev
FRA	49 CFR Parts 209-236 Railroad Safety Requirements			Railroad
FAA	14 CFR	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 bibliography for full citation.

until they have been accepted.

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

U.S. Requirements

The FRA in 49 CFR Part 209 is given legal powers to enforce all 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.

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, but there are no specific requirements for safety certification of systems that embody new technology.

FAA Regulations 14 CFR, Part 21, specify the certification process used for aircraft and aircraft components. In summary, this requires 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 test 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 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 particularly apply to vehicles which may operate on the lines of several different railroad systems. The process in Section C, Part II of the Manual of Standards and Recommended Practices, for the approval of new car designs is representative. 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 have to be performed. The content of these tests depends on the degree of innovation in the car design. Following successful completion of 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.

D. Comparison and Assessment

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

In Germany, two major systems safety studies have been performed on the Transrapid system, "Bassler and Hofmann" and the "Technical Readiness" studies. While the available documentation is not quite clear on the point, it appears that these reports were, in part, a response to a need for an independent assessment of maglev system safety. Components and subsystem specification and quality have been governed mainly by normal commercial specification and quality control practices, following recognized requirements such as the DIN's.

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 tests and can require specific 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. 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.

It is clear that a more structured certification process is required for high-speed maglev system than has traditionally been used for ground transportation systems. This is because of the novelty of maglev, and because of 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. A tentative conclusion of this review is that the German process as described above is probably closest to that needed in the United States. However, further study of this issue is recommended, particularly in the light of FRA's ongoing activity reviewing safety requirements for specific maglev high-speed wheel on rail applications.

E. Recommendations

Consideration should be given to the following certification requirements for high-speed maglev systems in the United States. These are primarily based on Section 7 of Chapter 1 of the RW MSB.

- 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 be available for inspection and review by a certifying authority.

- Active systems and structures including any mechanical moving parts such as vehicle suspensions and the guideway switch mechanism, must meet passive system requirements and, in addition, a proof-of-safety must 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 must be subject to a review by a suitably qualified independent organization.

It should be noted that these recommendations are highly tentative, given that experience in conducting safety reviews of HSGGT systems is rapidly growing in the United States and will lead to better information with which to determine an appropriate certification process.

3.5 Functional Area 105 - Computer Safety for Vehicle and Operations Control Systems

A. Description of Functional Area

A high-speed maglev system may include several computer systems that perform monitoring and control functions within safety critical systems. Such systems may include control of the magnetic levitation and guidance systems, the safety braking system, and in the control of 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 systems. 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, as follows:

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

Functional Area 102, Safety, Reliability and Redundancy, which 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 the vehicle-borne emergency or safety braking system may be computer controlled.

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

B. 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 techniques must be used to assure the correctness of any software used under all possible operating conditions. Computer hardware must be provided with an appropriate level of redundancy or fault tolerance plus fault indicating systems, so that the probability of a safety-threatening hardware failure is extremely low.

C. Description of Existing Requirements

Existing requirements identified in this functional area are listed in Table 3.6, and described below by country or origin: Germany, U.S. and International and Other.

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 will 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 also monitors the functioning of other safety-critical systems such as 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 specifies requirements for the Operations Control System. This system comprises all control systems functions, including guideway status sensing, the interlocking system which ensures that vehicles are only permitted to move when it is safe to do so, 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 2 out of 3 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:

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	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	-	Principals 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		Principals of Technical Approval in Signalling and Communication Engineering	Railroad
FRA	49CFR	Part 236	Instructions for the installation, inspection, maintenance and repair of signal and train control systems	Railroad

Table 3.6 Safety Requirements for Functional Area 105 (continued)

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
FAA	14 CFR Part 25 Airworthiness standards, transport category airplanes	Part 25.1309	Equipment, Systems, and Analysis	Commercial 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
DOD	MIL-STD 882B		System Safety Program Requirements	General, Military
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

Table 3.6 Safety Requirements for Functional Area 105 (continued)

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
FDA	-		Reviewer Guidance for Computer Controlled Medical Devices	Medical Equipment
UIC	738		Processing and Transmission of Safety Information	Railroad
Transport Canada	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 bibliography for full citation.

- 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 specifies testing requirements for software at various stages in software development from specification development, through draft software to finalized software.

The 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. These are that 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. This DIN includes recommendations for 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 '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 provides a detailed discussion of both hardware and software safety issues, and present 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 report by TüV, Guidelines for the Assessment of Safety-Relevant Computer Systems in Railroad Technology, 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 focusses particularly on software.

A further research report by TüV Minimum Requirements for Safety-Related Computers in Railroad and Nuclear Engineering (3-21-1988) focusses primarily on software diversity methods and the resulting benefits.

MUe 8004, "Ground-rules for the Technical Assistance of Signal and Telecommunications Engineering," is German Federal Railway's 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 record keeping 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 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.

U.S. Requirements

The Federal Railroad Administration regulation 49 CFR Part 236 specifies safety requirements for conventional railroad signal and train control. 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 Federal Aviation Administration requirements for commercial aircraft systems 14 CFR Part 25.1309 contains the general requirement that the failure of any systems 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 information 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, but in Paragraph 7i it is stated that the requirements of the Radio Technical Commission for Aeronautics Document RTCA/DO-178A should be followed for 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. Further discussion of the contents of AC 1309-1A is provided in Functional Area 101, Systems 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 the documentation needed to record and manage the software through its life-cycle from initiation of development through regular use in service.

A revision of this document 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 result in vital 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 vital software should be by means of a high-level language and should be stored in non-volatile memory.

Several other U.S. requirements address proper software development process, a prerequisite of safe software. The majority of these 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 focusses 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.

UIC and Other 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 "ACTS System Safety Validation Programs" 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) which describes in general terms the "lifecycle" of a PES from conception through use in its designed function, and the actions that are needed 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 the Cross-acceptance of Signalling Systems by the Railways" 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 tabulation of recommended development, validation and verification procedures is provided.

D. Comparison and Assessment

The essential characteristic of systems addressed in this functional area are that they rely on a computer program or programs for correct operation. Thus safe performance depends on the correct operation of both the hardware (the computer or microprocessor itself and any associated equipment), and on the correctness of the program. This is in sharp distinction from traditional railway signalling and other systems made up of a relatively small number of individual devices (electrical, electronic, mechanical), which generally have known failure modes.

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

1. 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.

2. 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. Inability of the system to function in the operating environment (temperature, humidity, electromagnetic) is also a systematic failure. When a systematic fault is present, the system will always produce an incorrect output in a particular set of 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.

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 this is a very broad subject, and it is not possible to fully address all the issues within the scope of this review. Continuing studies by the FRA are in progress

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, 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. Examples of recommendations for the highest safety class, taken from the TüV publication "Microcomputers in Safety Technique" 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 measure for the detection of information corruption and refresh faults.

The U.S. Requirements, and also Other International requirements such as Code 738 are more procedural in nature, specifying procedures to be followed at each stage in the system design and development process, but not recommending particular technical solutions.

It should be noted that 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 review of signal system safety validation, 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 same 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 will affect overall safety performance.

Random Failures

The methods of system safety assessment described under Functional Area 101, System Safety are generally applicable to random hardware failures in programmed systems. These include FMEA, Hazard Analysis as specified by MIL-STD 882B, 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 are 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.

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 they are not random failures, the 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, one caveat 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 meets requirements.

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 meet this need are found in the TüV reports, and ORE Code 738.

The IRSE report is also a helpful comparison of different railway-specific requirements, and provides very good checklist of safety assurance procedures. This checklist is reproduced in Table 3.7.

Overall Comment

Development of effective safety requirements for programmable computer controls of safety-critical processes in maglev or other guided transportation systems is clearly a major concern. The subject is both large and developing rapidly, and initial review only has been possible in this project. Further research into the overall subject 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:

1. 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 further validation and verification requirements.

2. 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 required for a particular application.

E. Recommendations

Consideration should be given to the following safety requirements for program controlled computer systems used in safety-critical maglev vehicle and operations control systems.

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

- The overall system must be designed and developed in accordance with requirements specified by a recognized requirements-setting organization for the same or an equivalent purpose. Such requirements include DIN-VDE 0801, MUe

Figure 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		

Figure 3.7 Safety Assurance Processes for Railway Safety-critical Computer Systems and Software (continued)

	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."]

8004, and UIC Code 738. Helpful guidance for system developers is also provided in the TüV reports and in the IRSE report, although these are not formal requirements.

- Appropriate analysis shall 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 should also be developed and applied.

- 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 include the ANSI/IEEE standards 730 and 1012 DIN VDE 0801, and RTCA/DO-178A.

Further research in this subject is recommended, particularly into the effectiveness of the recommended procedures, and into system design features that facilitate safe and convenient maintenance and modification procedures.

Chapter 4. Vehicle Safety Requirements

4.1 Functional Area 201 - Vehicle and Cab Structural Integrity

A. Description of Functional Area

This functional area is concerned with the overall safety performance of maglev vehicle structures, including the operators cab. There are two primary safety aspects to structural integrity: 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 and vibration modes, 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, it is essential to respect weight limitations to avoid imposing excessive loadings on the guideway.

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

Functional Area 101, System Safety, which addresses the role of collision avoidance (crashworthiness) in achieving overall safety goals.

Functional Area 104, Quality Assurance, which 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 of which discuss the strength of interior fittings.

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

B. 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.

Collisions could occur with maglev at low and moderate speed. Movements at up to 50 km/h may be permitted under manual control in the event of failures in the operations control systems. This means that the possibility of human error-caused accident exists at speeds up to 50 km/h (30 mph). Collisions at below 10 km/h (6 mph) can be defined as minor, and those at speeds up to 50 km/h (30 mph) will be more serious.

In minor collisions, 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 compartment due to passengers and loose objects such as baggage being thrown about the car.

Whilst good crashworthiness design provides some protection to vehicle occupants at higher speeds, the energy dissipated in a very high-speed collision is very high and it is not feasible to provide occupant protection using the vehicle structure. Thus, safety at high speeds depends 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 structural design has to meet a large number of requirements, including weight limitations and minimum stiffness requirements and overall dimensional limits. Lower factors of safety, and 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.

C. Description of Existing Safety Requirements

The existing safety requirements identified are listed in Table 4.1, and are described below.

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

The requirements are discussed by country of origin: German, U.S., UIC and other international.

German Requirements

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

- Chapter 5 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. These load cases cover both vehicle-guideway forces in normal operation and under emergency conditions such as failure of individual levitation or guidance magnets.

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	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 test for primary components	-		Railroad

Table 4.1 Safety Requirements for Functional Area 201 (Continued)

Vehicle and Cab Structural Integrity

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

Table 4.1 Safety Requirements for Functional Area 201 (Continued)

Vehicle and Cab Structural Integrity

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
Federal Aviation Administration	14 CFR Part 25 Airworthiness Standards, Transport Category Airplanes	Paragraphs 25-301 to 563 Paragraph 25-575	Definition of loads and proof of structures Fatigue and damage tolerance evaluation of structures	Aircraft Aircraft
Federal Railroad Administration	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 Section C Part II, M1001	Passenger car requirements Specifications for the design fabrication and construction of freight cars	Railroad
Canadian Government	Draft Passenger Car Design Safety Standards			Railroad

Table 4.1 Safety Requirements for Functional Area 201 (Continued)

Vehicle and Cab Structural Integrity

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
UIC	566 OR Coaches:load cases 651 515 Coaches, Running Gear	-		Railroad

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

However, this section (Paragraph 4.7) specifically excludes certain conditions from consideration as the risk of occurrence can be shown to be negligible. These are actual impact of guide or support magnets with guideway or a total loss of levitation at high-speed.

- Chapter 6 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. There are no specific strength requirements 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. These include a case for a collision with an obstacle.

- Chapter 7, Section 7.3, Vehicles is primarily concerned with quality assurance in vehicle construction and materials used. The standards for welded construction discussed below are cited in this section. These specify conventional railroad practice for aluminum and steel body structure construction with corresponding design stresses for welded structures. Aircraft type riveted aluminum structures are not referenced, but aviation welder qualification procedures are required.

  Chapter 7 also specifies that only materials manufactured to a recognized technical requirement (such as DIN standards, Eurostandards, etc.) 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 DIN and other standards are referenced in Chapter 7, generally providing technical requirements for welded and bolted joints, and the qualification of welders. Individual requirements documents referenced are as follows:

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

- DIN 29 591 Aerospace: Examination of Welders specifies what qualification tests welders have to undergo. 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 principals and detailed calculations used in the design of high duty bolted

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 crane. Consideration must be given to the vehicle weight, including supplies and equipment and excluding passengers, crew, and luggage.

[Source: RW MSB Chapter 6]

joints. The use of this requirement is for design of highly demanding joints, internal combustion engines, rotating couplings, gearboxes and similar applications.

- 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 are primarily concerned with spot welding techniques for vehicle body-shell construction. Individual requirements are as follows:

  - DVS 1603 Spot Welding of Steel in Railroad Rolling Stock Construction. This 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. This requirement is exactly similar as DVS 1603, but is for aluminum instead of steel.

  - DVS 1605 Welding of Aluminum in Railroad Rolling Stock Construction. This 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. This requirement 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. This document 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. This document 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 Railways requirement for welder skills qualification tests.

U.S. Requirements

The FRA regulations for locomotives 49 CFR Part 229 include requirements for the structures of multiple-unit (MU) locomotives in Part 229.141. These requirements for trains exceeding 273 tonnes (600,000 lb) empty weight, are illustrated in Figure 4.1 and Table 4.4, together with the equivalent UIC requirements discussed below. Trains of empty weight less than 273 tonnes must meet lower structural strength requirements as listed in Table 4.4.

Paragraph 229.123 requires that all lead locomotives and cab cars be equipped with an adequate pilot, end plate or snowplow.

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. These cover 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 is of interest because of the methodology used, rather than the potential applicability of specific requirements to maglev vehicles. This specification includes the following requirements.

- Acceptable materials for freight car construction, primarily by reference to national standards published by ASTM and similar organization.
- 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. This includes the strength of welds.
- Workmanship or quality requirements to be applied in construction, including those for welded, bolted and riveted joints.
- A detailed fatigue design procedure for structural components subject to fatigue loads. This procedure is based on measured structural load spectra in service. Cars in high-mileage service are 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 Airworthiness Standards for Transport Category Airplanes 14 CFR Part 25 provides detailed requirements regarding loads for which airplanes must be designed, and design and construction practices. Principal requirements are as follows:

- Design load cases are specified in Paragraphs 25.301 to 25.563. The loads are generally the maximum loads expected in service. Loads included are in-flight, and landing loads under all operating circumstances for which the aircraft is designed, and correspond to aircraft performance requirements specified elsewhere in Part 25.
- Paragraph 25.571 specifies that a fatigue life evaluation is required for all structural components subject to alternating loads for any component where failure would be catastrophic. Analyses, supported by test evidence, must be carried out to show that

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

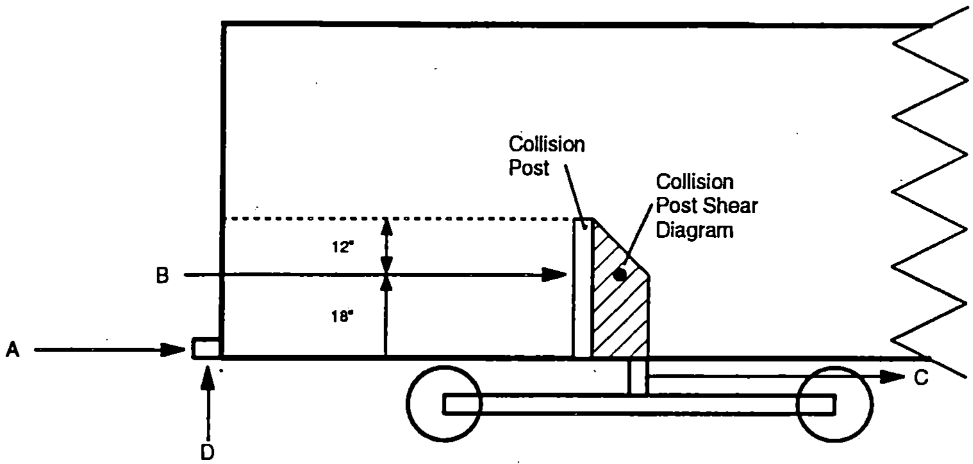
UIC Code 566 Requirements

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

Figure 4.1

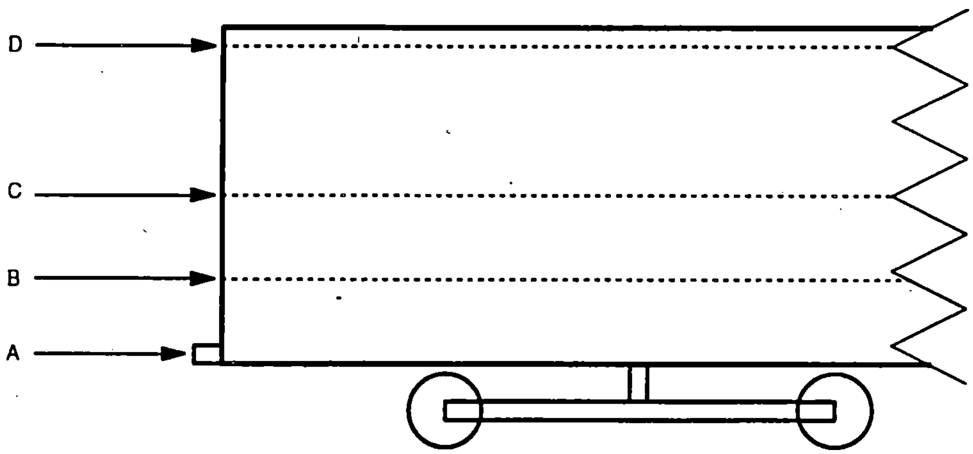
Comparison of North American and European Car Body Strength Requirements

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.

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 Paragraphs 25.561 and 562. This load case is specified in terms of static acceleration levels as follows:

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

Dynamic loadings are specified for seat attachments and passenger restraint systems. These are discussed in Functional Area 202.

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

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

- Paragraphs 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 vast 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. These standards and specifications include 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.

UIC and Other International Requirements

The primary UIC document concerned with the strength of passenger vehicles is Code 566, Load Cases. This requirement 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 specific and general 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 body to body connection be able to sustain a longitudinal load of five time bogie mass. For a typical passenger vehicle bogie of 5 t, this means a load of 250 kN.

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. These 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. These requirements are 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 train end vehicle structures.

- Vehicles must be designed so that unoccupied end spaces are less strong than occupied spaces, so 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 MV trains.

A general industrial international standard 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 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 standard can be used for slots and keyways as well as round holes and shafts. This requirement is referenced in the RW MSB with respect to mechanical structures.

D. Comparison and Assessment

There are three issues that require discussion with regard to vehicle structure. These issues are:

1. The specification of normal service load cases.

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

3. The specification of structural performance requirements in collisions.

4. Proof of Performance

1. Normal Service Load Cases

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

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 is achieved by following established and appropriate design material and manufacturing requirements. The different requirement documents reviewed emphasis different parts of this process. The DIN and other requirements referenced in the RW MSB include the series of DVS requirements concerned with welding procedures and some design requirements like VDI 2230. VDI 2230 is concerned with basic mechanics of bolted joints: the content is similar to that which would be found in a text book or engineering handbook. Materials 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 manuals cover 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 say less about manufacturing techniques. The FRA regulations only specify load cases associated with 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, and the detailed regulations are structured to address such risks.

A maglev vehicle is probably more like a rail vehicle than an aircraft with regard to structural failure risks. Apart from suspension components (discussed separately in Functional Area 206), there is much less likelihood of a undetected structural failure having catastrophic consequences than with an aircraft. The vehicle is close to the ground, and support and guidance functions are performed by suspension systems built to separate requirements. This conclusion may require review if structures are used for maglev vehicles that involve unconventional materials or very low safety factors.

3. Collision Performance

The traditional approach to defining collision performance in most conventional rail vehicles requirements, as reflected in FRA, AAR and UIC requirements, is to specify a 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, and because of differing control systems 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 a parallel VNTSC study, "Collision Avoidance and Accident Survivability" (CA/AS)(Reference 13). The principal conclusions of this study are:

- A systems approach should be used to develop CA/AS requirements for an HSGGT system, to meet an overall system safety requirement specified in terms of a risk profile (accident frequency vs severity graph). The proposed profile is shown in Figure 3.1

- Within the systems approach, however, all HSGGT vehicles should have a minimum collision performance, to ensure that extremely flimsy vehicles are put in service.

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

- 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 collision with another similar maglev vehicle, collision with debris and other smaller objects on the guideway, and a bullet impact scenario. The recommendations in Section E below are taken from the draft CA/AS report, and are subject to further review.

4. Proof of Performance

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 require instrumented tests of performance under the maximum buff load, but otherwise normal structural engineering analyses are used. However, since established data on maglev vehicle operations are lacking, the measurement of actual loads generated in operation is highly desirable to validate the assumed load cases. Once these have validated, it is reasonable to expect normal structural analyses to be sufficient to ensure structures to ensure structures are adequate to support the loads.

E. Recommendations

Consideration should be given to the following safety requirements in this functional area for U.S. maglev applications.

1. Specification of Normal Service Load Cases.

Vehicle structure load cases equivalent to those given in the RW MSB Chapter 6 should be developed for maglev vehicle structure design. Static and fatigue load cases should be clearly distinguished, and fatigue load cases should specify the 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.

2. Design and Manufacture of Structures

The recommended general requirement is that design analyses, allowable stresses and safety factors, materials and manufacturing processes should all conform to established engineering practice as specified by a recognized requirements-setting organization for the same or a similar purpose. More specifically this means:

- 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 and conform with recognized and published technical requirements. In particular, structural safety factors should reflect the severity of consequence of failure of each position of the structure.

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

3. Collision Performance

The following requirements are suggested. These requirements are taken from the draft report on Collision Avoidance and Accident Survivability and are subject to review.

Low-Speed Collision

A maglev vehicle of the maximum size normally operated shall sustain a 10 km/h (6 mph) impact with a stationary similar train. The consequences shall not exceed the following:

a) There shall be no structural damage to either train, except to energy absorbing structure forward of any passenger or train crew compartment in the leading vehicles.

b) The resulting acceleration pulse applied to vehicle occupants shall not exceed the following levels:

Maximum longitudinal acceleration	0.15g
Maximum rate of change of acceleration (jerk)	0.5g/sec

c) Compliance with this requirement must be demonstrated either by analysis using a validated computer model of the performance of energy absorbing structure or equipment incorporated into leading vehicle of a train, or by a test of this equipment or structure that accurately represents the scenario.

Medium Speed Collisions

A maglev vehicle of the maximum size normally operated shall sustain a 50 km/h (30 mph) collision with a similar stationary train. The consequences shall not exceed the following:

a) There shall be no crushing of any space normally occupied by passengers or train crew.

b) The shape and magnitude of the acceleration pulse produced must be such that no seated passenger will sustain a significant injury. Injury criteria should include the Head Injury Criteria (NIC) with a maximum impact value of 1000.

c) All baggage and equipment in the passenger vehicle shall be adequately restrained, such that there is no loss of restraint and no structural damage or distortion of interior vehicle fittings.

d) Compliance with this requirement shall be demonstrated through an acceptable combination of validated structural analysis and tests on individual components.

4. Proof of Performance

The following requirements are suggested:

- Instrumented tests must be carried out on substantially new maglev systems to validate the load cases used in design. The tests must be performed of all expected operational conditions, including with failed components where applicable.

- Other structural performance requirements shall be confirmed by using generally accepted analytical 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.

4.2 Functional Area 202 - On-Board Operator and Crew Compartments

A. Description of Functional Area

This functional area addresses all safety issues relating to the safety and working environment inside an operators compartment including the impact performance of forward facing or side facing windows if these are 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 are controlled or monitored.

Other functional areas which have an interface with or some overlap or similarity to this functional area are:

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

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

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

Functional Area 209, Emergency Access and Egress, which discusses these issues in detail, except for the specific issue of access and egress from operator and vehicle crew compartments.

B. Safety Baseline

Occupants of on-board vehicle operator's or crew compartments must be provided with an environment in which they can perform their duties effectively and 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 de-acceleration 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. This includes 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.

C. Description of Existing Safety Requirements

The existing safety requirements identified in this functional area are listed in Table 4.5 and are described below.

The requirements address three areas:

1. Glazing requirements, with particular reference to forward-facing windows.

2. The working environment in normal operation, including layout of controls and instruments, and heating, cooling and ventilation control, and the exterior visibility provided to an operator.

3. Protective features to minimize injuries and allow for emergency access and egress in case of slipping or falling incidents or a train accident.

These existing requirements will be discussed below by origin (German, US, UIC and other) for each of the three areas identified above.

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 (described below) for glazing requirements for forward facing windows.

There are no requirements cited in the EBO or MBO, or in the RW MSB for windows or glazing other than in forward facing windows.

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

Table 4.5. 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	Requirements	Chapter 7	Design Production and Quality Assurance of Mechanical Structures	
		Paragraph 2.1.2	- protection of persons in vehicles	maglev
		Chapter 4, Paragraph 4	Onboard Control System - operators console	maglev
		Chapter 5 Paragraph 3.6	Load Assumptions: Loads from disruptions caused by the environment (e.g., bird-strike)	maglev
German Government	MBO	Paragraph 3.7	Drivers Booth	maglev
UIC	651 Layout of Drive Cabs in Locomotives, Railcars, Multiple Unit Trains and Driving Trailers	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

Table 4.5. Safety Requirements for Functional Area 202 (Continued)

On-Board Operator and Crew Compartments

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 Principals 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
Federal Railroad Administration	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
Federal Aviation Administration	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 bibliography for full citation.

standards 33.400 to 403, 413 and 414.

The specific content of these DIN standards is as follows:

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

- DIN 33.401 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.

- DIN 33.402 provides standard human body dimensions for work-station dimensional design.

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

- DIN 33.413 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). The focus of this DIN is on the individual instrument. Note that this standard does not cover computer screen displays that are increasingly being used to replace conventional 'one purpose' instruments, for example in aircraft cockpits.

- DIN 33.414 provides recommendations for the design of control rooms and consoles. The focus is on the interface between the console and the operator and covers manual reach, comfortable field of view and dimensioning generally.

The 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. The more general question of requirements for onboard staffing, and monitoring and operating capabilities in systems that normally work in a fully automated mode is discussed in Functional Area 101 System Safety.

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

U.S. Requirements

Federal Railroad Administration (FRA) Regulation CFR Title 49, Part 223 specifies glazing requirement for locomotives and cab cars operating on US railroads. Locomotives and cars must be fitted with certified glazing with the following performance:

> Type I - Forward facing locations (e.g., driving cabs). Sustain impacts from 10.9 Kg (24 lb) object with dimensions 8" x 8" x 16" at 13.4 M/sec (44 ft/sec) and a 0.22 caliber rifle bullet of 40 grains weights 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 requirements.
>
> Type II - For side facing windows sustain impacts from a 10.9 Kg (24 lb) object with dimensions 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.)

Test procedures for obtaining certification are described in detail.

The Federal Aviation Administration (FAA) Regulations 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 (V_c) 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 (49 CFR Part 229) for operators cabs specify adequate illumination of in-cab instruments, the provision of a reading light, and adequate heating and ventilation (paragraphs 119 and 127). 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 emphasize 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 delineated in the DIN standards discussed above.

Specific parts of relevance to the operation and crew member's environment in 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.

Several paragraphs of FAA Regulations in 14 CFR, Part 25, for commercial aircraft apply to the aircraft's cockpit occupied by the pilot and flight crew. The specific requirements are:

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

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

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

Association of American Railroads (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, giving dimensions, strength and cushion requirements (including flammability)

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

- RP 500 provides glazing requirements, which go beyond the FRA requirements to include fire resistance, light transmittal and distortion and abrasion resistance. Requirements are also provided for electrically heated windows.

- RP 542 covers cab heating system design details, but give a performance requirement identical to the FRA regulation in 49 CFR 229.119 cited above.

- S 521 specifies a non-slip cab floor material, primarily with regard to strength and surface finish.

The FRA regulations regarding measures to minimize injuries in case of a slipping or falling incident or sudden acceleration are found in 49 CFR Part 229. Particular paragraphs of interest are:

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

- Paragraph 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.

- Paragraph 229.119 requiring that cab floors and passageways be kept clear of obstruction or debris also will help minimize the role of injury.

The FAA Regulation 14 CFR 25 Paragraph 772 requires an emergency exit from the cockpit if it is separated from the rest of the aircraft by a lockable door.

The AAR Manual, Section F, Standard S 528 requires that all exposed corners shall be rounded to minimize injury risk. The seat standard S 504, 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.

UIC and Other

This section is devoted exclusively to UIC Code 651: Layout of Drivers Cabs.

Section 2.7 and Appendix 3 of Code 651 provides glazing requirements for forward-facing windows. These are 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. The philosophy behind this requirement is 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) 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. A footnote adds that 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 aspects of the in-cab operating environment. In summary, these are:

- Requirements that define a field of view from the normal operators position and related requirements to ensure an adequate view of the track ahead. (Appendix 5 and Section 3 of Code 651). Window materials and positioning must be such that the external view is not impaired in any way by visual distortion, (especially of colors) 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.

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

- 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. (Section 2.8)

Detailed recommendations based on good ergonomic principals 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. There are also recommendations 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 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. This is similar to the AAR Standard S 528.

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

- 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.

D. Comparison and Assessment

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. These are:

- Bird impact
- Gunfire, unless the right of way is so inaccessible that there is no way that a malicious person can get near enough
- Other flying objects, whether these have a source external to the maglev system (such as objects picked up by a strong wind), objects that have been thrown or dropped by vandals, or objects that have become detached from the vehicle or guideway. Vehicles traveling on an adjacent guideway can be a source of this last type of object.

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 and includes such factors as the following:

- 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 80m or 262 ft).
- Presence of overbridges accessible by the public. These might be avoided in high-speed areas, but this could be more difficult in low speed areas near terminals.
- Use of a double guideway right of way, 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 recommended (see Functional Area 304), full protection against these hazards cannot be guaranteed. Therefore, impact requirements are essential for both forward facing and side facing windows. For forward facing windows, these requirements should include gunfire protection as in the present FRA requirements, and a suitable "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 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 4.6 below:

Table 4.6 Large Object Impact Test Requirements for 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 350 km/h vehicle* m/sec ft/sec	13.4 44	97 319	142 465
Kinetic Energy of object KN-m 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, and the UIC projectile is as hard or harder than the cinderblock. This suggests that the UIC test may be the most severe for penetration, but both UIC and the FAA bird strike test are similar for retention of the glazing in its mounting.

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 most conservative choice. The FRA impact requirement may not be suitable for high speed maglev vehicles because the relatively low energy may not be representative of the high-speed impacts to which maglev vehicles may be exposed.

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 there is no impact requirement. At least glancing impacts of large objects on side windows appear to be possible, and the FRA requirement may be appropriate.

Operating environment requirements for cover ergonomics or human factors, 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. It would appear that any of the requirements described either alone or in combination would be suitable for application to maglev systems in the U.S. The series of DINs in the 33400 series cited in the RW MSB provide a good set of ergonomic principals for crew compartments and control consoles. The only significant omission in the DINs is a 'visibility' and 'field of view' requirement through operator's compartment windows. UIC 651 field of view requirements for this are comprehensive but dimensioned specifically for conventional railroad operations. The need for maglev will depend on the nature of operator duties which require an external view, and will likely have to be maglev-system specific. These would include a forward view for manual operation, or providing the ability to make a visual check along the length of the vehicle or train to ensure there are no problems before departure. A further concern is the growing use of computer screen displays to replace conventional instruments. None of the requirements reviewed address such displays.

The UIC 651 requirements for temperature control of 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).

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. These requirements address the general requirement in RW MSB (Chapter 7, Paragraph 2.1.2) requiring that potentially injurious situations should be avoided, but are not specifically referenced.

The principal requirements mentioned in one or more of the referenced documents, and which could be applicable to a maglev system in the United States, are as follows:

- Avoidance of sharp corners, protruding objects, etc., to minimize injury risk in the case of sudden acceleration or deceleration. The subject of protection against interior impacts in the case of sudden acceleration or deceleration is being studied in a parallel VNTSC project, "Collision Avoidance and Accident Survivability." This effort may provide a recommendation for a quantitative impact protection requirement to replace this qualitative requirement.

- Adequate protection of hazardous equipment and surfaces against accidental contact.

- Requirements for non-slip flooring.

- Requirements for the strength of attachment of seats and other equipment to the structure. It is customary to express attachment strength requirements in terms of lateral and longitudinal accelerations. It would seem logical to apply the same requirements to equipment in operators and crew compartments as have been applied to passenger compartments. Functional Area 203 contains a detailed assessment of this matter.

- Provision for emergency access and egress from the compartment, which could be 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.

E. Recommendations

Consideration should be given to the following safety requirements in this Functional Area for U.S. maglev applications.

1. Glazing Requirements

A safety requirement for the impact strength of the glazing of forward-facing and side facing windows will be essential for high speed maglev vehicles. Such requirements should include:

- A bullet impact requirement identical to the present FRA requirements in 49 CFR Part 223 for both forward and side-facing windows.

- A large-object impact requirement for forward facing windows. The FRA may wish to consider adopting one of the higher energy requirements for high speed maglev operations such as the FAA 4 lb bird-strike requirement (14 CFR 25.775) or the UIC 651 1 kg projectile, and possibly carrying out a comparative investigation to see which is the most appropriate.

- A large object impact test for side windows. The existing FRA requirement for Type II windows would be suitable.

2. Working Environment

Consideration should be given to the following safety requirements.

- Ergonomic (Human Factor) layout of cabs and control console. The DIN-standards in the 33.400 series cited in the RW MSB provide comprehensive requirements that would be acceptable. However, some research into ways of properly presenting operating information on a computer screen is desirable, since these are increasingly being used in transport vehicles.

- A requirement to demonstrate that external visibility from the operators compartment through the windshield or other windows is adequate and consistent with the operator's duties.

- Requirements concerned with interior lighting both for key instruments and controls, and as otherwise necessary for the operator or crew member to carry out their duties.

3. Measures to Minimize Injuries and Provide for Emergency Egress in an Accident

Consideration should be given to the following requirements:

- A requirement for protection against accidental contact with hazardous equipment in cabs as in to the existing FRA regulation (49 CFR 229.41).

- A requirement covering the avoidance of sharp corners and protrusions to minimize the risk of injury to persons falling or being thrown against interior fittings and equipment, such as AAR S 528 in Section F of the AAR Manual or that in UIC 651.

- A requirement for non-slip flooring similar to AAR S521 in Section F of the manual.

- A requirement for the adequate attachment of seats and other equipment in operator and crew compartments, to resist both loads from slipping and falling incidents, and loads from sudden acceleration. The adoption of specified 'g' levels along each axis, (vertical, lateral, longitudinal) as is suggested for passenger compartment interior fixtures in Functional Area 203 is recommended.

- 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 25.772.

4.3 Functional Area 203 - Passenger Vehicle Interior Fittings and Components

A. Description of Functional Area

This functional area addresses safety requirements for passenger compartment interior fittings and components. Requirements for seats and other interior equipment, baggage storage, the performance of windows and other glass, and the treatment of interior surfaces and fittings to minimize injuries in the case of sudden deceleration or slipping and falling incidents are included. The other functional areas which address related safety requirements are:

Functional Area 201, Vehicle and Operator's Cab Structural Integrity and Collision Survivability, which covers all aspects of the overall vehicle structural performance, both in collisions and in normal operation, other than the impact performance of windows.

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

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

Functional Area 503, Emergency Features and Equipment, which addresses emergency access and egress, as well as other emergency features and equipment that are required.

B. Safety Baseline

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

- Protection against the penetration of 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 due to sudden deceleration in a vehicle accident or be a result of 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 acceleration, or fall out of overhead racks or bins.

C. Description of Existing Safety Requirements

The requirements identified are listed in Table 4.7, and described below by origin.

German Requirements

The RW MSB, Chapter 7 Paragraph 2.1.2 states that the 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. No other requirements are referenced. 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. These load cases would logically apply to vehicle interior fittings and equipment. The EBO and 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 as glass that, when broken, breaks into fragments that do not have sharp edges.

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 are not specified .

The FAA regulations for commercial aircraft in 14 CFR Part 25 contain several requirements for interior fittings and attachments. The basic "design" case is an emergency landing which produces the following acceleration levels (Paragraph 25.561):

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 deformation 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 Paragraph 25.562, when occupied by a 77kg (170 lb) anthropomorphic dummy, with seat belts fastened and properly adjusted. These dynamic loads are:

Table 4.7 Safety Requirement for Functional Area 203

Passenger Vehicles 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
	MBO	Section 3.4	Vehicle compartments	maglev
UIC	566 OR Load cases 560 OR Doors, Entrance Platforms, Windows, etc.	- -		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
FRA	49 CFR	Part 223	Glazing standards	Railroad
Amtrak	-	-	Passenger car interiors: strength of seats and fittings	Railroad
Canadian Government	Draft railroad passenger car safety standards	-		Railroad

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

- 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.

Maximum injury criteria for head, compression of spine, and legs, as measured with the dummy must not be exceeded. Seats and their attachments must not deform in any way that would impede emergency evacuation of occupants.

Paragraph 25.785 specifies that seats and 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 Paragraph 561 and 562. Seats must be designed assuming a 77 kg (170 lb) occupant. A safety factor of 1.15 shall be used in design (Paragraph 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. These factors apply whenever the seat strength has not been proven by a direct test.

Paragraph 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 Paragraph 25.561, as cited above.

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

The FAA regulations do not specify impact loads for side windows, but Paragraph 25.775 states that all windows must be designed to withstand the pressure and temperature differentials applying to high altitude flight of pressurized airplanes. They must also be designed to withstand the pressure differentials associated with a cabin pressure altitude of 15000 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.

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

Only the FAA in 14 CFR 25 has requirements concerned with protecting occupants from impacts with interior surfaces and fittings. Paragraph 25.785 requires that the seated occupant be protected against injury during the emergency landing scenario by a lap-tying 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.

Other Requirements

There are two sources of other requirements, the UIC code which is 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 attachment 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 requires in Code 560 that tempered or laminated safety glass shall be used for both side windows and interior glazing and mirrors. Safety glass is defined as glass that when broken does not produce sharp-edged fragments. The Canadian requirements are identical to the UIC requirements.

With regard to baggage storage, UIC requires that the general dynamic load case as described above should be applied. The following specific loadings are 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 use the baggage rack for support. There is no requirement for the enclosure of overhead racks. This, in fact, is 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.

D. Comparison and Assessment

With regard to side windows, only the FRA specifies impact tests. The FAA requirements are concerned with pressure and temperature differentials in high altitude flight. 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 the gunfire, therefore, the FRA bullet impact requirement in 49 CFR 223 should apply. There is also risk of a glancing impact on a side window from flying objects, and the FRA large object impact test in 49 CFR 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.

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 at higher acceleration levels. These acceleration levels are summarized in Table 4.8 below.

Table 4.8. Vehicle Fittings and Attachments Acceleration Load Cases

Requirement Source	Applicability	Acceleration		
		Vertical	Lateral	Longitudinal
14 CFR 25.561	Aircraft, Static	3.0g upward 6.0g downward	4.0g	9.0g forward 1.5g rearward
14 CFR 25-562	Aircraft, Dynamic	14g downward	--	16g forward
Amtrak	Intercity Rail	3g	3g	6g
UIC 566	Passenger Rail	3g	1g	5g
Canada	Passenger Rail	3g	3g	5g

For seat strength, the aircraft requirements specify that the seat occupant weights 77 kg (170 lb). The Canadian specifies a 83.8 kg (185 lb.) occupant and the UIC specifies a 100 kg occupant.

As with a conventional railroad vehicle, the situation which may produce these accelerations in a maglev vehicle is likely to be a collision, or a loss of support or guidance as in a suspension system failure. In contrast to a rail vehicle, maglev configuration 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. The high vertical acceleration in the FAA requirements arise from a heavy landing vertical impact which has no equivalent in maglev operations.

The longitudinal accelerations arise 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, they 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 is being studied in more detail in a parallel VNTSC project "Collision Avoidance and Accident Survivability."

None of the railroad-related requirements addressing 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 14CFR25.561 and 562 without exceeding specified injury criteria. A similar approach is attractive for maglev, but considerable analysis and testing is required to demonstrate compliance with an injury criteria requirement. The Collision Avoidance and Accident Survivability project is addressing this issue also.

With regard to baggage storage, all the requirements reviewed specify that baggage storage has to withstand the static accelerations listed in Table 4.7. 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.

E. Recommendations

Consideration should be given to the following safety requirements in this Functional Area for U.S. maglev applications:

1. Side Window Glazing

The present FRA bullet and large-object impact requirements, for Type II glazing as given in 49CFR223 must be used.

2. Interior Glass and Mirrors

The requirement of UIC Code 560 regarding the use of safety glass throughout vehicle interiors should be adopted to reduce the risk of injury from accidental breakage.

3. Strength of Fittings and Attachments

It is suggested that the present Amtrak requirements of designing all interior and fittings equipment and their attachments to the vehicle structure to withstand lateral and vertical acceleration of 3.0g be applied to high speed maglev systems. A recommendation for a longitudinal strength requirements should be developed after completion of the parallel study 'Collision Avoidance and Accident Survivability Study.'

4. Protection Against Injuries Due to Occupant-Interior Impacts

Hard surfaces and objects throughout the passenger compartment should be padded as required in the FAA regulation 14CFR25.785. More detailed requirements may be developed in the future from the results of the 'Collision Avoidance' study mentioned above.

5. Baggage Storage

The application of aviation practice is recommended. Baggage can be placed in enclosed overhead bins, up to a maximum placarded weight, (14CFR25-787) or in purpose-designed baggage compartments. Fully loaded compartments shall be able to contain baggage under the acceleration loads specified in item 3 above.

4.4 Functional Area 204 - Passenger Vehicle Doors and Entryways

A. Description of Functional Area

This Functional Area addresses safety issues relating to the functioning of passenger vehicle doors and other vehicle components or areas directly adjacent 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 503, Emergency Features and Equipment Including Access and Egress, which addresses all requirements for emergency access and egress, including the use of regular doors in an emergency.

B. Safety Baseline

Doors must not present a hazard to travellers using the maglev system, either during the processes of getting on and off the vehicle, or during the course of a maglev journey. Specific concerns that should be addressed are as follows:

- 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 failing incidents during entering or leaving the vehicle

It is assumed that automatic doors will be used in the maglev vehicle.

C. Description of Existing Safety Requirements

The existing safety requirements identified in this functional area are listed in Table 4.9. The requirements are discussed below by origin, German, U.S. and Other.

German Requirements

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

The 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 system for

Table 4.9 Safety Requirement for Functional Area 204

Passenger Vehicle Doors and Entryways

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
RW MSB	Requirements	Chapter 4	On-board Control System	Maglev
German Government	MBO	Section 3.4	Vehicle compartments	Maglev
	EBO	Chapter 29	Railroad car equipment	Railroad
UIC	560 0R 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 23	Railroad Safety Appliance	Railroad
FAA	14 CFR 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	Section 42	Automatic Doors	Railroad

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

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.

U.S. Requirements

The Federal Railroad Administration (FRA) regulation 49CFR part 231.13 and 231.14 provide requirements for steps and handrails below doors.

The Federal Aviation Administration (FAA) regulation 14CFR put 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 both inadvertent operation, or failure of any single structural element. Provision for the 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 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.

Other Requirements

The UIC Code 560 contains detailed requirements for both power 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. These are:

- Doors must be locked automatically at speeds exceeding 5 km/h. 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 open the doors from both inside and outside the vehicle. Usually this is a handle situated behind a breakable glass panel. Instructions for use must be displayed.

- Sliding doors must be equipped with a pressure sensitive edge or equivalent so that they can detect an obstacle and either fail to close or re-open in this event.

- 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. There is also provision for external steps and handrails to facilitate conventional railroad switching activities.

The draft Canadian Railway Passenger Safety Design Standards issued by the Canadian Transport commission (CTC), Section 42 are similar to the UIC requirements, with the additional provisions 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.

D. 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 similar Canadian requirements. These are both consistent with the less comprehensive German requirements. Furthermore, the UIC and Canadian requirements appear to address all the Safety Baseline needs identified in Section B above, and are consistent with practice on mass transit systems in the United States equipped with automatic doors.

E. Recommendations

Based on the information presented and discussed above, consideration should be given to the following safety requirements in this Functional area for United States maglev applications. All are derived from UIC Code 560 or the very similar draft Canadian rail passenger car safety standards.

1. The automatic doors shall be under the control of the on-board operator of the maglev train, who shall be provided with a system monitoring the status of all doors on the train at all times. The operator shall also have a means of looking back down the train to observe the platform adjacent to the doors prior to departure.

2. An interlocking must be provided between the door mechanisms and the power controls for the maglev train such that the train cannot start moving until all doors are properly closed and locked. A high reliability locking mechanism must be used to ensure that doors cannot open while the vehicle is in motion. This locking mechanism can be disengaged when vehicle speed falls below 5 km/h.

3. Emergency means must be provided to manually release the door locking mechanism and to open the door from both inside and outside the vehicle. These means must be clearly identified by appropriate signs, and instructions for their operation must be provided.

4. To ensure safety during closing, the door closing mechanism must be provided with means to detect entrapment of any object by the door and follow this by a temporary opening to release the trapped object. Maximum closing force shall 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.

5. 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.

4.5 Functional Area 205 - Fire Safety

A. Description of Functional Area

This functional area addresses all safety issues associated with minimizing the incidence of fires 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 503, in which Emergency Features and Equipment, including Access and Egress in all types of emergency, including fires, are discussed, together with other safety related emergency features and equipment needed in maglev vehicles such as emergency lighting and communications.
>
> 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.

B. 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 the 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.

C. Description of Existing Safety Requirements

The existing fire-related safety requirements identified are described below. The requirements address the following areas of fire safety:

1. 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.

2. Miscellaneous vehicle design requirements to reduce fire risks.

3. Requirements for the flammability, smoke emission and toxicity of materials incorporated into the vehicle.

4. Requirements for fire barriers between equipment compartments and compartments occupied by passengers and crew, and between passenger compartments.

5. Requirements for fire detection and suppression equipment.

The above requirements are discussed by origin (German, U.S. and Other). A list of the requirements identified is provided in Table 4.10.

German Requirements

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

DIN 5510, concerned with fire safety in conventional 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. (DIN 5510 Part 1). The fire protection levels are:

Level 1 - The risk to the passenger vehicle is not markedly determined by its use on subterranean line sections.

Level 2 - The risk to the passenger vehicle is markedly determined by use on subterranean line sections, and the distance between emergency stop stations is greater than 2000 m.

Level 3 - The risk to the passenger vehicle is markedly determined by use on subterranean line sections, and the distance between emergency stop stations is less than 2000 m.

Level 4 - The risk to the passenger vehicle is markedly determined by use on lines without a safety space.

Chapter 11 of the RW MSB requirement specifies that Level 4 requirements shall apply to high-speed maglev vehicles.

The DIN 5510 series also specifies a number of vehicle design requirements to reduce the risk of fire. DIN 5510 Part 4 specifies precautions to be taken to minimize the risk of fire

Table 4.10 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	MBO	Section 3.4	Vehicle Compartments	maglev
DIN	50060 Testing of burning behavior of materials and products, terms and definition	-		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
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

Table 4.10 Safety Requirements for Functional Area 205 (Continued)

Fire Safety - Materials and Devices

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FTA/Federal Register	Volume 49 No. 158 August 14, 1984	-	Recommended Fire Safety Practices for Rail Transit Materials Selection	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	Mass Transit
Amtrak	352 Specification for flammability, smoke emissions and toxicity	-	-	Railroad
AAR	Manual of Standards and Recommended Practices	Section E RP539	Fire Protection for Diesel-Electric Locomotives	Railroad
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 bibliography for full citation.

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. These 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.

DIN 5510 Part 5 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 enclosing 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 gasses given off by the batteries.

Several German requirements cited in the RW MSB address the flammability and smoke emission performance of materials installed in the maglev vehicle. These are as follows:

- DIN 50060 provides a 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 has 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 4.3). A fire door and barrier meeting this requirement must be provided between vehicle sections.

DIN 5510 Part 6 provides requirements for fire detection and suppression systems for rail vehicles operating in a level 4 environment. Such vehicles must be equipped with the following:

- One fire extinguisher in each passenger or crew compartment.

- 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.

U.S. Requirements

There are no formal U.S. requirements regarding the classification of a transportation operating environment with regard to fire risks.

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. An FAA requirement 14 CFR 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 fire resistance of materials used in transportation have been developed in the U.S. by the FRA, FTA, FAA, Amtrak, and NFPA. The principal requirements are as follows:

- The FRA requirements, Federal Register January 17, 1989, provide guidelines for selecting rail passenger car materials to improve their fire safety characteristics.

  Test procedures and performance requirements are specified for flammability and smoke emission for all commonly used materials, as indicated in Table 4.11 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.

- 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. Paragraph 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. Paragraph 25.858 provides requirements for cargo compartment fire detectors.

- The FTA for material fire resistance 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, to 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.

- NFPA 130 - Chapter 4 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. This should be below 80 BTU per cubic foot to keep fire propagation risk to acceptable levels.

With regard to barrier requirements to contain a fire, the current FRA guidelines for railroad passenger cars (Federal Register January 17, 1989) recommends that floors should resist penetration by an under-car 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.

With regard to fire detection and suppression equipment, NFPA 130, Chapter 4 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 25.851 specify a minimum of one fire extinguisher for approximately every 30 seats in the passenger cabin and in each cargo compartment

Table 4.11 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	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 175$
	Seat and/or Mattress Frame [1,5,8]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Seat and Toilet Shroud, Food Trays [1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Seat Upholstery, Mattress Ticking and Covers, Curtains [1,2,3,5]	FAR 25.853 (Vertical)	Flame time $\leq$ 10 sec.; Burn length $\leq$ 6 inch
		ASTM E-662	$D_s(4.0) \leq 250$ coated $D_s(4.0) \leq 100$ uncoated
Panels	Wall [1,5,10]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Ceiling [1,5,10]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Partition, Tables and Shelves [1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Windscreen [1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	HVAC Ducting [1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(4.0) \leq 100$
	Window [4,5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Light Diffuser [5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Flooring	Structural [6]	ASTM E-119	Pass
	Covering [7,10]	ASTM E-648	C.R.F $\geq$ 0.5 w/cm^2
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Insulation	Thermal [1,2,5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
	Accoustic [1,2,5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
Elastomers	Window Gaskets, Door Nosing, Diaphragms, Roof Mat	ASTM C-542	Pass
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Exterior Plastic Components	End Cap Roof Housings	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Component Box Covers	Interior, Exterior Boxes	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$

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

accessible in flight. Smoke detectors are required in lavatory and most cargo compartments.

The Association of American Railroads Manual of Standards and Recommended Practices, Section E Locomotive and Electrical Equipment requires on fire extinguisher having a minimum capacity of 9 kg (20 lb) in the operators 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 avoiding a build-up of dirt and debris at high risk locations in the cab and equipment compartments.

Other Requirements

Two primary requirements for rail vehicle fire safety have been identified. These are British Standard 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 operating in confined situations (tunnels or elevated structures), sleeping cars and unmanned cars. (BS 6853 3.1)

Category II - all other vehicles.

BS 6853 recommends that the total amount of combustible material in the vehicle be limited as far as possible, and that the fire hazard implications of the proximity of different materials to each other and to ignition sources, and the effects of ventilation 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:

- Part 3 addresses non-metallic material fire performance requirements by referencing other requirements documents. Tests under the DS 899/35 requirements are one of the acceptable alternatives.

- 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 fire-proof 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.

Airbus Industrie specification ATS 1000.001 was cited by the RW MSB for toxicity requirements. This specification provides flammability/smoke and toxicity minimum criteria for non metallic 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 Parts 25.853. Toxicity requirements are expressed in terms of allowable concentrations of toxic gases of 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).

D. 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 rail cars. If the maglev 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 will be desirable 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.

Vehicle Design Practices

Good design practices are addressed in DIN 5510 Part 4, BS 6853 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 principle requirements are:

- Use good practice with regard to electrical equipment and cabling (NFPA 130, DIN 5510 Part 5). This subject is discussed in more detail in Functional Area 404, Electrical Safety.
- Provide for ventilation systems to be shut off either automatically or remotely in a vehicle (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 easily 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 (FAA 14 CFR 25.865).

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.

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 requires reporting of 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.

Fire Barriers

The referenced documents contain a variety of different requirements for barrier location and performance. Amtrak, FRA, NFPA, 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 any 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, as specified by the FRA and others.

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's 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.

Philosophy with regard to fire and smoke detectors varies. 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.

E. Recommendations

Consideration should be given to the following fire safety requirements for U.S. maglev applications.

General Design Requirements

The following general design requirements are recommended to minimize the risk of fire:

- Use good electrical equipment design practices as detailed in Functional Area 404, Electrical Safety (NFPA 130, DIN 5510 Part 5).
- Provide for ventilation systems to be shut down either automatically or remotely in the event of fire (NFPA 130, DIN 5510 Part 4).
- Ensure that safety-critical on-vehicle equipment or communication systems are protected from fire damage so that they can function for at least the time taken for the vehicle to reach an emergency evacuation point (FAA 14 CFR 25.865).
- Design vehicle interior arrangements that are easy to clean and do not have places where dirt and debris can accumulate, especially in the vicinity of heaters (DIN 5510 Part 4, BS 6853, UIC 564-2).

Flammability, Smoke Emission and Toxicity of Materials

The Flammability and Smoke Emission requirements in the present FRA Recommended Fire Safety Practices are clearly applicable to high-speed maglev in the U.S. In addition, calculation of the total fire hazard load (per NFPA 130 Appendix D) in a passenger compartment is recommended. The Amtrak toxicity requirements should also apply.

Fire Barriers

Fire resistant floors (FRA, Amtrak) and transverse bulkheads between vehicles and between passenger and above-floor equipment compartments are recommended (BS 6853, UIC 564-2). Protection time must be at least the time needed for the vehicle to reach a safe evacuation point under the most unfavorable circumstances, plus time to evacuate all occupants through emergency exits.

Fire Detection and Suppression

One fire extinguisher of not less than 6 kg (13 lb) capacity should be provided in each passenger compartment and operator's cab (NFPA 130 and several others).

Automatic fire or smoke detectors should be provided in any vehicle compartment where there is a risk of an undetected fire. This particularly may include unsupervised cargo compartments, electrical equipment compartments and lavatories (BS 6853, FAA 14 CFR 25.858).

Detector alarms should be transmitted to a continuously occupied operator or crew member control console (DIN 5510 Part 4).

4.6 Functional Area 206 - Suspension Design and Installation

A. 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.

This functional area addresses the overall functional 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 air gap of each magnet is addressed in Functional Area 107, Computer Safety for Operations, Monitoring and Control 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, Safety, Reliability and Availability, which addresses the safety 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.

B. Safety Baseline

Maglev vehicle suspension components and subsystems are subject to a high vibration environment, and also transmit 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 a deflector or pilot fixed to the vehicle body.

Therefore, suspension systems and components must be designed so that adequate structural and functional integrity is maintained under 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.

C. Description of Existing Safety Requirements

Existing safety requirements relating to suspension design and construction are listed in Table 4.12 and described below. The descriptions are organized by country of origin (Germany, US, and International and Other).

German Requirements

Chapter 1 of the RW MSB, Section 3.1.1 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 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. Loads defined as interface loads are the most significant for the suspension system, and comprise the following categories:

- External loads due to wind, and temperature
- Response of suspension components and the vehicle to guideway geometry variations, whether these are due to initial construction tolerance, vehicle static and dynamic loading, or external factors such as 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 suspension systems

Table 4.12 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	Requirements	Chapter 1 Chapter 5 Chapter 6 Chapter 7	System Properties, including safe hovering Load assumptions Stability Analyses Guideway/Vehicle Design, Production and Quality Assurance of Mechanical Structures	maglev
German Government	MBO EBO	Paragraph 3.4 Paragraph 3.5 Section 3, Paragraphs 19-21	Vehicle bodies Vehicles - carrying and guidance system Vehicles	maglev Railroad
UIC	515, Coaches: running gear	-		Railroad
FRA	49 CFR	Part 213 Part 229	Freight Car Safety Standards Railroad Locomotive Safety Standards	Railroad
AAR	Manual of Standards and Recommended Practices	Section C Section D Section G	Specifications for the Design, Fabrication and Construction of Freight Cars Trucks and Truck Details Wheels and Axles	Railroad

Table 4.12 Safety Requirements for Functional Area 206 (continued)

Suspension Design

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	Paragraph 25	Fail-safe Design of Circuits and Systems	Railroad

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

Chapter 6, 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 could 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 105, Quality Assurance. Requirements for welded and bolted connections are also specified. These are described under Functional Area 201, Vehicle and Cab Structures, but also apply to mechanical suspension components.

The MBO, Section 3.4 has 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 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 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.

The EBO Section 3, 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 dimension limits for wheels and axles.

US Requirements

Several parts and paragraphs of the FRA railroad safety regulations include safety requirements for the suspension systems of conventional railroad vehicles.

Part 213, Freight Car Safety Standards, Paragraphs 103-117, specify minimum dimensional and other car condition requirements, including wheelsets, axles and truck components. These requirements are primarily wear and deterioration limits (discussed more fully in Functional Area 210, Vehicle Inspection and Maintenance), but newly constructed cars must also meet the requirements.

Part 229, Railroad Locomotive Safety Standards, Paragraphs 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 210, Vehicle Inspection and Maintenance) but newly constructed locomotives must also meet the requirements.

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. Relevant items are:

- Chapter 1, Section 1.2 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 perturbed track 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 are discussed under Functional Area 208, Vehicle-Guideway Interaction, but also define requirements to be met in suspension design.

The AAR Manual Section D provides dimensional and material requirements for conventional railroad wheels and axles.

UIC and International

UIC Code 515, Coaches: Running Gear specifies requirements for 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. This is further discussed in Functional Area 201, Vehicle and Cab Structural Integrity.

- 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. This is to avoid 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 10×10^6 load cycles, at various load levels. Loads are specified as a function of vehicle and bogie mass.

- Paragraph 25, draft Canadian Passenger Car Design Safety Standards, require 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.

D. 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 fourth 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.

Structural Integrity

The normal air gap between guideway and the levitation or guidance magnets of an EMS 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 and 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 are subject to this high vibration environment and cyclic loads, and must be designed to withstand this environment. Trucks and truck components of a conventional wheel-on-rail vehicle, are similarly subject to a high vibration and cyclic loading environment. The RW MSB (Chapter 6) 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 also 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 adequate. Instrumented track tests are customarily performed with new design trucks over perturbed track to confirm that service loadings are as expected, and this also would be good practice for maglev.

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 microprocessor based control system to control magnet power, the levitation or guidance magnets and a suspension system consisting of spring and damper elements between the magnets and the vehicle body. The RW MSB states (Chapter 1) 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 of the magnet itself, in the magnet power supply or in the gap sensor and control system. In such an event, the RW MSB requirement means that remaining operating suspension units can 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 are structured to ensure that only high quality materials are used, and serious defects are found and corrected before there is a high risk of failure.

However, conventional railroad safety requirements do recognize that suspension components such as springs and dampers can fail. Where air springs are used, rail vehicles must be able to operate at maximum speed with the springs deflated (UIC Code 515). Accidental over-inflation, due to a malfunction of a levelling valve could also occur. Failures are also possible with coil springs and hydraulic spring units. Because of the possibility of failure, rail vehicle suspensions are provided 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.

Operating Environment

This is not discussed in any of the referenced documents. However, support and guidance magnets and other suspension components, including magnetic gap sensors, are exposed under the vehicle. As such, they are exposed to ambient climate conditions (temperature, ice and snow, water), and also may be exposed to impacts with small foreign objects lying on the guideway. These are objects small enough to pass under any guard fitted to the front of the vehicle. In view of this environment, it is essential that under-vehicle suspension components are able to operate satisfactorily the full range of ambient temperature/moisture conditions likely to be encountered, and adequately protected against impacts with debris on the guideway. Impact protection will be especially important for potentially delicate items such as gap sensors.

E. Recommendations

Based on the information presented and discussed above, consideration should be given to the following safety requirements in this functional area for US maglev applications.

Suspension Component Structural Integrity

- All suspension structural components should be designed using good material fatigue design techniques, and best available estimates of operating loads, as detailed in the RW MSB, Chapter 6.

- Loadings and stresses in suspension components should be measured during pre-service instrumented tests, to confirm design assumptions.

- Structurally critical and complex components should be subject to laboratory static and fatigue strength tests.

- Complex assemblies (such as levitation or guidance magnets) which have to operate in a high-vibration environment shall be subject to vibration durability tests using representative vibration frequencies and amplitudes.

These requirements are adapted from those used for conventional rail vehicle suspension systems such as in UIC Code 515 or the AAR Manual of Standards and Recommended Practices. Design load cases can be derived from RW MSB.

Redundancy and Failure Tolerance

The vehicle must 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. Particular detailed 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 interface 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 to limit maximum movements, and safety hangers, stops and other appropriate means to minimize the risk of suspension component becoming detached from the vehicle or dragging on the guideway in case of a structural failure.

Environmental Tolerance

The maglev suspension system must be able to function satisfactorily in ambient temperature of between -40°C and + 60°C (-40°F to + 140°F), and in wet and blowing snow conditions. External parts of the system must be able to sustain impacts of debris on the guideway which may pass under the vehicle.

4.7 Functional Area 207 - Brake Installation and Performance

A. 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 braking action in service and emergency modes.

This includes the service brake used for stops in routine operation, 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 a parking brake to secure an out-of-service or unattended vehicle.

Other functional areas having an interface with this functional area are:

Functional Area 101, System Safety, which 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, Safety, Reliability and Availability, which 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, in which the software and hardware requirements for computer systems used for safety-critical functions are discussed. The vehicle on-board brake control computer and wayside train control systems are systems of this type.

Functional Area 401, Operations Control System Design, which 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 systems to respond to braking commands.

B. Safety Baseline

A maglev vehicle braking system (regular service or emergency) must be capable of bringing the vehicle to a stop to 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 bought to rest at the designed stopping point under regular service or emergency conditions. An uncontrolled stop may be permissible in an extreme emergency, but both uncontrolled and controlled stops must be achieved without significant damage to either the vehicle or guideway. A parking brake or equivalent means must be provided to ensure that an out-of-service or unattended vehicle is secure against unintentional movement.

C. Description of Existing Safety Requirements

The existing safety requirements identified for this functional area are listed in Table 4.13 and are described below. The descriptions are given by country of origin (Germany, US, UIC and other international).

German Requirements

RW MSB, Chapter 1, Section 5 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. If this is not functioning, 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.

RW MSB Chapter 2 states that there must be a highly reliable system to shut-off propulsion power on initiation of emergency braking using 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.

RW MSB Chapter 4 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 also requires that a passenger emergency signal is provided (in each vehicle section or compartment?). Upon use, the signal notifies the on-board operator and the operations control center, but does not automatically initiate braking.

The MBO, Section 3.6, states that two independent brake systems are required. One of these, the emergency or secondary brake must be independent of the propulsion system. The explanatory notes to the MBO indicate that this requirement 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.

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 form of parking

Table 4.13 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	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	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			
	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	
		541-6	Tests of Electropneumatic Brakes	
	543, Brakes - Regulations relative to the equipment and use of the vehicles			
	544, Brakes - High power brakes for passenger trains	544-1	Brakes - Braking power	

Table 4.13 Safety Requirements for Functional Area 207 (Continued)

Brake Installation and Performance

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FRA	49 CFR	232	Railroad Power Brakes and Drawbars	Railroad
		231.12-231.14	Railroad Safety Appliance Standards	
FAA	14 CFR Part 25	Paragraph 125	Landing	
	Airworthiness Standards, Transport Category Airplanes	Paragraph 735	Brakes	
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	
		Standards S-463-77 and S-464-78	Performance testing procedure for freight brakes	
		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 bibliography for full citation.

under the assumption that the friction coefficient is sufficient to hold the vehicle stationary even on the steepest gradient.

The EBO, Paragraph 23, states 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.

This paragraph of the EBO 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 states that all trains operating at more than 50 km/h must be equipped with continuous brakes. Maximum permitted stopping distance is 1000m (3284 ft) unless an exception has been authorized by a responsible authority.

US Requirements

Federal Railroad Administration (FRA) regulation 49 CFR Part 232 contains requirements for conventional railroad brakes. The principal relevant requirements are:

- Paragraph 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.

- Paragraph 232.3 references the Appendix to Part 232, which specifies construction and performance requirements for railroad brakes. These requirements are written specifically for the conventional railroad air brake system and performance requirements are specified in terms of braking forces produced by specific pressure reductions in the brake pipe. In summary, these are:

  - Appendix Paragraphs 14-17 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 pressure 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 Regulation 49 CFR Part 231, Railroad Safety Appliances Standards specifies hand brake requirements for each type of railroad vehicle. Paragraphs 231.12 to 231.14 for passenger cars specify that each car must be equipped with an efficient hand brake that operates in harmony with the power brake, and be so located that it can be safely operated with the car in motion.

The Federal Aviation Administration (FAA) in 14 CFR Part 25, specifies requirement for aircraft braking systems. Paragraph 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 Association of American Railroads, Manual of Standards and Recommended Practices, Section E provides specification for Brakes and Brake Equipment. A large part of Section E provides detailed design specification for railroad air brake system components, which have little relevance to maglev brake systems. Other 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)

However, 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.

UIC and Other

A series of UIC codes address brake system requirements, as summarized below. 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 monitoring and control of braking efforts. 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 are used on each truck or axle, and the WSP must function properly when used in conjunction with non-adhesion brakes.

• Code 541-5, Electropneumatic Brakes for Passenger and Freight Trains, provide design requirements for electropneumatic brakes. The most significant requirement is that both 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, 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). There are also numerous requirements for pressure change responses and response times.

• 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 giving the longest braking distance) must be used in calculating braking weight. Vehicles using unconventional brakes, such as eddy current or electro-magnetic 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 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 0.85m/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 vehicle 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 5 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.

The Canadian regulations also require (Paragraph 33) 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.

D. Comparison and Assessment

The highest safety requirement of a maglev braking system is that it must be capable of bringing the vehicle to rest at all times and with a high degree of certainty. All existing and proposed guided transportation vehicle brake systems consist of control unit, and multiple individual brake units. Thus the ability to stop depends on a high certainty that the control unit will provide the necessary control information to the individual brake units, and there are sufficient functioning individual brake units available.

There are also a number of other braking requirements which have to be met to ensure that braking is carried out safely. These are:

- Stopping distances must be consistent with the headways between trains, and stopping distances assumptions used in formulating train control instructions.

- The brake system must provide the degree of controllability needed to stop the vehicle at a desired location within acceptable tolerances.

- The brake system must safely absorb the braking energy and transmit the braking power to the energy sink.

- The stop must be performed without damage to the vehicle or guideway or injury to vehicle occupants.

Separately from braking the vehicle or the train to a stop, there are two further common requirements related to brake systems. These are:

- Requirements for a parking brake to secure an unattended vehicle.

- Requirements for a passenger alarm connected to the brake system to stop the train in an emergency.

Safety requirements pertaining to each of the demands on a braking system are reviewed below in more detail, assessing how each is addressed in the existing requirements, and considerations to be taken into account for a high speed maglev braking system.

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 107.

Individual Brake Unit Requirements

Both maglev and conventional railroad 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 control of remaining brakes effected via the train air line. Conventional railroad safety requirements, such as FRA 49 CFR Part 232, require that a specified 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, but this is not stated.

Braking Rate or Stopping Distance Requirements

Most of the requirements cited in Section C include a stopping distance or deceleration rate requirement. The EBO for conventional railroads in Germany uses a 1000m stopping distance requirement; US 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 show that this can be achieved with the proposed braking system. Traditional railroad requirements as embodied in the FRA, AAR, and most UIC requirements generally use a design-oriented approach, specifying air pressures, component details, and other indirect requirements to specify 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 MBO requirements for maglev in Germany, do not explicitly require specific deceleration or stopping distance performance. This appears to be an omission, since braking distance have clearly been considered in the design of prototype maglev vehicles (for example, in Reference 7).

Therefore, it is suggested that an explicit minimum deceleration rate be specified for a maglev system, and resulting stopping distances must be consistent with stopping distance criteria used for train control.

Another point regarding deceleration rates is the distinction between service and emergency braking rates and between primary and secondary or back-up brake systems. This is principally a matter of definition. In normal railroad usage, a service braking rate will be 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 combination of circumstances.

The distinction between a primary and secondary braking system is made in the German maglev requirements only. The primary brake is the non-fail-safe linear motor braking 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 braking is used in many conventional railroad and rail transit systems, but as with the maglev it is not usually expected to function as a safety brake.

Brake Controllability

In railroad practice, an emergency brake application is uncontrolled. Once initiated, the train will simply stop at the emergency deceleration rate, with little or no ability to adjust the braking rate. Because the maglev safety concept is to always reach a safe stopping place in an emergency, emergency braking must be 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.

Brake Energy and Power Performance

This is always considered by brake system designers. Brake components are sized to absorb or transmit the braking energy without damage or an excessive temperature rise. However, braking power and energy requirements are not addressed in railroad regulations or in the RW MSB or MBO maglev regulations. The only mention found is in those for aircraft brakes, which require analysis to demonstrate that brake energy/power capabilities are sufficient for worst case conditions. Information of a similar nature would be desirable for maglev braking systems.

Braking Loads and Acceleration

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 Reference 6, 'Railroad Passenger Ride Safety.' Reference 6 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.

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 mention in the RW MSB or MBO maglev requirements, 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 snow. The equipment should be capable of operating satisfactorily under all such environmental conditions likely to be encountered in operation.

Parking Brake

Virtually all the existing requirements reviewed require vehicles to be equipped with a parking brake, 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 power for operation, or to hold the vehicle indefinitely, and that it should be capable of holding the vehicle 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., steep gradient, wet conditions) would be desirable.

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 maglev, 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 discussed in Functional Area 209, Emergency Features and Equipment.

E. Recommendations

Based on the information presented and discussed in Sections C and D above, consideration should be given to the following safety requirements in this functional area.

These requirements apply to the secondary or safety brake. Since the primary brake, using linear motor reversal, is not regarded as a fail-safe system, there are no safety requirements for the primary brake other than it be shut off (like the power system) on initiation of safety braking. The requirements are based on the RW MSB with minor adaptations.

Safety Brake Control and System Requirements

- A very high level of integrity of the safety brake control system must be assured by either:

  a) intrinsically fail-safe behavior. All possible system failures will cause the brakes to be applied. This is the approach used in the conventional railroad air brake, or

b) sufficient redundancy or fault tolerance in the control system to ensure that a single failure will not render the brakes inoperative. Also, means must be provided to detect such a failure, which must result in an emergency stop

- The linear motor propulsion and service braking system must be reliably shut-off on initiation of safety braking.

- The safety brake must be adequately controllable to bring the vehicle to rest at a safe stopping place.

- The safety brake system must be entirely self contained, not dependent on any external power source, and always available for operation when the vehicle is in motion.

- Brake equipment situated outside the vehicle and exposed to ambient conditions must be able to operate reliably in wet conditions, with blowing snow, and over an ambient temperature range of -40°C to + 60°C (-40°F to + 140°F).

Individual Brake Units

- The safety brake system must include multiple totally independent brake units, each with its own power supply.

- Prescribed stopping distances must be achievable with 10 percent of the brake units or one unit of the brake out of service, whichever is the greater.

- Loss of brake units in excess of 10 percent or one unit must automatically lead to initiation of safety braking.

- Individual brake units must be arranged to fail off, to avoid the dangers of dragging an applied brake.

- The brake units must be capable of absorbing or transmitting the maximum braking energy and power generated during a maximum deceleration stop.

Stopping Distances

- A design braking performance must be specified in terms of a minimum acceptable average deceleration to stop.

- Stopping distances at this design deceleration must be consistent with stopping distance criteria used in train control system design.

Guideway and Vehicle Loadings and Occupant Safety

- Maximum safety braking should not impose unacceptable mechanical loads on the vehicle or guideway.

- To avoid risk of injury to vehicle occupants, maximum braking rates should not exceed 0.2 g and maximum jerk of 0.1 g/sec at any time during a stop.

Parking Brake

- A manually operated parking brake must be provided capable of holding a fully loaded vehicle stationary on the steepest grade in the system.

- The parking brake shall be independent of any source of electrical or hydraulic power.

- Use of vehicle skids may be acceptable as a parking brake as long as performance is adequate under adverse conditions (such as a wet or icy guideway surface).

Brake Tests

- A series of track tests to demonstrate braking performance from all operational speeds up to maximum speed must be carried out. This includes both service and emergency braking, demonstrations of "safe programmed braking" to bring the train to rest at the designated location; and operation with simulated failures to which the system is expected to respond safely.

- A demonstration of the parking brake under the most adverse conditions must be carried out (maximum gradient, low friction, etc.).

4.8 Functional Area 208 - Vehicle-Guideway Interaction

A. 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. For the guideway, this means that the loads imposed by the vehicle on the guideway and the resulting guideway structural deflections do not exceed safe limits. For the vehicle, this means that it 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 Operations Monitoring and Control, which 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, covering safety-critical mechanical and electrical components of the maglev vehicle suspension and guidance system and its components.
>
> Functional Area 301, Guideway Design and Construction, addressing guideway loading specification, design procedures for steel and concrete structures and manufacturing and construction processes for guideway structures and attachments.

B. Safety Baseline

The safe operation of a maglev vehicle over a guideway requires that a number of potentially unsafe conditions or events be avoided. These unsafe conditions and events are as follows:

- 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 componentry, 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 lead to the potential for 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 poor selection of vehicle suspension stiffness and damping rates, leading to an inadequate response to reasonable guideway geometry irregularities.

A lack of adequate passenger ride quality comfort is not a safety concern, but shares most causes with excessively poor ride quality as discussed above.

C. Description of Existing Safety Requirements

The existing safety requirements are listed in Table 4.14, and are described below, organized by country of origin: Germany, US, and UIC and other.

German Requirements

German requirements for vehicle guideway interaction are contained only in the RW MSB and the MBO. No DIN-standards or similar requirements were cited by RW MSB in connection with this functional area.

The RW MSB Chapter 5 outlines the load assumptions to be used in designing both the maglev vehicle and the guideway structure. The chapter specifies that the types of loading to be taken into account in determining vehicle-guideway loads, to be used for vehicle and guideway design are 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 electro-magnetic 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 4.14 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	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
MBO		2.1.2 2.1.3 3.2	Guideway Geometry Terracing Stresses from the vehicle	maglev
FRA	49 CFR	Part 213 Part 215 Part 229	Track safety standards Freight car safety standards Railroad locomotive safety standards	Railroad
UIC	505-2 515 560 711 720		Kinematic gauge for coaches and vans used on international services Coaches - running gear Coaches - load cases Geometry of points and crossing with UIC rails permitting speeds of 100 km/h or more on the diverging tracks Laying and maintenance of track made up of continuously welded rail	Railroad

Table 4.14 Safety Requirements for Functional Area 208 (continued)

Vehicle-Guideway Interaction

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
AREA		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 bibliography 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 goes on to specify 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 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 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.

US Requirements

A number of parts and paragraphs of the Federal Railroad Administration (FRA) railroad safety regulations provide requirements that are relevant to guideway/vehicle interactions in conventional railroad operations. These are:

- Part 213, Track Safety Standards, 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, Railroad Freight Car Safety Standards specify the minimum acceptable conditions for a freight car to be permitted to operate. Within this part, Subpart B specifies the minimum acceptable of components critical to safe operation such as wheels, axles, bearings and suspension components.

- Part 229, Railroad Locomotive Safety Standards, Subpart C, Paragraphs 229.63 to 229.75 specifies 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 Association of American Railroads' Manual of Standards and Recommendations 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, as follows.

  - 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. This includes in Section 7.3 details of load spectra 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 of this section requires specific analyses and tests to be carried out to ensure that vehicle-guideway interaction effects are within acceptable limits.

These include a series of tests over unperturbed track, and track with specified periodic and 'single-event' perturbations. 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 US freight car 3-piece trucks.

- Section G specifies dimensional 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 American Railroad Engineering Association (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.

UIC and Other Requirements

Several UIC codes contain requirements for conventional railroad vehicles concerned with or relevant to ensuring that vehicle-guideway interaction effects are within safe limits. These are 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 loading is specified as a function of axleload. This maximum must not be exceeded under maximum speed and maximum cant deficiency operation. Finally, a criterion is provided maximum wheel unloading on twisted track. Instrumented tests must be carried out to demonstrate compliance with these requirements.

  Maximum forces on the truck frame and other truck components are also specified.

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.

D. Comparison and Assessment

The requirements reviewed in Section C 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 developed for conventional railroads cannot be applied directly to maglev. This is because the railroad requirements are specified in terms of loadings, dimensional tolerances and other criteria that are specific to conventional railroads. However, the railroad criteria can provide useful guidance regarding the need for equivalent criteria for maglev systems, both in regard to what kinds of criteria are required, and also how best to devise and define suitable criteria together with appropriate performance assessment techniques.

Review of the requirements indicates that the approaches adopted by RW MSB for Maglev and in the conventional railroad industry for vehicle guideway interaction requirements (freight car requirements or UIC code 515) are broadly similar. These approaches may be summarized as follows:

- 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. These include emergency and partial failure conditions.

- Definition of maximum acceptable guideway geometric deviations which the vehicle can negotiate at different speeds, including dynamic deflection under moving vehicle loads. This includes such conditions as minimum lateral and vertical curvature and rate of guideway twist.

- Definition of a minimum safety-related ride quality in the vehicle, including quasi-static conditions such as cant deficiency in curves, and operation with a partial failure of the suspension system. A report by the FRA (Ref. 6) provide useful information on safety-related ride quality.

More 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 in part aimed at ensuring that the vehicles do not impose unacceptable loads on the track, but do this by defining dimensional, materials and specific designs, rather that specifying 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 B of this discussion. The requirements in the RW MSB generally meet this need, but are scattered 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. The recommendation section below makes some suggestions for analysis and tests to be performed to address vehicle guideway interaction safety concerns.

These recommendations depart from the conventional railroad analogy in one respect. Conventional railroad vehicle guideway 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 defined guideway, without exceeding safe force, deflection and other limits. 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 trade off guideway tolerances and vehicle suspension performance to achieve the desired performance. A safety requirement should as far as possible, preserve this design flexibility, but also ensure that the particular system chosen can operate safely. This means defining safe loads, dimensional tolerances and deflections for the guideway, and demonstrating that the vehicle can operate safely at the specified speed under these conditions.

E. Recommendations

Based on the information presented above, consideration should be given to the following safety requirements in this functional area for U.S. Maglev applications.

1. Clearance diagram

A maximum clearance diagram or envelop within which the vehicle must fit at all times must be specified. This clearance diagram must be such that there is no conflict with the guideway itself, or with any structures adjacent to the guideway. Analyses must be carried out to demonstrate that vehicle cannot violate the diagram under maximum movements on its suspension. This should include any condition of partial failure of a support and guidance suspension unit under which the vehicle may operate in an emergency.

2. Specification of guideway geometry requirements and tolerances

These comprise requirements for both low speed and high speed operations and will be the maximum deviation acceptable on a properly maintained guideway.

Low speed requirements cover the most severe geometries that the vehicle must be able to negotiate without damaging itself or the guideway. These are:

- 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 unit.

- Maximum amplitude of longer wavelength irregularities. This may 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.

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.

4. Safety analyses and tests

Both analyses and tests must 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 item 3 above, reducing the air gap between the guideway functional surfaces, support and guidance magnets below an acceptable minimum or exceeding ride quality limits in the vehicle passenger or crew compartments. This performance should be demonstrated at all speeds up to the maximum design speed 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 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

A. Description of Functional Area

This functional area addresses inspection and maintenance procedures and practices needed to ensure that vehicles are in safe operating condition at all times.

Vehicle systems and components that need 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 vehicle safety-critical systems and components that are subject to wear and degradation with time and usage. The specific vehicle system and component functional areas for which inspection and maintenance requirements will be needed are:

> Functional Area 201, Vehicle and Cab Structural Integrity, particularly for structural defect such as fatigue cracks in high stress areas.
>
> Functional Area 202, 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 are required for failures of structural components and the proper functioning of 'active' elements such as springs, dampers, levitation and guidance magnets and associated systems.
>
> Functional Area 207, Brake Installation and Performance, where virtually all subsystems and components require regular inspection and maintenance.
>
> Functional Area 503, 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.

B. 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 done correctly plans and procedures are typically needed as follows:

- Schedules detailing the frequency (by time or km operated) and nature of inspections that have to be performed on each subsystem or component.
- A definition of component condition acceptability criteria, such as dimensions, freedom from structural flaws, wear, and electrical/electronic outputs (e.g., from sensors), and associated remedial actions to correct deficiencies.
- Requirements for preventative maintenance or replacements at defined time or distance intervals.

C. Description of Existing Safety Requirements

The existing safety requirements are listed in Table 4.15 and described below by country of origin: Germany, US, and International and Other.

German Requirements

The RW MSB, Chapter 4 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 RW MSB is primarily concerned with safety requirements related to maglev system design and manufacture, and does not generally address maintenance requirements.

The 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 that these 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). Otherwise, no requirements are provided for the inspection and maintenance of specific subsystems and components.

The MBO, Paragraph 1.5 states that the operator must keep installation vehicles and appurtenances in good, operationally safe condition. No more specific inspection and maintenance requirements are provided.
The EBO Section 3, 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 acceptance inspection before placing in service.
- Vehicles must be systematically inspected.

Table 4.15 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	Requirements	Chapter 4	On-Board Control System	maglev
German Government	MBO	1.4	Basic Rules	maglev
German Government	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	49CFR	Part 215 Part 229	Freight Car Safety Standards Railroad Locomotive Safety Standards	Railroad
FAA	14CFR	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

Table 4.15 Safety Requirements for Functional Area 209 (Continued)

Vehicle Inspection and Maintenance

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 bibliography for full citation.

- There must be at least one inspection every six years, and

- Records must be kept of vehicle inspections.

Paragraph 33 provides detailed requirements for the inspection of locomotive boilers and other pressure vessels. These have to 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, none of the MBO or EBO requirements are specific with regard to inspection processes or the acceptability of vehicle condition.

TüV Rheinland, in a paper discussing certification requirements (Reference 11), 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: "Operational Fields of the New High-Speed Rail Systems in the Federal Republic of Germany" (Reference 10), describes an inspection maintenance philosophy for a high-speed magnetic levitation trains. The principal elements of the approach described are as follows:

- 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:

  1. Ensure safety
  2. Ensure operational availability
  3. 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 of the maintenance goals (safety, availability, amenity) is impacted by the failure. This is best summarized in tabular form, as shown in Table 4.16.

A detailed example of an inspection and maintenance program is provided for the maglev guideway. No details is provided for vehicle inspection and maintenance.

US Requirements

The FRA railroad safety regulations 49 CFR contain numerous inspection requirements and acceptability criteria for conventional railroad cars and locomotives. The principal requirements of interest are in the freight car safety standards (49 CFR Part 215), and the locomotive safety standards (Part 229).

49 CFR Part 215 specifies safety standards for railroad freight cars. Most of these standards detail maximum acceptable wear and degradation limits for safety-critical components. Vehicles with defects exceeding the acceptable criteria cannot continue in service and must be moved directly to a suitable facility for repair. Paragraph 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, Paragraph 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 Railroad Locomotive Safety Standards, contain inspection and maintenance requirements for locomotives.

Subpart B specifies periodic inspection requirements for locomotives as follows:

• Paragraph 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 shall be reported and repaired before the locomotive is used.

• Paragraph 229.23, Periodic Inspection, applies to locomotives and steam generators, and specifies that the period between inspections not to exceed 92 days (3 month cycles). Non-complying equipment shall be reported and repaired.

Table 4.16 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

- Paragraph 229.25 specifies that every 92 day periodic inspection shall include tests and inspection of gauges for braking, electrical devices and visible insulation, cable connections, and all automatic controls, alarms and protective devices.

- Paragraph 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.

- Paragraph 229.29 specifies that the brake controllers on locomotives are to be cleaned and tested at no more than 736 day intervals (2 years).

- Paragraph 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, Paragraph 229.46-229.91 include wear limits and other component condition safety criteria for brakes, wheels and suspension systems, drawgear and electrical systems. In general, the specific limits and conditions 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 which is in compliance 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, Paragraph 43 which gives details regarding the qualifications of maintenance and inspection personnel (see Functional Area 601, 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. These include mandatory life limits or test intervals for some components.

UIC and Other Requirements

Draft Canadian Railway Passenger Car Minimum Inspection, Safety and Design Standards specify when inspections are to be performed and 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 (Reference 12).

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 also made of on-line sensors and diagnostic systems to monitor for unacceptable conditions.

D. Comparison and Assessment

Traditional railroad inspection requirements consist of two main components: The first 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 contains detailed definitions of maximum acceptable wear and deterioration.

Traditional rail vehicles are such that most safety-critical components are readily accessible for test and 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 and replacement or reconditioning intervals. Roller bearings and air brake control valves are maintained in this way, 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, and so does French practice for the TGV train, except that inspections are at more frequent intervals and are more comprehensive.

The FAA requirements for commercial aircraft inspection and maintenance are largely driven by the requirement to develop a comprehensive manual of inspection and maintenance requirements 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, 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 situation differs from conventional railroads and aircraft primarily in the nature of the safety-critical systems and components for which inspection and maintenance procedures have to 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 eddy-current safety brake. These are all systems that may fail without warning. Conversely, there are very few safety-critical moving parts subject to mechanical wear, the suspension system being the principal area. The maglev vehicle will somewhat resemble conventional rail vehicles with regard to the need for inspection and maintenance of vehicle body structures.

Another factor in maglev inspection maintenance is the use of condition monitoring systems. These are essential to detect faults in fault-tolerant and redundant micro-electronic systems, and are increasingly used to monitor in real time systems that would otherwise need to be inspected at frequent intervals. These techniques are also being introduced into conventional railroad practice, especially high-speed wheel-on-rail trains. An important question will be the extent to which such systems can replace inspection at regular intervals by conventional means.

The paper, Reference 10, 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.

F. Recommendations

Based on the information presented and discussed above, consideration should be given to the following safety requirements in this functional area for US maglev application.

- A comprehensive condition monitoring inspection, preventative maintenance and maintenance manual shall be assembled for each type of maglev vehicle put into operation. The manual should reflect manufacturers recommendations and other available and relevant knowledge regarding component failure modes and criticality [adapted from FAA Regulation 14 CFR, Part 121, Subpart L].

- Properly qualified staff, and proper tools and equipment shall be available (from FAA Regulation 14 CFR, Part 121, Subpart L).

- Safety-critical microelectronic systems, including sensors (e.g., for magnet gap, or vehicle location) shall 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 them functioning when needed, based on best available estimate of failure rates (developed from Reference 10).

- Safety-critical mechanical components (such as suspension components, and set-down skids) shall be inspected daily and be subject to periodic non-destructive tests for structural integrity (adapted from current railroad car and locomotive safety standards).

- Detailed records shall be kept of the operation of each maglev vehicle and of all inspection results and maintenance work. The records must be subject to continuing analysis and surveillance so that problems can be identified and corrected (based on FAA 14 CFR, Part 121, Subpart L).

- 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.

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 and Exterior Vehicle Noise

A. Description of Functional Area

Virtually all transportation vehicles produce noise when in operation, which can be heard both inside the vehicle and by persons near the right-of-way. This 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 both inside and outside the maglev vehicle.

B. Safety Baseline

Both occupants of a maglev vehicle and persons engaged in activities near the maglev right-of-way should be protected from excessive disturbance or potential injury due to high noise levels. More specifically, safety concerns that may be addressed by noise-related safety requirements are:

- For vehicle occupants, especially operators and vehicle crew, fatigue or disorientation caused by high ambient noise levels, leading to a reduction in ability to perform their duties. Also hearing loss may occur due to long-term exposure to high noise levels.

- Persons living, working and otherwise engaged in activities near the maglev right-of-way may be disturbed by excessive exterior noise from passing maglev vehicles. This concern is particularly important when the maglev right-of-way is adjacent to schools, hospitals or residential areas.

C. Description of Existing Safety Requirements

Interior and exterior 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 4.17. A description of these requirements is provided below.

U.S. Requirements for Interior Noise

The Federal Railroad Requirement for locomotive cabs, 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 the table below.

Table 4.17 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	49CFR	Part 210 Part 229 Paragraph 121	Railroad Noise Emission Compliance Regulations Locomotive Cab Noise	Railroad
FTA	DC-08-9091-1		Guideline Manual for Transit Noise and Vibration Impact Assessment, Sept. 1990	Mass Transit
TRB	TRR1255		Hanson, C.E., "High Speed Rail System Noise Assessment" (paper) Jan. 1990	High Speed Guided Systems
EPA	Environmental Assessment Manual	Chapter 5	Noise	General
EPA	40 CFR	Part 201	Noise Emission Standards for Transportation Equipment: Interstate Rail Commerce	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 bibliography for full citation.

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 noise exposure of different levels, their combined effect shall be 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 on 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).

U.S. Requirements for Exterior Noise

Two types of U.S.-based requirements have been identified, one for maximum noise levels and one for averaged noise levels over a 24 hour period.

The maximum noise level requirements are contained in the FRA regulation 49 CFR Part 210, based on the EPA regulation 40 CFR Part 201. The EPA requirement, provides more detail regarding definitions and measurement procedures but is otherwise identical. The key provisions in these requirements are that locomotives built after December 1979 shall not exceed the following noise levels, measured at 30 m (100 ft) from the vehicle or train:

Stationary, Throttle at idle	70 dB(A)
Stationary, Throttle at other settings	87 dB(A)
Moving	90 dB(A)

Rail cars must not exceed the following maximum noise levels (also measured at 30 m (100 ft) from the vehicle or train):

Moving at 45 mph or less	88 dB(A)
Moving at over 45 mph	93 dB(A)

The APTA Guidelines for Rail Rapid Transit Facilities recommend the following maximum external noise goals. These are measured 15 m (50 ft) from track centerline in the open with no reflecting surfaces within 30 m (100 ft) of test location.

Car stationary, all auxiliaries operating	60 dB(A)

	2-car	4-car	6- or 8-car
Ballast and Tie Track (fast meter response):			
Train operating at 80 mph	84 dB(A)	86 dB(A)	87 dB(A)
Train operating at 60 mph	80	82	83
Concrete Trackbed (fast meter response):			
Train operating at 80 mph	88	90	91
Train operating at 60 mph	85	87	88

Noise levels are measured with a sound level meter which meets the Type 2 requirements of ANSI SI.4-1971 Specification for Sound Level Meters.

Recommendations are also provided in the APTA guidelines for noise levels in stations as follows:

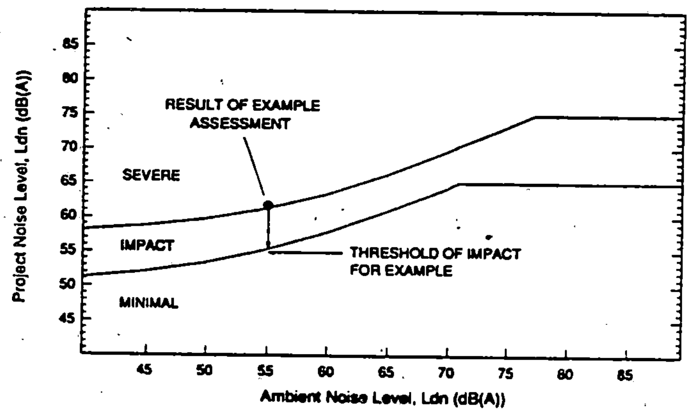
Platform level, trains entering and leaving:

Ballast and Tie Track, above ground stations only	78-80 dB(A)
Concrete trackbed, above ground stations and all underground stations	80-85 dB(A)

Complex noise requirements for commercial aircraft are specified in 14 CFR Part 36. The noise criteria used is Effective Perceived Noise Level in decibels (EPNdB), as measured at designated points on the take-off and approach flight paths. EPNdB is maximum sound level weighted for duration and tone content. Permitted maximum measured sound level at the designated points for Stage 3, aircraft varies between 104 and 89 EPNdB, depending primarily on aircraft weight and number of engines.

For average noise levels, the Federal Transit Administration (FTA) is proposing use of a combination of absolute criteria and relative criteria using the day-night sound level; L_{dn} averaged over 24 hours, as shown in Figure 4.2. The sound levels are measured at the part of any building or area in which a potentially affected activity is taking place. The lower line shows the lowest sound level at which an impact is considered to exist. The upper line shows the sound level at which an impact is considered to be severe. In this case, mitigation measure will always be required -- usually in the form of noise barriers, or additional building sound insulation. Mitigation may be required if noise levels are between the upper and lower lines, depending on the sensitivity to noise of the activity to be protected, and the cost of mitigation.

Figure 4.2
Proposed Noise Impact Criteria for Mass Transit



[Source: Hanson, Reference 5.]

The Federal Aviation Administration (FAA) has developed a procedure for identifying and controlling noise in the vicinity of airports, detailed in 14 CFR Part 150. A map must be developed giving one-year averaged day-night sound level contours for all areas where averaged day-night noise is expected to exceed 65 dB(A), using forecasts of aircraft movements five years in the future.. A noise compatibility program must be undertaken wherever incompatibilities between noise levels and land use exist, as indicated in Table 4.18 reproduced from Part 150. These can include changing land use, changes in aircraft operations, or improved sound insulation in buildings. A new plan is required if averaged day-night noise levels are expected to change more than 1.5 dB(A).

Table 4.18 Land Use Compatibility with Yearly Day-Night Average Sound Levels from Airport Operations

Land use	Yearly day-night average sound level (L_{dn}) in decibels					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential						
Residential, other than mobile homes and transient lodgings.	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware and farm equipment.	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction.	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation.	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

*The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

KEY TO TABLE 1

SLUCM=Standard Land Use Coding Manual.
Y (Yes)=Land Use and related structures compatible without restrictions.
N (No)=Land Use and related structures are not compatible and should be prohibited.
NLR=Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35=Land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure.

NOTES FOR TABLE 1

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.
(2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
(3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
(4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal level is low.
(5) Land use compatible provided special sound reinforcement systems are installed.
(6) Residential buildings require an NLR of 25.
(7) Residential buildings require an NLR of 30.
(8) Residential buildings not permitted.

(Source: 14 CFR Part 150, Appendix A)

FAA regulations in 14 CFR Part 161 give administrative procedures for airports that wish to restrict use to aircraft complying with the 'Stage 3' noise requirements, as part of their noise abatement programs.

The EPA Region 1, Environmental Assessment Manual, Chapter on Noise - provides a complete definition of terms used for environmental assessment of exterior noise impacts. The EPA manual defines noise impacts as follows:

Increase in L_{dn} Level	Impact Extent
0-5 dB(A)	slight
5-15 dB(A)	moderate
15 or more dB(A)	severe

D. Comparison and Assessment

All the requirements described in Section C 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 operators cab is much lower than the FRA requirement for locomotive cabs for the same exposure time of 87 dBA. The mass transit requirement may be more appropriate for high-speed maglev. 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 level, leading to a better working environment is desirable where this difficulty is not present and should be achievable in a maglev vehicle with very little on board moving machinery.

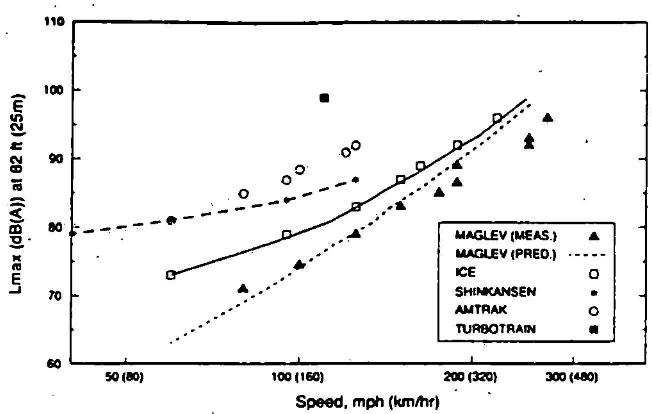
Requirements for maximum noise levels in the passenger compartments in the open at normal operating speed are typically 70 dB(A) for mass transit equipment. Similar or lower levels are specified for intercity rail passenger cars. The objective of these requirements are to ensure an adequate level of passenger comfort. They are well below any level that could be considered harmful.

With regard to exterior noise, the maximum levels permitted under the FRA/EPA regulations for a rail-car is 93 dB(A) at 30 m (100 ft) from the vehicle. The highest level recommended by APTA for mass transit systems is significantly lower: 91 dB(A) measured at 15 m (50 ft) from track centerline. The high FRA/EPA requirements reflect the fact that railroad railcars may have an on-board prime mover. Also, railroad movements tend to be both less frequent and less concentrated in urban areas than transit operations, so a higher maximum noise level may be more tolerable. Permitted sound levels due to aircraft on takeoff or landing can be much higher than permitted railroad or transit levels, up to 106 dB. However, sound levels of this magnitude are very unlikely to be acceptable for any ground transportation system.

Actual maximum sound levels produced by high speed maglev and rail systems have been investigated by Hanson (Ref. 5). Results illustrated in Figure 4.3 suggest that actual maximum sound levels generated at the highest speeds (over 300 km/h (187 mph)) are in the range 90-100 dB(A) and could exceed the FRA/EPA maximum of 93 dB(A). Although the measurements illustrated in Figure 4.3 are at 25 m (82 ft) rather than the 30 m (100 ft) specified in the FRA/EPA requirements, the difference would be slight - below 1 dB(A).

Figure 4.3

Maglev and HSR Noise Data:
Maximum A-Weighted Sound at 25 m (82 ft) Level Versus Speed



[Source: Hanson, Ref. 5.]

Therefore, efforts to reduce maglev noise at the highest speeds may be necessary. Alternatively, noise levels slightly exceeding present FRA/EPA maxima might be permitted where there is an adequate buffer distance between the guideway and the nearest occupied building or other activity likely to be disturbed by excessive noise. Sound barriers, as have been required at certain locations on high-speed rail lines in France, Germany and Japan, are an alternative mitigation measure.

The averaged noise impact criteria, as shown in Figure 4.2 appear to be suitable for application to high-speed maglev in an urban and suburban environment. It could be unduly restrictive in rural areas having low ambient noise levels, requiring the guideway to be located at a minimum of several hundred feet from any activity or occupied building (Hanson, Ref. 5). A possible alternative requirement for average day-night noise level acceptability are the noise compatibility criteria developed for airport regions. As indicated in Table 4.2, these criteria are based on the type of land use and could be useful determining guideway alignment and the need for noise mitigation measures. The permitted sound levels, however, will generally be higher than those derived from the FTA noise impact criteria, especially in suburban and rural locations, and may not meet community acceptance. However, these averaged noise level criteria are primarily concerned with the community acceptability of noise rather than health and safety. Health and safety concerns would arise only in instances where a maglev route is located close to a particularly sensitive activity such as a hospital.

E. Recommendations

Based on the information presented and discussed above, consideration should be given to safety requirements as described below in this Functional Area for U.S. maglev application.

Interior Noise

The application of noise requirements representative of U.S. mass transit practice is recommended for maglev operators cab and other on-board crew compartments, as given below.

- A 12 hour time-weighted average of 78 dB(A) shall not be exceeded.

- Continuous noise shall 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 shall meet the requirements of ANSI S1.4 - 1971, Type 2.

The same 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.

Exterior Noise

The following requirements for high-speed maglev vehicles are suggested:

- Maximum sound levels during passage of the maglev vehicle or train at 30 m (100 ft) from the outside skin of the vehicle should not exceed 93 dB(A). This is based on the existing FRA and EPA requirements for self-propelled rail cars.

  If this requirement cannot be met (for example at the highest speed of operation), mitigation measures may be required, such as noise barriers, or a buffer zone between the maglev guideway and any activity that might be adversely affected by noise.

- Averaged day-night sound levels measured at the nearest point of buildings adjacent to the guideway in urban and suburban areas should be guided by the FTA noise impact criteria shown in Figure 4.2. Mitigation of noise impacts will be required if sound levels exceed the upper line in Figure 4.2. Depending on the sensitivity to noise of activities adjacent to the guideway, mitigation actions may be needed if impacts fall in the area between the two lines in Figure 4.2.

  It may be appropriate to relax these requirements in rural area, unless the guideway is located near a noise-sensitivity facility such as a hospital or school.

Chapter 5 Guideway

5.1 Functional Area 301 Guideway Design and Construction

A. Description of Functional Area

This functional area is concerned with all aspects of the design and construction of the maglev guideway. This includes all elements of the guideway structure such as foundations, support piers, guideway beams, and the mechanical attachments for guideway mounted equipment, including the linear motor stator, and magnetic levitation and guidance reaction rails. The technical subjects of concern in this functional area are the correct determination of loadings from the vehicle and other sources, the design of a structure (in steel or reinforced concrete) that can withstand these loads, and ensuring that the necessary quality in construction is maintained, including dimensional tolerances.

This functional area is closely related with several other functional areas as follows:

Functional Area 104, Quality Assurance, which 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, which addresses actions and procedures that need to be implemented to ensure that the guideway remains in serviceable condition.

Functional Area 303, Guideway Switch, which addresses requirements for the bending beam switch. The switch shares many safety requirements with the fixed portion of the guideway.

B. Safety Baseline

The guideway has to 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 at the design maximum speed.

A complete guideway design and construction process must include the following elements:

1. A specification of loads to be withstood by the guideway structure. These include:

- 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 static loads from the weight of the guideway structure.

2. Appropriate design procedures for steel and reinforced concrete structures, including allowable stresses and safety factors for static, cyclic and extreme load cases.

3. Specifications for the quality of materials used in the structures and for the correspondence construction techniques.

4. Guideway dimensional tolerances for the location of maglev support and guidance reaction rails, the linear motor stator segments, and for guideway curvature, twist, superelevation gradient and curvature in both the lateral and vertical planes.

C. Description of Existing Safety Requirements

Existing safety requirements concerned with each of the four subareas of interest are described below. They have been organized by country of origin (Germany, United States, International and Other). Table 5.1 is a full list of all safety requirements reviewed.

German Requirements

1. <u>Design Loadings</u>

RW MSB, Chapters 5 and 6 provide detailed specifications for load cases that should be considered in structural design. These have been adapted from the DS series requirements of German Federal Railways (DB) and DIN 1055, 1072, and 1079. Loads from the vehicle itself are based on vehicle static and dynamic loadings, plus any forces generated by the magnetic support and guidance systems, and the propulsion and braking systems. DS 804 and the DIN's 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. It is noted that DS 804 frequently references the DIN's for non-railroad-specific requirements.

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	MBO EBO	Part 2 Section 2	Operating Installations Railroad Installations	maglev Railroad
DIN	1045		Structural use of concrete - design and construction	General Construction
DIN	1072		Road and foot bridges, design loads	
DIN	1075		Concrete bridges, dimensioning and construction	
DIN	1084		Quality Supervision in concrete and reinforced concrete construction	
DIN	4149		Building in German earthquake zones - design loads, etc.	
DIN	4227	Parts 2, 3, 4, 5, 6	Prestressed concrete	
DIN	18200		Inspection of construction materials, structural members, and types of construction	
DIN	18800		Steel structures, design and construction	
DIN	18809		Steel road bridges and footbridges	

Table 5.1 Safety Requirements for Functional Area 301 (continued)

Guideway Design and Construction

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Chapter, etc.	Applicability or Intent
German Federal Railways	DS 804 DS 899/59		Code for railroad bridges and other structures Supplementary requirements for railroad bridges on new lines	Railroad Railroad
FRA	49 CFR	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 Structure

Table 5.1 Safety Requirements for Functional Area 301 (continued)

Guideway Design and Construction

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Chapter, etc.	Applicability or Intent
ASTM	A6 General Requirements for rolled steel plates, shapes, sheet piling and bars for structural use			Steel Structures

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

The listings of design loads covered in the RW MSB chapter 5 and NVA 0320/02/89 take into account additional loads resulting from the relatively higher speeds and tolerance restrictions associated with the operation of the Maglev system. Document NVA 0320/02/89 is a specification which describes design loads for design and dimensioning of guideways of the Transrapid High Speed Magnetic Railway. RW MSB defines and classifies the design loads as primary, secondary and special loads as in "DS 804" as follows:

- Primary loads (Section 1.1.1) include but are not limited dead loads, standard traffic loads, prestress, creep and shrinkage of concrete, water pressure forces, construction loads, forced strain of bending switches, etc.

- Secondary loads (Section 1.1.2) include but are not limited to loads due to hunting motion, wind, snow, temperature, resistance of bearings to displacements.

- The special loads (Section 1.1.3) include but are not limited to bearing skid due to bearing magnet and controlled lowering of vehicle, construction soil movements, impact from other vehicles, ice pressure, earthquake, derailing, etc.

RW MSB Chapter 5 describes the load assumptions and subdivides them into external guideway loads, external vehicle loads, and interface loads as follows:

- External guideway loads are loads acting on the guideway girders and substructures (including foundation), and include but are not limited to the following:

  Dead weight, welding stress, creep 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, construction loads, etc.

- External vehicle loads are loads acting on the vehicle from the following:

  Structural components, working loads, inertia forces, aerodynamic loads, temperature, environmental loads such as bird impact, collision with an obstacle, etc.

- Interface loads are loads acting between vehicle and guideway and include the following:

  Stator pack, guide rail, and slide rail mounting, levitation magnet, guide magnet, and eddy-current brake suspension, bearing and guide skid.

The RW MSB, Chapter 6 further explains the classification of these loads into the three categories mentioned above.

1. Primary loads (P) are maximum loads occurring frequently during normal operations.

2. Secondary loads (Se) are loads that occur infrequently during normal service.

3. Special loads (Sp) occur as a result of an emergency situation or another type of unusual event.

Tables 5.2 and 5.3 list the loads and the corresponding load category for external loads and interface loads applied by the vehicle.

These loads are combined to form load cases for which the structure is to be designed. These are listed in Table 5.4.

2. Design Procedures

The general design procedure in Germany is to define the working loads acting on a structure, and apply a safety factor between these loads and the design ultimate loads in order to ensure that the structure continues to function properly under working 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 highest severity class (catastrophic risk). Particular attention must be paid to fastenings, for the linear motor states 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 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 above requirement in Chapter 6.

The RW MSB references several German structural engineering requirements documents for structural design procedures. These requirements are listed below.

- 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, including loadings, allowable stresses, and material selection.

Table 5.2 Classification of External Guideway Loads

Type of Load	Steel Guideway		Concrete Guideway	
	Open Track	Stopping Points	Open Track	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 5]

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 Sp4:	Continual loads and special loads from impact with vehicles

Source: RW MSB Chapter 6

- DS899/59, Supplementary requirements for railroad bridges on new lines covers provisions for design and construction of railroad structures for speeds ranging from 200 km/hr. to 250 km/hr.

- DIN 1045, Structural use of concrete is a comprehensive manual, which covers the design and construction of plain and reinforced concrete structures and structural 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 which are to be used in the calculation instead of the effects actually arising.

- DIN 1075, Concrete bridges cover the dimensioning and construction applicable to the superstructures and substructures and also to the foundations of bridges made of concrete, reinforced concrete and prestressed concrete. It is also applicable to other structures which are loaded in accordance with DIN 1072 or DS804 (e.g. retaining walls of backfills supporting).

- 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 18809, Steel road bridges and footbridges specifies design loadings and required analyses for steel bridges. Loadings are to be 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 in general parts to the design of prestressed concrete structures.

  Part 2, Partially Prestressed Structural Members: applies to the design and construction of structural members made of normal weight concrete, the members sections of which are partially prestressed by means of prestressing steel tendons.

  Part 3, Segmental Type Structural Components applies exclusively to the dimensioning and constructional design of joints.

  Part 4, Prestressed Lightweight Concrete Structural Components applies to the design and construction of prestressed lightweight concrete components.

Part 5, Injection of Cement Mortar into Prestressing Concrete Ducts applies to the injection of cement mortar into prestressing concrete ducts of components made of prestressed concrete with subsequent bonding.

Part 6, Structural Components with Unbonded Prestressing applies to the design and construction of components made of ordinary concrete where the concrete is prestressed by prestressing steel tendons which are not bonded into the concrete.

- DIN 18 800, Steel structures is a general guide to the design and construction of concrete structures 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 bolted, riveted and welded joints as a function of the type of loading (static, or variable) and material specification.

- Document No. NVA 0320/02/89 Sections 0 through 5, appendix A and B lists the design loads for design and dimensioning of guideways 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 superseded by this document. The tolerance and restrictions requirements were based on document No. NVA/0693/03/89 (Part III only).

  The document also states that it is valid only when used in conjunction with document No. NVA/5033/11/88: "General Requirements for Guideways of the Transrapid High Speed Magnetic Railway" which has not bee reviewed.

3. <u>Manufacturing and Construction Requirements</u>

German manufacturing/construction procedures are described in the following requirements document:

- 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.

- DS899/59, Supplementary requirements for railroad bridges on new lines covers provisions for design and construction of railroad structures for speeds ranging from 200 km/hr. to 250 km/hr.

- 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 covers the dimensioning and construction applicable to the superstructures and substructures and also to the foundations of bridges made of concrete, reinforced concrete and prestressed concrete. it is also applicable to other structures which are loaded in accordance with DIN 1072 or DS804 (e.g. retaining walls of backfills which are travelled over).

- DIN 4227, Prestressed concrete is described above in the discussion of design loadings

- DIN 18 800, 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.

The RW MSB, Chapter 7 also references a number of requirements documents concerned with welding procedures and the qualification of welders. The titles are listed below. 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.

- DIN 29 591, Aerospace travel; testing of welders; welding metallic components.

- DIN 65 118, Aerospace travel; welded, metallic components.

- DVS 1603, Resistance spot welding of steel in rail vehicle construction.

- DVS 1604, Resistance spot welding of aluminum in rail vehicle construction.

- DVS 1608, Fusion welding of aluminum in rail vehicle construction. (Not translated.)

- DVS 1609, Resistance spot welding of high alloy steel in rail vehicle construction.

- DVS 1610, General guidelines for planning weld production in rail vehicle construction.

- DVS 1611, Evaluation of irradiation in rail vehicle construction.

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 levitation and guidance forces.

The RW MSB, Chapter 7, Paragraph 2.2.2 gives some general requirements for guideway tolerances, mentioning that these include random long wavelength deviations and short wavelength discontinuities. It states that these must be compatible with the vehicle's geometrical arrangements and the properties (including air gap) of the support and guidance magnets. Internal Transrapid documents are referenced for actual dimensions.

The MBO, Section 2 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 air gaps of these are in the range 8-10 mm. The MBO indicates that these dimensions are preliminary. Dimensioned clearance diagrams both for the vehicle and wayside structures are also provided.

Section 2.1.3 of the MBO gives limits on curve parameters as follows:

- Minimum radius of curvature 400m
- Maximum guideway cant (superelevation) 12°
- Maximum unbalanced lateral acceleration 1.0m/sec^2 (approximately 0.1g)

At-grade crossings with highways are not permitted.

U.S. REQUIREMENTS

1. Design Loadings

In general, the design loads specified in RW MSB and DS804 are similar to the type of loadings covered by the AASHTO Standard specifications for Highway Bridges and the AREA Manual for Railway Engineering (AREA). DS804 classifies design loads as primary, secondary and special loads, while AASHTO Standard defines and classifies 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

The AREA Manual defines and classifies the design loads for steel structures in Chapter 15, and for concrete structures in Chapter 8 as follows:

- Chapter 15, Part 1, Section 1.3.1 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.

- Chapter 8, Part 17, Section 17.2.3 specifies impact requirements for prestressed bridges.

2. Design Procedures

In the United States, the general design procedure is to calculate stresses either by the use of working loads or by the strength design or ultimate load method. Further description and comparisons with German procedures are provided in Section D (Comparison and Assessment).

Design requirements for specific structural elements are described in the following documents:

a. The AASHTO Standard, Division I covers the requirements for the design of bridges and other major transportation structures. The following elements are covered under the sections listed below:

- Concrete design is specified under the following sections:

  - Foundations: Section 4
  - Retaining Walls: Section 5
  - Substructures: Section 7
  - Reinforced Concrete: Section 8
  - Prestressed Concrete: Section 9

- Steel design is specified under the following sections:

  - Steel piles: Section 4
  - Structural Steel: Section 10

- Bearings are specified under Sections 14, 15, 19 and 20.

- Other miscellaneous design requirements are covered under the remaining sections of Division I.

b. The AREA Manual provides design requirements in the following locations:

- Concrete structures and foundations are covered under Chapter 8 in the following parts:

– Reinforced concrete:	Parts 1 and 2
– Foundations and retaining walls:	Parts 3, 4, and 5
– Prestressed concrete design:	Part 17
– Bearings:	Part 18

- Steel structures are covered under Chapter 15 in the following parts:

– Steel Design:	Parts 1, 2 and 5
– Movable Bridges (1987):	Part 6

c. The American Welding Institute AWS D1.5-88: Bridge Welding Code provides welding design procedures.

3. Manufacturing and Construction Requirements

Manufacturing and construction requirements are described in the following documents:

a. The AASHTO Standard, Division II covers the basic technical construction specifications needed for the construction of bridges and other major transportation structures. The following materials are covered under the sections listed below:

- Concrete construction is specified under the following sections:

– Concrete Structures:	Section 8
– Reinforcing steel:	Section 9
– Prestressing:	Section 10

- Steel construction is specified under the followings sections:

– Steel Structures:	Section 11
– Steel grid flooring:	Section 12
– Painting:	Section 13

- Bearings are specified under Section 18
- Other miscellaneous construction is covered under the remaining sections of Division II.

b. The AREA Manual: Covers the construction requirements in the following Chapters and parts.

- Concrete structures and foundations are covered under Chapter 8 in Part 1, Materials, Test and Construction Requirements
- Steel structures are covered under Chapter 15 in the following parts:

– Fabrication (1990):	Part 3
– Erection (1984):	Part 4
– Movable Bridges (1987):	Part 6

c. The AWS D1.5-88: Bridge Welding Code provides welding procedures and testing requirements.

4. <u>Dimensional Tolerances</u>

Safety-related dimensional tolerances for conventional railroad track are provided in the FRA regulations 49 CFR Part 213, Track Safety Regulations, Subpart B. 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 track superelevation, based on a maximum deficiency of superelevation of 3°.

The AREA Manual, Chapter 5, Track 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 listed below obtained from the following references:

- AASHTO, Division II.
- AISC Specifications
- Prestressed Concrete Institute
- ASTM Section A6.

a. Driven Foundation Piles:

Piles shall be driven with a variation of not more than 1/4 inch per foot from vertical or from batter. Foundation piles shall not be out of design position by more than 1/4 of their diameter or 6 inches, whichever is greater.

b. Drilled Piles and Shafts;

- The drilled shaft shall be within 3 inches of the plan position in the horizontal plane at the plan elevation for the top of the shaft.

- The vertical alignment of the shaft excavation shall not vary from the plan alignment by more than 1/4 inch per foot of depth.

- After all the shaft concrete is placed, the top of the reinforcing steel cage shall be no more than 6 inches above and no more than 3 inches below plan position.

- When casing is used, its outside diameter shall not be less than the shaft diameter shown on the plans. When casing is not used, the minimum diameter of the drilled shaft shall be the diameter shown on the plans for diameters 24 inches or less, and not more than 1 inch less than the diameter shown on the plans for diameters greater than 24 inches.

- The top elevation of the shaft shall be within 1 inch of the plan top of shaft elevation.

c. Cast-In Place Concrete Structures:

For cast-in-place concrete structures, the calculated deflection of falsework flexural members shall not exceed 1/240 of their span irrespective of the face that the deflection may be compensated for by camber strips.

d. Steel Structures:

Fabrication tolerances 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 or unit and to verify or prepare field splices. Attaining accurate geometry is the responsibility of the contractor.

e. Precast Concrete Members:

The Prestressed Concrete Institute Design Handbook covers the various tolerances associated with the fabrication of precast and prestressed concrete members. Tolerances must be used as guidances for acceptability and not limits for rejection. If specified tolerances are met, the member should be accepted. If not, the member may be accepted if it meets any of the following criteria:

- Exceeding the tolerance does not affect the structural integrity or architectural performance of the member.
- The member can be brought within tolerance by structurally and architecturally satisfactory means.
- The total erected assembly can be modified to meet all structural and architectural requirements.

Typical tolerances 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

Note that these tolerances are based on recommended guidelines. Different values may be applicable in some cases.

D. Comparison and Assessment

1. Design Loadings

Design loadings for vehicle-generated loads will necessarily be specific to a maglev system. Design loadings specified in the German DS-series requirements or in the AREA Manual for conventional railroad bridges, or in the AASHTO standards for highway bridges do not apply. Appropriate loading from the maglev vehicle, including propulsion and braking forces as well as vehicle support and guidance loads are given in RW MSB, Chapter 5 and 6. These loads appear to be the result of careful consideration of vehicle operating conditions. However, they lack some specificity with regard to clearly distinguishing between high-cycle fatigue loads and low-cycle loads.

There is some question regarding the applicability of non-vehicular loads such as from snowfall, high winds, temperature extremes, foundation settlement and residual stress in structural members. Given the range of climatic and soil conditions in the U.S., it is necessary to take into account local conditions in determining these loads. Thus, loadings derived from AASHTO or AREA requirements should be used. Also, local conditions and requirements in local building codes reflection such factors as incidence of heavy snowfall, high winds, temperature range and the likelihood and severity of earthquake should all be taken into account.

The process of combining individual loads into load cases (as listed in Table 5.4) appears to be reasonable. There are no equivalent U.S. requirements with which to compare these load cases. However, they are analogous to the representative load cases used to design structures for a specified purpose, such as the "Coopers" loading for railroad bridges specified in the AREA Manual.

2. Design Procedures

In general, U.S. and Germany have a basically similar approach with respect to the design of reinforced concrete and structural steel structures to support defined loadings. The methodology as well as a comparison between the two approaches are described below.

a. Reinforced concrete design:

In the U.S., there are two methods by which the structural safety of a reinforced concrete structure might be considered. 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 to structural safety is the one used in structural design (or ultimate load) in which the working loads are multiplied by certain load factors (L_f) that are greater than one. These load factors are used to account for possible unusual increases in load beyond those considered or inaccurate assessment of effects of loading or other reasons. In addition, to accurately estimate the ultimate strength of a structure, it is considered necessary to take into account the uncertainties in material strengths, 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. In Germany, the design analysis based on DIN standards uses one safety factor which allows for a safety margin between the working load and design ultimate load. The safety factor is equivalent to the combination of the strength reduction factor and the load factor.

To illustrate the above approaches, consider for example, the design strength in flexure of a cross section which may be expressed as:

$M_u = A_s f_y Z$/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.
Safety Factor = L_f/S_f, in U.S. and Britain
= varies in Germany

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 so much better than the magnitude of live loads. The following table lists the various safety factors for a cross section in flexure in accordance with the various codes/standards:

Comparison of Safety Factors for a Concrete Cross Section in Flexure

Code/ Standard	Load Factor L_f		Strength Reduction Factor S_f	Safety Factor L_f/S_f		
--	Dead Load	Live Load	--	Dead Load	Live Load	Average
DIN	Not Applicable		Not Applicable	1.75		1.75
AASHTO	1.3	2.17	0.9	1.44	2.41	1.92
AREA	1.4	2.33	0.9	1.55	2.59	2.07
ACI	1.4	1.7	0.9	1.55	1.89	1.72
CP110*	1.4	1.6	0.87	1.61	1.84	1.72

* *CP110 is the British Code of Practice for the structural use of concrete.*

Note that the average safety factor shown above may be either larger or smaller depending on the magnitude of the dead load and live load.

b. Structural Steel Design:

Steel members are generally designed using the allowable stress design procedure. This method is described below with the application of the German and U.S. requirements.

German Railroad Requirements DS 804 and DS 899/59: The allowable stresses for structural steel for primary loading case and primary plus secondary loading case in tension, and tension and compression due to bending when buckling does not occur: are as follows: (Part 3, Section 11.4)

- Primary loading case: 0.67 Fy (Fy = yield stress)
- Primary & Secondary Loading case: 0.75 Fy.

The AASHTO Standard, Division 1, structural steel: The basic allowable stress for structural steel (from Table 10.32.1A, Section 10) for compression due to bending when flange is supported laterally along its full length is 0.55 Fy. For Group I service loads (See table 3.22.1A, Section 3) the allowable stress is 100% of 0.55 Fy. For Groups II to IX service loads, the allowable stress varies from 125% to 150% of 0.55 Fy.

To give an example of a comparison between DS 804 and the AASHTO Standards, the Primary and Secondary loading case of "DS 804" (Allowable stress 0.75 Fy) could be compared with Group VI service loads of "AASHTO" which gives an allowable stress of 140% of 0.55 Fy which equals 0.77 Fy. There is, therefore, very little difference between these two requirements.

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. 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. It is essential that this requirement be applied in the United States.

3. Manufacturing and Construction Processes

The structures must be manufactured or constructed so that they will provide the expected service life without structural damage or premature failure under normal operating loads. 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. equivalent requirements for construction and fabrication processes appear to be similar to the German requirements and should produce a structure of equivalent strength.

4. Dimensional Tolerances

The dimensional tolerances in normal civil engineering construction and fabrication in the U.S., as described in Section C above, fall short of the cross-sectional dimensional accuracy required for positioning the maglev levitation and guidance reaction rails. Therefore, ways need to be developed of either adjusting the attachment of these surfaces to the guideway beams to achieve the desired position accuracy, or of improving the steel fabrication or concrete casting processes to substantially improve on conventional processes. In either case, careful control must be exercised to ensure that in improving accuracy there is no loss of structural strength properties in either the guideway beam, its attachment to other structural members, or the fastening of any levitation or guidance reaction rails.

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 has been provided in Functional Area 208. In that discussion, 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.

- Maximum amplitudes of long wavelength irregularities, expressed as a spacial power spectral density, or as a maximum amplitude of individual or periodic repetitive irregularities.

In both cases, these deviations 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.

Overall, a careful analysis of dimensional tolerances and structural deflections under load is essential to ensure that guideway geometry requirements for high-speed 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. Proof of Performance

In most civil engineering structures, normal inspections of design calculations, materials and workmanship is 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 stresses and deflections, to ensure that these are within acceptable limits, in addition to normal design review and quality control.

E. Recommendations

Consideration should be given to the following safety requirements in this functional area for U.S. maglev applications.

1. Specification of Operating Loads and Load-Cases

Guideway structure load cases equivalent to those given in the RW MSB Chapter 6 should be used for maglev guideway structure design. Static and fatigue load cases should be clearly distinguished. Fatigue load cases should include a specification of the number and magnitude of load cycles during the expected life of the structure. The load cases should reflect all phases of vehicle operation: acceleration, braking, maximum speed operation, emergency braking, etc.

German requirements with respect to externally applied loads should be modified as necessary to reflect the U.S. operating environment. In particular, estimated loads due to high winds (including hurricanes), temperature variations and earthquakes should be modified to reflect local conditions.

2. Design of Guideway Structures

The recommended general requirement is that the design analysis, material specification, allowable stresses, structural safety factors, and design details should all conform to established engineering practice as specified by a recognized requirements-setting organization for the same or similar purpose.

More specifically, this means:

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

- Working stresses and safety factors used should be comparable to those used for the same materials in the same or a similar application, and conform with recognized technical requirements.

Particular attention must be paid to the design of equipment fastened to the guideway and the fastener system used. A redundant fastening arrangement must be used such that the failure of a fastener will not result in any loss of attachment, and that the failed fastener is easily detected in inspection.

Since excessive soil movement is critical to the proper operation of the maglev system, consideration should be given to using deep foundations especially where scour, erosion, or settlement may occur, and the conditions permit its use, even though the bearing capacity of the soil is sufficient to make practical the use of shallow foundations.

Either German or U.S. technical requirements may be used in design provided a consistency is maintained in requirements used for design construction and materials. Using of German and U.S. requirements (such as using the German design process with U.S. materials) may only be permitted after a thorough review to ensure that such mixing will not impair the performance of the resulting structure in any way.

3. Construction and Manufacture

The construction and manufacture of structures, including steel or concrete structures, foundations and all other elements should be to recognized technical requirements. Either U.S. or German technical requirements may be used, provided 'mixing' of requirements is avoided, or carefully reviewed as indicated under item 2 above.

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 Vehicle/Guideway Interaction. 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 are used to ensure dimensional accuracy, these should be reviewed to ensure that strength is not impaired.

5. Proof of Performance

An instrumented test of guideway structures shall be performed with any new or substantially modified guideway/vehicle combination to confirm that guideway stresses and deflections are within acceptable limits.

5.2 Functional Area 302 - Guideway Inspection and Maintenance

A. Description of Functional Area

This functional area addresses inspection and maintenance procedures and practices required to ensure that the guideway is in safe operating condition at all times. This includes 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 which discusses acceptable guideway loadings and geometrical requirements as a function of vehicle speed and suspension characteristics.

Functional Area 301, Guideway Design and Construction which covers all activities up to the point at which a newly constructed guideway is ready for service.

B. 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 loadings and meet the geometrical requirements specified in the recommendations to Functional Area 208 Vehicle/Guideway Interaction. In more detail this means.

- 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 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.

C. Description of Existing Safety Requirements

The existing safety requirements identified are listed in Table 5.5 and described below by country of origin: German, United States, and International and Other.

German Requirements

Chapter 6 of the RW MSB Section 4.4 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, 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.

Chapter 7 of the RW MSB Section 2.2.2 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 detect and determine the location of unacceptable geometrical deviations.

The MBO Paragraph 1.4, Basic Rules states that operating installations must be regularly inspected as regards their proper condition.

Paragraph 2.1.2 states that guideway dimensional tolerances shall be specified by the operator. The back-up discussion associated with this paragraph indicates that these tolerances are derived from a balance between operating speed, passenger comfort and engineering and economic feasibility. This paragraph further states that limit values should be specified for the initiation of maintenance measures.

The EBO, Paragraph 17 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.

U.S. Requirements

Federal Railroad Administration Track Safety Standards (49 CFR Part 213) specifies the following:

- Dimensional track geometry and track component condition requirements for each speed-defined track class.

Table 5.5 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 7	Design production and quality assurance of mechanical structures	Maglev
German Government	MBO EBO	Section 1.4 Section 2 Paragraph 17	Basic rules Operating installations Operating installations	Maglev Railroad
FRA	49 CFR	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 bibliography for full citation.

- Required track inspection intervals. On high-density main-line track, these are:
  - Twice weekly visual inspection, for example from a Hi-Rail vehicle
  - Annual automated rail flaw inspection
  - Monthly inspection on foot of turnouts
  - 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 American Railroad Engineering Association Manual for Railway Engineering (AREA) recommends that thorough inspections of steel and concrete structure be made at least once a year. Forms and checklists are provided to help organize the inspection process.

Part 21 of Chapter 8 of the AREA Manual provides requirements for the inspection of Concrete and Masonry structures. Conditions identified in 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.

Part 7 of Chapter 15 of the AREA Manual 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 condition of bridge bearings or expansion rollers.

Chapter 2 of the AREA Manual provides some 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 - foundations, piers, beams, and road surfaces, record keeping and methods for assessing the strength of existing bridges. Inspection intervals must exceed two years.

International and Other

A technical paper, Reference 15, provides details of the inspection and maintenance procedure for the French TGV high-speed lines. The inspections performed are as follows:

- Acceleration monitoring with vehicle-based instrumentation - weekly. This provides an assessment of track geometry condition.

- Automated track geometry inspection - three month intervals

- Rail defect detection - one year after construction, then at year eight, then every two years

- Catenary inspection - six month intervals

D. Comparison and Assessment

This functional area is primarily concerned with inspection requirements to ensure that the guideway remains in safe operating condition. Within the general subject of inspection there are three subareas that need to be reviewed, as follows:

1. Overall guideway structural condition
2. Condition of guideway mounted equipment and fastenings
3. Guideway geometry

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 inspections every two years. Both AREA and AASHTO provide detailed instructions for inspections and record keeping 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, see for example Ref. 16. It is likely that any structural problem encountered in maglev structures has already been encountered in rail and highway structure inspection and maintenance, and procedures will be available for addressing the problem. 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, and AREA one-year inspection interval would appear unnecessary, and the AASHTO two-year interval would be appropriate. Both requirements recommend shorter inspection intervals if a specific structure has a significant defect, and this is also appropriate for maglev structures.

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. Thus such 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 single failure will not result in loose or misplaced equipment. This is effective only if the defective fastening is found and replaced prior to a second failure 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 to acceptable levels. 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.

3. Guideway Geometry

Guideway geometry deviations must be keep within acceptable limits. These limits are related to maglev vehicle magnet air gap dimensions and vehicle response to geometry deviations at any speed up to the maximum operated, as discussed in Functional Area 208. The RW MSB, Chapter 7, requires regular automated inspections of guideway geometry. Conventional high speed and other railroads also conduct regular automated track geometry inspections at intervals of three to six months: Amtrak on the high-speed portions of the North-East Corridor, has conducted track geometry inspections at one-month intervals. The accuracy of a guideway geometry measurement system must be consistent with the need to measure guideway conditions that could adversely affect the vehicle. This means discrete or short wavelength geometry defects in the maglev guidance or support surfaces must be measured with an accuracy of the order to 10% of the magnet air gap. The measurement system must also be capable of detecting the longest wavelength regulations likely to affect the vehicle, which could be of 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 from which potentially unsafe conditions are easily detected. It is also essential to retain geometry records and have the ability to easily compare the result 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.

F. Recommendations

Consideration should be given to the following safety requirements in this functional area for application to maglev systems in the US. The recommendations are primarily derived from the German requirements in RW MSB, amplified by US structural and railroad inspection procedures and experience.

1. Overall Guideway Structural Inspections

Comprehensive inspections should be carried out of guideway structures, including foundations, piers and guideway beams following established procedures as recommended in the AREA or the AASHTO manuals. Good 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. More frequent inspections are required if significant defects exist, as recommended by AREA and AASHTO. Inspections must be performed by a Registered Professional Engineer, or an individual with equivalent qualifications and experience.

2. Inspection of Guideway Attachments and Fastenings

Regular inspections must be performed of equipment attached to the guideway and the fastenings used for such attachments. The inspection procedures must be capable of detecting loose, missing, broken or otherwise defective components. Inspection intervals must be based on known failure rate 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.

3. Guideway Geometry Inspection

Regular automated inspections of guideway geometry must be carried out. Geometry must be measured at the magnetic levitation and guidance rails. Parameters measured must 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. Geometry measurement records must be maintained in a form that permits comparison of successive inspections to detect instances of rapid geometry change.

4. General

Additional inspections of all types shall be made of the affected portions of the guideway before resuming operation after "unusual events." The following will 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)

5.3 Functional Area 303 - Guideway Switch

A. 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 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, which discusses many structural requirements that are equally applicable to switch structures.

Functional Area 302, Guideway Inspection and Maintenance, which discusses appropriate inspection procedures for maintaining the guideway and its attachments in good operating condition.

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.

B. 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 a 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 must have the following characteristics.

- The mechanism used to move the switch must be safe and reliable, including the safety considerations for any high pressure pneumatic or hydraulic systems used.

- 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 disengaged in normal operations.

- Guideway geometry must be of a standard that permits safe vehicle operation at maximum design speeds for the switch.

- Switch structures, both of the moveable and fixed portions must be designed and constructed so that they can safety support all vehicle and externally applied loads without damage or unacceptable distortion.

C. Description of Existing Safety Requirements

All existing requirements identified and described under Functional Area 302, Guideway Design and Construction, are applicable also to this functional area. Further requirements specific to switch design and construction are listed in Table 5.6 and described below by country of origin: Germany, U.S. and International and Other.

German Requirements

The requirements in RW MSB, Chapter 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.

The RW MSB, Chapter 8 provides detailed requirements for a bending-beam type of switch, driven by either an electric or hydraulic actuation system. Other possible types of switch are not covered. The requirements in Chapter 8 are primarily concerned with the actuation mechanisms and the mechanisms used to lock the moveable beam in line with the fixed portion of the guideway.

Section 2 of Chapter 8 specifies the general safety requirements for the switch. These are that the switch is safe for the movement of a maglev vehicle over it if the following conditions are satisfied:

- The switch is safely closed at all "setting points" along the length of the switch.

- The end of the moveable part of the switch must 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 must remain locked and unanticipated movements prevented even in the case of breakdown of switch locking or actuating mechanisms.

- Safeguards must be provided against excessive loads being applied to the switch structure as a result of fault in the electrical or hydraulic switch actuating mechanism.

Table 5.6 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	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

Table 5.6 Safety Requirements for Functional Area 303 (continued)

Guideway Switch

Issuing Organization	Title and/or Reference Number	Part Chapter, etc.	Title Complete Document and Part	Applicability or Intent
FRA	49 CFR Part 213 Track Safety Standard	Parts 213.133 to 213.143	Turnout Requirements	Railroad
	49 CFR Part 236 Rules Standards and Instructions for Signal and Train Control Devices	Part 236.312 Parts 236.314 to 236.3334	Locking of Moveable Bridges Switch locking requirements	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

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

Other requirements of the switch actuating mechanisms and locking systems specified in Chapter 8 of the RW MSB include the following:

- If the switch is held in position by a non-positive system (such as pressure in a hydraulic cylinder), then this lock must convert to a positive lock in case of a fault such as a hydraulic leak.

- A hydraulic check (non-return) valve 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 RW MSB, Chapter 8 are concerned with switch monitoring and control, and are discussed under Functional Area 401, Operations Control System Design.

The MBO, Section 2.1.7 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 can be operated over without danger.

The EBO, Paragraph 14, 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. These are 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 series of 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.

U.S. Requirements

The FRA Track Safety Standards 40 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, bolts, etc., tight and undamaged.

Part 236 of the FRA Regulations covers Rules, Standards and Instructions for signal and train control devices, including those associated with switches and moveable bridges. Relevant parts include:

- 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, 236.328, 236.329, 236.330, and 236.334 all specify various mechanical details of switch locking mechanisms, so trains can safely operate over a properly locked 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, Track 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 closed 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 forces 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 activate 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.

D. 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 appear to be equally suitable for application to switch structures.

For the moveable portion of the switch, loads produced by the bending action (if the bending beam 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 some kind of overload protection mechanism, so that the force exerted by each actuator (whether hydraulic or electric) cannot exceed a pre-determined level. Otherwise there could be a danger of the actuating forces damaging or distorting the moveable portion of the switch.

Both the RW MSB, and conventional railroad track and turnout requirements such as in the AREA Manual and the FRA Regulations 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 size of the vertical and lateral alignment discontinuity where the moveable portion of the switch connects to the fixed guideway can be safely negotiated by the vehicle. Safety will be assured if the discontinuities are within the acceptable range of guideway geometry deviations as discussed under Functional Area 208, Vehicle-Guideway Interaction, and Functional Area 301, Guideway Design and Construction.

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 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 must clearly be accurate, reliable, and sufficiently strong to resist any forces tending to cause undesired movement of the switch. These requirements suggest that 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, even when this occurs in the cylinder. This conflicts with RW MSB, which does allow hydraulically-locked cylinders to be used to hold the switch in operating condition.

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 appear to be German government regulations, and may not meet U.S. requirements in all respects, although this has not been checked in detail. 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 these codes include certification of manufacturers, it will probably be desirable to only use pressure vessels manufactured to U.S. requirements in any maglev switch mechanism. However, time did not permit detailed research in this issue.

E. Recommendations

Consideration should be given to the following switch safety requirements for U.S. maglev safety application. These requirements are based mainly on RW MSB and generally conform with the intent of U.S. requirements for railroad switches and moveable bridges.

1. Switch structural load cases, design and construction

Guideway switch structures must comply with all the recommendations developed for Functional Area 301, Guideway Design and Construction.

2. 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 must be arranged such that the locks will stay in position without any externally applied force, cannot vibrate loose in any way with the passage of vehicles, and can resist normal operational loads tending to move the switch.

3. Switch actuating mechanism

Switch activation can be either hydraulic or electro-mechanical. In either case, system design and components should conform to generally accepted technical requirements. These requirements may be either of U.S. or German origin with the exception that any pressure vessels used must be in compliance with applicable U.S. regulations.

5.4 Functional Area 304 - Right-of-Way Security

A. Description of Functional Area

Right-of-way (R.O.W.) security is concerned with minimizing the risk of foreign objects on the guideway, the presence of an unauthorized person on the guideway or other maglev facilities, or any object being dropped, thrown or shot at a train which could threaten the safety of the vehicle or its occupants. 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 right-of-way security. These are:

> Functional Area 201, Overall Vehicle and Cab Structural Integrity, and 202, On-board Operator and Crew Compartments, which discuss a maglev vehicle's ability to survive a collision with an obstruction on or in the air above the guideway.
>
> Functional Areas 401, Signalling and Train Control Design, and 403, Communications, both of which have to interface with and respond to a signal from any automatic system used to detect violation 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.

B. Safety Baseline

The guideway must be protected from external events that could lead to an obstruction on the guideway, or damage to the guideway or system facilities that could lead to an accident. Specific system features that provide this protection are:

- Physical barriers, such as fences, to limit the access of unauthorized persons to the guideway or other maglev system facilities. This includes barriers to discourage vandals from dropping or throwing objects onto the guideway, or to prevent such objects from reaching the guideway.

- Barriers to protect against encroachment from an adjacent transportation right-of-way, such as a highway or conventional railroad that is sharing a transportation corridor with the maglev system.

- Detection systems to warn of obstructions on the guideway, encroachments on to the maglev right-of-way or 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.

C. Description of Existing Safety Requirements

Existing safety requirements concerned with right-of-way security are described below by country of origin (Germany, U.S., international and other), and are listed in Table 5.7.

German Requirements

Chapter 1 of the RW MSB, Section 4.1 requires precautions against environmental disruptions to maglev operations. In particular, sensors should be installed to detect guideway damage due to earthquake or sudden foundation subsidence.

There are no 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. These are 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 some other reason (i.e., other than the above, or by other vehicles) blockages could include obstructions on the guideway as a result of accidental events or malicious acts.

A similar indirect requirement to the above is found in Chapter 7 of the RW MSB, Section 2.2.2.2 which requires that measures to protect persons and property in the guideway area (e.g., to protect crossing traffic and/or in the case of an at-grade guideway) must be provided if necessary. This requirement implies that the guideway must be adequately segregated from adjacent activities.

Table 5.7 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	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	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	213.37	Track Safety, Roadbed Vegetation	Railroad
APTA	Guidelines for rapid transit facilities design	Section 2.1	Way and Structures - Security	Mass Transit
UIC	734 R 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 bibliography 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 endangers operations. Railroad police are given the responsibility to guard against such activities. Specific security precautions are not required.

U.S. Requirements

The FRA Track Safety Regulation, 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 Volume 1, Paragraph 6, Section 6.5 provides a specification for right-of-way fence design. No requirements regarding where fences should be used are provided, except in the case of snow-fences.

The APTA guidelines for Design of Rapid Transit Facilities, Section 2.1.1 describes security of facilities and right-of-way 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 right-of-way is crossed by a pedestrian walkway, barriers should effectively prevent objects being dropped on the right-of-way 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.

- 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.

UIC and Other

UIC Code 738 Adaptation of Safety Installations to High Speed Requirements, Appendix A, Section 6 requires the installation of communication systems so that the presence of any obstacle on the track can be communicated instantly to the train control system, leading to stop commands being sent to trains approaching the obstacle. These communications means must be available to train crew and staff on the ground who may discover an obstacle. 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.

D. Comparison and Assessment

The most complete requirements identified for right-of-way security are those given in the APTA guidelines for the design of rail rapid transit facilities. These require 2.4 m (8 ft) high fencing or equivalent throughout the right-of-way and barriers to prevent objects being dropped onto 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 maglev 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 suitable for containing livestock, but would not be adequate to prevent trespass, where trespass is considered a significant problem.

Although not embodied in published requirements, a number of practices have been adopted by both foreign high-speed wheel-on-rail systems, and by U.S. mass transit systems to protect the right-of-way. Those of relevance are:

- High-speed rail systems in France and Japan are fenced throughout.

- Detectors are used on certain U.S. mass transit systems (e.g., in Washington and Atlanta) to warn of encroachments onto the right-of-way from an adjacent highways or railroad, or an impact with aerial structures. The most common kind of detector is a fragile wire. Breakage of the wire produces an encroachment alarm. Detector systems are also 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.

- 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 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. False alarms disrupt operations at best, and if too frequent will render the warning system useless. Thus, systems must be very reliable. Those linked to a signal system will have to be of a high technical standard in any case to avoid interference with the signalling function.

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 currently in progress. This will provide further information on right-of-way security and intrusion threats, and options to protect against these threats.

E. Recommendations

Consideration should be given to the following safety requirements for application to high-speed maglev systems operating in the United States.

- Fencing. The guideway and safety critical fixed installations such as switch mechanisms, power supply and control substations, and communications facilities shall be protected by a fence of 2.4 m (8 ft) total height or equivalent, wherever the guideway passes through an urban area, or other location where unauthorized entry is considered a risk (based on APTA guidelines for rail transit). Acceptable alternatives to a fence could include elevated guideway having sheer vertical piers at least 2.4 m (8 ft) high from ground level, or a sheer vertical embankment or wall of the same height.

- Where vandalism is not a concern, fencing should conform to the AREA requirements.

- Means for emergency access and egress through guideway security fencing must be provided, per NFPA 130.

- Vehicle and pedestrian bridges over the guideway should have the following forms of protection:

  - 8 ft high fences, plus barriers to prevent or catch objects being thrown or dropped onto the guideway (APTA guidelines)

- Suitable crash barriers to minimize the risk of an out-of-control road vehicle falling on the guideway (APTA guidelines)

- An automatic system to detect when a vehicle or other heavy object is not contained by the barriers, and falls on the guideway (French Railways practice)

* Trees and other vegetation near the guideway must be trimmed or otherwise controlled to minimize the risk of falling or being blown onto the guideway and causing an obstruction, impairing visibility, or damaging safety critical installations (adapted from FRA regulation 49 CFR 213.37).

* Automated detection systems for earthquakes and potentially dangerous weather events (heavy snow accumulation, high wind, flooding) must be provided where necessary. Information from these detectors should be displayed in the system control center (Shinkansen, BART practice).

* Barriers and encroachment or impact detection systems may be required where the maglev guideway shares a corridor with another mode of transportation. Information on this subject is being developed in another study being performed for the FRA.

* Impact detection systems may be desirable where the maglev guideway crosses over an existing highway or rail line, to detect impacts with the guideway due to oversized loads or as a result of an accident on the existing highway or rail line. This is a new suggestion, not based on any existing requirement.

6. Operations Control, Communications and Electric Power Systems

6.1 Functional Area 401 - Operations Control System Design

A. Description of Functional Area

This functional area addresses the safety requirements for maglev operations control systems. The systems that perform the three principal safety critical functions of a train control system are covered; a vehicle location system, 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 Operations Monitoring and Control.

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

Functional Area 101, System Safety, which address the functions of the train control systems within the overall system safety concept.

Functional Area 103, Safety, Reliability and Availability discusses definitions and system performance requirements for safety-critical systems.

Functional Area 105, Computer Safety for Vehicle and Operational Systems addresses safety requirements for computers performing operational control functions.

Functional Area 207, Brake Installation and Performance, which 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, which covers inspection and maintenance procedures and practices needed to keep a train control system in good working order.

Functional Area 403, Communications, which includes the safety-critical communication links between the components of an operations control system.

B. Safety Baseline

Both the overall system architecture of a signal and train 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. This performance level is comparable to that currently achieved with automated guided transit systems, or with the Automatic Train Protection systems used on high speed conventional 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 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 detection subsystem must be designed in such a manner that the real time location of a train cannot be "lost", or misinterpreted in vital vehicle control logic. Maglev vehicles cannot use the closed loop technology of conventional railroad track circuitry. The detection system must be of a fail-safe 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 (safe hovering), and stopping distance parameters.

A quantitative, and a generally understood qualitative definition of reliability requirements for operations control systems and components is required to define the nature of fail-safe, fault tolerant or redundant systems required for safety performance.

C. Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6.1 and are described below.

The requirements are discussed by country of origin, German, U.S. and International and Other, and within each country by the three major operations control system functions - vehicle location and guideway status, interlocking units, and safe speed enforcement.

German Requirements

Chapter 1 of the RW MSB specifies certain vital system properties, especially "safe hovering". "Safe hovering" is defined as a method of excluding a set-down above a predetermined speed. .Safe hovering includes the use of a stopping place system whereby the "safe-life" levitation will be controlled by the system such that a safe stop is accomplished at a predetermined location. It provides that the means for providing safe hovering or other supplemental strategy for each application must be determined individually. Safe hovering methods are to include synchronization between the vehicle and the travelling field, and will provide for protection in the event of a stator short circuit.

Chapter 4 of the RW MSB specifies the role of the on-board safety computer and its necessary capability of providing safe emergency operation. Vital information conveyed from the operator's console to the safety computer must be transmitted with an accepted data security method. On-board controls for levitation and setting down are defined as such with special safety levels. Lower safety level signals are described as diagnosis signals such as those monitoring door status, and their interfacing to disallow the vehicle to proceed unless monitored in their proper position. The role of the safety computer to provide emergency braking following loss of communications or other system error is defined.

The on-board vehicle location system requirements include the use of three or more location sensors, and provides for initiation of safe braking if not more than one source for location sensing is available. The reliability of the information installations must be extremely high, so as to provide location data at all times the vehicle is in motion.

The wayside to vehicle transmission installation must include a multiple computer system of a fail-safe design, such as a 2-out-of-3 system. Proof of safety-engineering suitability is required by means of detailed tests and analyses of the software. A description of one accepted transmission system is included, whereby secured telegrams are provided for among three computers, with a single computer channel failure being permitted. Should transmission be disrupted to more than one

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	MBO	Section 2.4 Section 4.4	Railway Safety Systems Speed	Maglev
German Government	EBO	Paragraphs 14, 15, 16, 39	Switches, Signals, Train Control, and Train Speed	Railroad
German Federal Railways	MUe 8004 Principals of technical approval of signalling and communication engineering			Railroad
DIN VDE	0831 Electrical equipment for railway 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		Communication Signals	Railroad

Table 6.1 Safety Requirements for Functional Area 401 (Continued)

Operations Control System Design

Issuing Organization	Title and or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
UIC	Code	512	Rolling Stock: Conditions to be fulfilled in order to avoid difficulties in operation of track circuits and treadles	Railroad
		641	Conditions to be fulfilled by automatic vigilance devices used in international traffic	
		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 bibliography for full citation.

computer, the emergency braking procedure is initiated. In this system, transmission disruption is declared if three successive telegram cycles are recognized as faulty.

Chapter 8 of the RW MSB 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 provides requirements for construction, equipment and function of the operational control system as they pertain to the safety relevant portions of the guideway and vehicle systems. Safety of the guideway is defined to include that all guideway elements are free of obstacles that can be recorded in terms of safety engineering, and precautions have been taken such that no conceivable objects will get onto the guideway.

The goal of vehicle protection provides for vehicle speed to be 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 stopping, is to be provided by the operations control system, with back-up from the on-board safety computer and braking system.

The requirements of operating points are provided for, and includes an operational control center and other decentralized points, that may be either stationary or vehicle-based. The following must be provided for by operational points:

- Guideway - 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 further related requirements for operational control systems as listed and described below.

DIN VDE 0831 Electric railroad signaling systems

DIN VDE 0801	Principles for computers in systems with safety functions (described in Functional Area 105)
MUe 8004	Principles for technical approval in signaling and communication technology; German Federal Railroad
UIC 738 E (2nd Edition)	Processing and transmitting safety information

The MBO, Paragraph 1.7, Safety Measures 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 moveable guideway elements (such as switches), must feature elements that safely report whether they can be operated over 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, guideway status must be technically safeguarded until a vehicle movement is completed, speed must be technically monitored, and automatic braking action initiated if operation does not react to vehicle control instructions.

The EBO, Paragraph 14 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 operators position meets this requirement.

VDE 0831; Electrical Equipment for Railway Signaling provides relevant requirements for a high speed system, 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.

German Federal Railroad, MUe 8004; Principles for Technical Approval in Signaling and Communication Engineering provide the requirements used to the German Federal Railway (DB) for system design material, components installation, and testing of vital railway signalling systems. It is similar in content to the AAR Signal Manual of Recommended Practice, covering such items as they specifically apply to the systems in use on the German railroad.

MUe 8004 is structured as a specification document for the purchase of signals 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 taken directly from VDE 0831, referenced as DIN 57831 in the available copy of MUe 8004.

Chapter 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.

U.S. Requirements

Federal Railroad Administration (FRA) Regulations 49 CFR, Part 236 apply to all railroads that operate on standard gauge track, and are not rapid transit systems operated on track exclusively for its use. These regulations do not currently have requirements that are meant to apply exclusively to electronic components or microprocessor based systems, but equivalence with relay based systems is broadly covered 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 Association of American Railroads (AAR) Communications and Signals (C&S) Division provides the Signal Manual of Recommended Practice to recommend 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 design are recommended to meet other established standards. Safety design standards are provided for software to result in vital 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 are prevented by the user. 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 may be allowed. User vital software should be by means of a high-level language and should be stored in non-volatile memory.

International and Other

The UIC Code 734 R provides for the adaptation of safety installations to high speed (up to 300 km/h) requirements. Its requirements state that high-speed lines shall not have at-grade highway crossings at speeds above 200 km/h. It recommends broken rail protection and signal system interfacing of hot bearing detectors. It states that braking distance curves must be met on high speed lines without the use of electromagnetic rail brakes.

It defines the problems associated with high speeds and visual observance and reaction to signals. It states that the cab should be manned at all times, and provided with a continuous display of information provided by the signal system, which will automatically monitor an operator's actions. Automatic monitoring of operator actions involves the automatic initiation of braking 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 3 minutes is stated as a minimum safe separation of high speed trains. It requires a method by which the driver may emit a signal that will automatically cause trains on his line, or adjacent lines to be signalled to stop, requiring a vital ground to train communication link.

Code 734 refers to ORE A 46/S 1005 for more information on "European continuous automatic train-running control system" for signal systems on very high speed use. A method of providing and processing such a system, requiring a multiple computer, 2-out-of-3 comparison logic to provide the vitality and fault tolerant reliability.

A communications system for ground/train vital transmission is well defined, that may use a microwave system or antenna/trackside cable system.

The UIC Code 738 R provides general guidelines for the processing and transmission of safety information, and is based upon the work of ORE Committees A 155 and A 118 on the "use of electronics in railway signalling". This describes the necessary complementary effect of qualitative and quantitative methods of addressing railway signal systems.

It acknowledges that 100% prevention of any danger state is unattainable. However, fail-safe behavior is accepted when a failure detection system can assuredly be identified within a defined threshold that includes all but "improbable" failures. More complicated failure detection systems may reduce system reliability, therefore creating operational restriction. As train movement must usually be continued even with signal system restrictions present, human decisions may control their movement with the safety systems being partially or completely over-ridden. Such human intervention creates new dangers, and experience has shown that human error rate is a thousand times higher than technical systems. Therefore, safety systems should have a high reliability of performing the required functions, being called high availability, and may include duplication of parts within an installation.

Any failure that occurs that does not result in more restricted operation must be detected and eliminated before a second failure can invalidate the system safety.

Initially, any safety system must be proven free of design, programming and manufacturing errors that can prevent any safety requirements from being met. Proof of the system's integrity to function as intended must be accomplished by theoretical, static and dynamic testing procedures, to ensure no probable combination of failures will result in unsafe operation.

As well as 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, and their protection against mechanical damage, 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.

D. Comparison and Assessment

The reviewed documents address two aspects of operations control system requirements: the definition of the functions the system must perform with an appropriately high safety level, and requirement for components and devices to carry out the functions.

Functional Requirements

The key requirements for a high-speed maglev system are specified in Chapter 9 of the RW MSB and Section 4 of the MBO, and can be summarized as follows:

1. Monitor the guideway status for vehicle location and speed, position of moveable elements, and the presence of any obstruction that would prevent safe operation.

2. 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.

3. 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 Automatic Block or Centralized Train Control interlocking and signalling systems as specified in the current FRA Regulation 49 CFR Part 236 provide functions equivalent to items 1 and 2 above, except that vehicle or train speed is not monitored, and the capability to detect obstructions on the track is limited to few special situations (such as rock-fall fences). The item 3 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, 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, the RW MSB and MBO functional requirements for operation control systems for high-speed maglev systems are in excess of 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 maglev functional requirements are closely comparable to practice on wheel-on-rail high-speed systems, as specified in UIC Code 734, and 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.

Requirements for Devices and Components

Devices and components used in high-speed maglev operational control systems will necessarily differ from those used in conventional railroad signal and train control systems. This is primarily 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 rail vehicle. Specific safety-relevant issues are as follows:

- Requirements for software-controlled computer systems used to provide the interlocking function, and vehicle on-board speed monitoring and control functions are fully 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 will differ. Thus, it is reasonable to expect that the devices used should have a safety performance comparable to the equivalent devices on conventional switches. In any case, the locking and position status sensors must be such that there is no way a false "OK" signal can be generated under any anticipated failure conditions, or unintended unlocking and movement of the switch can be initiated while the guideway is cleared for operations. This requirement is also directly comparable to the equivalent requirement for conventional switches.

- The vehicle location and speed sensing system is 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 at the wayside interlocking unit. Further research and analysis may be required to properly understand the capabilities and safety concerns associated with alternative vehicle location systems. Existing railroad-oriented requirements, such as FRA, AAR, MUe 8004 and VDE 0831 do not provide much help in resolving these concerns.

- 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.

Overall Safety Concerns

Some individual devices, such as switch position and locking status sensors are sufficiently similar to equivalent conventional railroad equipment, that 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.

E. Recommendations

The following recommendations are made for safety requirements for high-speed maglev operations control systems in the United States.

Overall System Functional Requirements

The functional requirements underlying present FRA signal system requirements in 49 CFR Part 236 are applicable to high-speed maglev, specifically.

- Guideway status must be continuously monitored for vehicle location, the position and locking status of moveable guideway elements such as switches, and to the extent possible for other obstructions that would prevent safe operation.

- An interlocking system must be provided, to ensure that vehicle movements are only permitted when the guideway is clear of obstructions and other vehicles, and switches are properly set. This is equivalent to the functions of automatic block and interlocking systems in conventional railroads.

In addition, a safe speed enforcement system must be used to ensure that safe minimum and maximum speed limits are not violated, taking into account guideway and vehicle conditions, location of safe stopping points, and the point at which the vehicle must be able to stop. This requirement is equivalent to that in UIC Code 734 for high-speed wheel-on-rail systems.

Component and Subsystem Requirements

Recognized existing conventional railroad requirements such as FRA, AAR, UIC, MUe 8004 and VDE 0831 must be followed where components and subsystems are directly comparable to conventional railroad components or subsystems used for an equivalent purpose. This would include switch position and locking status sensors, and wayside communication links.

Programmable computers used for interlocking systems, or an on-board safe-speed enforcement system should follow the requirements developed for Functional Area 105, Computer Safety for Vehicle and Operations Control Systems.

Research is required to develop requirements for components used in a high-speed maglev system for which there are no applicable existing requirements. The most notable example of such components are various alternative vehicle speed and location detection systems and associated communication systems. Assurance that there is safe response to all possible failure modes is particularly critical.

System Safety Assurance

A detailed FMEA and quantitative failure rate analyses should be performed on the overall operations control system to ensure that overall safety requirements can be met. This should particularly include failure modes and consequences for the vehicle location and speed detection system, and the vehicle to wayside communication systems.

6.2 Functional Area 402 - Operations Control System Inspection and Maintenance

A. 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, Safety, Reliability and Availability which 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, covering computer systems used in operational control systems.

Functional Area 303, Guideway Switch addressing the structural and operating aspects of the switch.

Functional Area 401, Operations Control System Design covering design requirements for the overall system, and system components of different types.

Functional Area 403, Communication Systems which includes communications between operations control system functional components.

B. 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 special operational precautions and responses to automatically indicated faults.

- Requirements for preventative 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.

C. Description of Existing Safety Requirements

Existing safety requirements are listed in Table 6.2, and described below by country of origin: Germany, U.S. and International and Other.

The RW MSB, Chapter 4, 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. Also, 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. This implies that maintenance or replacement of the faulty equipment must be carried out before returning the vehicle to normal use.

Chapter 9 of the RW MSB 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.

The MBO, Section 1.4, Basic Rules 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-

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	MBO	Section 1.4	Basic Rules	Maglev
German Government	EBO	Section 2	Railroad Installations	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 bibliography for full citation.

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 (Reference 11), 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: "Operational Fields of the New High-Speed Rail Systems in the Federal Republic of Germany" (Reference 10), describes an inspection and maintenance philosophy for a high-speed magnetic levitation trains. The principal elements of the approach described 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 preventative 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:

  1. Ensure safety
  2. Ensure operational availability
  3. 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) is impacted by the failure. This is best summarized in tabular form, as shown in Table 6.3.

U.S. Requirements

The FRA railroad safety requirements, 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 supply 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 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.

The AAR specifies numerous inspections and tests in the Manuals of Recommended Practices. Tests have to be carried out at 1, 3, 6, 12, 24, and 60 month intervals depending on type of equipment. Cab signal and ATC equipment in a locomotive or driving cab has to be inspected daily in the shop and tested daily by the engine man on departure or on entering ATC territory.

International and Other Requirements

UIC Code 731, Inspection of Signalling Installations provides some general guidance regarding a signalling inspection program. The types of equipment that should be

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

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. 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.

D. Comparison and Assessment

The requirements identified above are either very general statements to the effect that adequate maintenance is required (such as in the MBO), or are highly detailed requirements for devices used in conventional railroad installations such as relay interlockings, track circuits, or switch machines. Requirements of this type are contained in the FRA safety regulations and the AAR Manual.

Conventional 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. This is likely to be true of switch systems, and wayside cabling, but will generally not be true of vehicle location and speed detection systems and vehicle to guideway communications. These latter two systems are highly-critical to safe and reliable maglev vehicle operations. Therefore, 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 the repair procedure itself to make sure the equipment is functional after repair, and any 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 paper, Reference 10, makes a good start in providing a 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.

E. Recommendations

Consideration should be given to the following safety requirements for Operations Control Equipment Inspection and Maintenance.

- A daily operational check shall be made of all vehicle-borne safety critical operations-control apparatus. This check shall take place prior to the first departure of the day, or shortly after departure where a running test is appropriate. These checks shall include, but not be limited to the following:

  - 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 computers, including multiple redundant installations where used

  This requirement is adapted from the present FRA requirements for train control apparatus 49 CFR Parts 236.586 and 587.

- Where operations control system components are comparable to equipment used in conventional railroad signal and train control systems, the requirements of the FRA safety regulations 49 CFR Part 236, and the AAR Manual shall apply.

- A comprehensive condition monitoring, inspection, and maintenance manual shall be prepared for the operations control systems used on each maglev system put into service. The manual shall 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 shall 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 shall be subject to suitable pre-service tests. With microprocessor systems, it will be particularly important to ensure that both the correct hardware and software has been installed at a specific function and/or location. A careful 'configuration-management' process is required.

- Detailed records shall 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.

Insufficient information is available to make more detailed recommendations regarding inspection and maintenance procedures for safety-critical computer systems, and further research in this area is desirable.

6.3 Functional Area 403, Communications

A. Description of Functional Area

This functional area is concerned with all forms of communication which might be used in managing and controlling the movements of maglev vehicles. 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 activities.

This functional area is closely related to other functional areas addressing vehicle movement control and guideway status, particularly including the following:

Functional Area 101, System Safety which includes the role of communications in the overall safety performance of a maglev system.

Functional Area 103, Safety, 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, which 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 601, Qualifications and Training, and 602, Operating Rules and Practices both address the use of radio, and particularly voice radio in maglev operations from the point of view of employee skills and operating procedures.

Functional Areas 603, Emergency Features and Equipment, and 604, Emergency Plans and Procedures address requirements for communication capabilities and procedures in an emergency situation.

B. Safety Baseline

The safe operation of maglev vehicle 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 possibly 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. This means that good voice radio procedures are required to minimize the risk of such an occurrence.

C. Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6.4, and are described below by country of origin: Germany, U.S., and International and Other.

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.

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	MBO	Section 2 Section 3	Operating Installations Vehicles	Maglev
German Government	EBO	Section 16	Railroad Installations: Communication Facilities	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	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

Table 6.4 Safety Requirements for Functional Area 403 (Continued)

Communications

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FCC	47 CFR Federal Communications Commission Regulations	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 755 Laying of Telecommunication and Signalling Cables 781 Transmission Systems and Methods of Remote Control for Signalling Installations			Railroad

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

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.

Section 9 of Chapter 4 requires that a passenger emergency signal must be transmitted in a fail-safe manner to the on-board safety computer nd 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 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 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 MBO, Section 2.4 has the general requirement that train safety installation shall be reliable and fail-safe.

The 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's cab. These requirements refer to radio voice transmissions, separate from radio or other communications used for vehicle control data.

The EBO, Section 16, 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.

U.S. Requirements

The U.S. requirements for safety-relevant communications are contained in FRA, FAA, AAR and Federal Communications Commission (FCC) requirements.

The FRA in 49 CFR Part 220 specifies procedures for voice communication by radio. These procedures include requirements for designating radio channels to be used, 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 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 (Part 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 vital data communications, but are likely to differ from the 40 GHz range used for train control in Germany. In particular, radios and communications equipment of all types have to 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 Communication 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.

International and Other 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:

- Classification and identification of error sources.

- Methods for protecting against errors including information redundancy, 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 analyses of a communication system should be carried out to confirm that safety performance is within acceptable bounds.

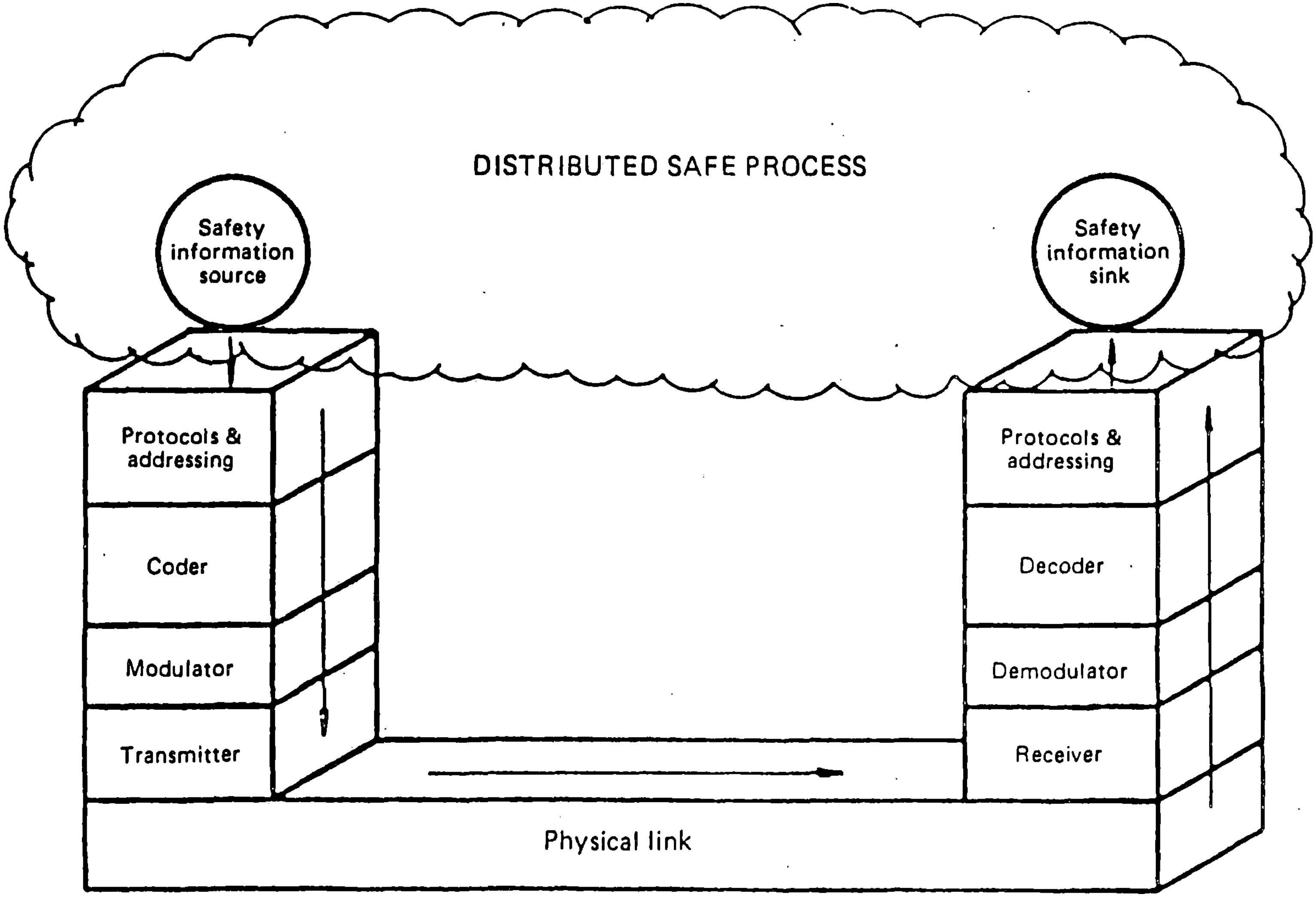
There are also two other UIC Codes that provide recommendations for conventional railroad communications installations:

- 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.

Figure 6.1 Communication System Model from UIC Code 738

Processing and Transmission of Safety Information



D. 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.

System-Level Requirements

The RW MSB and UIC Code 738 provide the most complete system-level requirements. 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 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 are performed to demonstrate that requirements can be met. The need for such analysis are also implied by the MBO in the requirement that all systems be adequately safe.

In any case, 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.

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.

E. Recommendations

The following recommendations are made for safety requirements for safety-relevant maglev communications systems.

- Safety-critical communications systems must 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 must be designed so that the probability of acceptance of erroneous data is extremely low.

- FMEA, Quantitative Risk Analysis and other types of safety analysis must be carried out as recommended in Functional Area 101, System Safety to demonstrate that an unsafe communications failure or error is extremely improbable.

- A voice-radio link between vehicles and the control center shall be provided, and shall be completely independent of any other radio system used to communicate train control data to the vehicle and be provided with an independent power source. Voice radio procedures should comply with FRA requirements in 49 CFR Part 220.

- All radio communication systems must comply with applicable FCC regulations, including 47 CFR Part 2, Frequency Allocations and Part 90, Private Land Mobile Radio Service.

- Conventional communication system components used in maglev applications should conform to the FRA requirements for signal systems 49 CFR, Part 236 with regard to insulation, grounding and marking. Also, conventional communication components and cabling should preferably comply with the requirements of the AAR Manual of Recommended Practices, Communications.

6.4 Functional Area 404 - Electrical Safety and Power Supply

A. 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 on the vehicle. This includes 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. 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, which discusses requirements for electromagnetic compatibility between electric power systems and electronic and communication systems used in the maglev system.

- Functional Areas 301 and 302, Guideway Construction and Maintenance which cover the mechanical mounting of the stator on the guideway.

- Functional Areas 206 and 207, which cover 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.

B. 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 and rectifiers. 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. These would include IEEE, ANSI, NFPA, IEC as well as DIN and VDE standards that address the technical and safety issues involved with the design, construction and operation of a fixed guideway system, including all appurtenances such as the power supply for vehicle operations and auxiliary power.

C. Description of Existing Safety Requirements

Since this functional area covers a very broad range of electrical equipment and components, these descriptions have been broken down into several sub-areas as follows:

Electrical Safety Requirements

1. Protection against electric shock

2. Grounding system

3. Disconnection equipment

4. Equipment and cable insulation.

5. Overload and short circuit protection

Comparison of Equipment Design Requirements

6. Transformers

7. Switchgear

8. Rectifiers

The German and international requirements are described first, followed by the equivalent U.S. requirements. International and German requirements have been grouped together because the RW MSB cites both German (DIN-VDE) and international (IEC) requirements in different instances, and because many DIN-VDE and IEC requirements are interchangeable.

A full list of both German and U.S. requirements documents referenced are given in Table 6.5.

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

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	Propulsion, including energy supply	Maglev
DIN VDE	0100	Part 410	Installation of power plant with rated voltages not exceeding 1000V	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
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

Table 6.5 Safety Requirements for Functional Area 404 (Continued)

Electrical Safety and Electric Power Supply

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
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 substaticers and fuses	General Industrial
Amtrak	323		High performance wire and cable used on Amtrak passenger vehicles	Railroad

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

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 energy systems on-board the maglev vehicle. This chapter includes requirements for power supply to the vehicle, energy storage on the vehicle, power controllers for on board equipment such as 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.

1. Protection Against Electric Shock

- DIN 57 100 Part 410/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 since the nominal propulsion voltages in the feeders subsystems and the long stator subsystem are in excess of, the voltages discussed in this standard.

- DIN-VDE 0101 Erection of Power Installations with Nominal Voltage Exceeding 1 Kv. This standard is similar to VDE 0100, except for higher voltages, and therefore applicable. However, there is notice in this standard 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 standard is not applicable 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 is a traditional steel wheel on steel rail railway standard. Although VDE 0101 refers to this standard since it is not pertinent to railways, it is assumed that VDE 101 is listed in Chapter 2 because VDE 0115 is not applicable.

- 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.

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.

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 a standard for equipment, this is a functional standard that describes minimum clearances, prevention of accidental reclosing and remote control of the disconnect means. It is noted that Chapter 2 calls for 1.2 times the clearance specified in this standard.

4. Cable Insulation

The area of cable insulation standards was not reviewed in great detail. However, the reviewer is aware of the important role that the fire characteristics of cable insulation plays in a public transit environment. RW MSB, Chapter 2 cites DIN-VDE 0266 Halogen-free Cable with Improved Behavior During Fire. Work in the U.S. as well as efforts of the UITP have made the transit operators as well as cable manufacturers aware of the need for improved fire safety in the area of electrical insulation. The specification of halogen-free, low smoke, flame retardant cables citing either U.S. or German standards should be required.

5. Overload and Short Circuit Protection

This area of protection includes ground fault protection. The content of the requirements documents was as follows:

- DIN-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.

- DIN-VDE 0160 Electronic Equipment for Use in Electrical Power Installations and Their Assembly into Electrical Power Installations. DIN-VDE 0160 requires electronic equipment incorporated into power equipment and installations to function after involvement in a fault on the power system.

6. Transformers

Transformers built to the applicable VDE's have been used on US transit systems in the past. In general, the requirements of VDE 0532 are on a par with the ANSI/IEEE standards. It should not be a problem, either safety related or qualitywise to use a transformer manufactured in accordance with VDE on a US Maglev project.

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 Maglev system in the US. German manufacturer's in the past have manufactured switchgear for application in the United States that meets the requirements of metal clad switchgear.

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 project.

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:

1. Protection Against Electric Shock

- NFPA 70 National Electric Code (NEC). 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." The forgoing is taken from 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.). This requirement classifies 13 categories of enclosures for protection against entering by water and foreign bodies.

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. These are covered in IEEE Standard 80.

3. Disconnection

ANSI C2 National Electrical Safety Code (NESC) is similar in intent to VDE 0101.

4. Cable Insulation

Amtrak's specification 323 for cable to be installed in passenger vehicle appears to be broadly similar to VDE 0266. One notable difference is that Amtrak requires low temperature performance to be demonstrated at -55°C, while the VDE standard requires only -15°C. This illustrates the potential importance of climatic factors in some U.S. applications.

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. Transformers

The ANSI/IEEE C57 standards for transformers would not give any advantage over use of the VDE standards in the areas of safety or of a quality product.

7. Switchgear

ANSI/IEEE C37 provides requirements for metal clad switchgear appropriate to use in maglev power supply and distribution systems.

8. Rectifiers

ANSI/IEEE Standard C34 is comparable to the VDE requirements in the safety aspect of semiconductor rectifiers.

D. Comparison and Assessment

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.

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 derived at by applying both standards. This is thought to be beyond the scope of this study. In addition, IEEE Standard 80 was not available for use in comparing touch potential recommendations.

3. Disconnection

These two requirements are similar and cover, among other things, the methods of disconnecting power from equipment. In this case, 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 rather than how to accomplish this disconnect in a practical manner, i.e., the application of a circuit breaker or load break switch. The spacing of isolating links and bus spacing is spelled out in the VDE's, 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.

4. Overload and Short Circuit Protection

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 specific in VDE 0160 and this is a requirement that 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.

5. Cable Insulation

It would seem, except for some possible termination problems due to different sizes (Metric vs. English) of conductors, that it would seem practical to use US manufactured cable in the project. However, the concern of smoke and fire characteristics of wire and cable, considered so 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. Transformers

It can be noted from experience that German manufactured transformers have been employed in the U.S. transit industry with excellent success. It is the opinion of the reviewer that the safety issues of German manufactured transformers are considered in much the same manner that U.S. manufacturers regard safety in accordance with U.S. requirements.

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.

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.

General Observations

Requirements for installation, operation, and maintenance were not reviewed. Due to many factors, 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, only the U.S. standards for installation, operation, and maintenance should be followed.

While there were no RW MSB, or other, known references to installation, operation and maintenance of electrical systems, adoption of U.S. methods/practices and staff personnel for these functions should be required. An important factor to promote safety is familiarity with the equipment one works on, installation, etc. Where

German or other methods deviate from U.S. practice, but achieve the same objective, U.S. practice is more familiar. Therefore, safety risks are lowered by using familiar methods to the extent possible.

Based on this review, it does not appear that significant differences exist between German and U.S. requirement for the electrical systems involved in the high-speed maglev trains. In some cases further study of the requirements, such as those involving grounding, should be conducted to determine if 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, all wayside heavy-current electrical equipment, including the guideway-mounted stator packs should follow whatever 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. Similar standards should also apply 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.

U.S. requirements are preferred over German or other foreign requirements. U.S. contractors and maintenance staff will be more familiar with the U.S. requirements and thus there will be less risk of error. It is suggested that a code of practice be developed specifying these electrical requirements by reference to U.S. national requirements developed by recognized standards-setting organizations. International or foreign requirements may be identified as acceptable alternates, providing the differences are minor.

E. Recommendations

The following recommendations are made regarding electric power system requirements for the safe construction of electric power systems on maglev vehicles and wayside installations.

- 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 to 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.

6.5 Functional Area 405, Electromagnetic Interference and Electromagnetic Compatibility (EMI and EMC)

A. 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.

Functional areas that are closely related to this functional area are:

Functional Area 105, Computer Safety for Vehicle and Operative Control Systems which 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 discuss 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.

B. 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.

C. Description of Existing Requirements

Existing requirements are listed in Table 6.6, and described below by country of origin: Germany, US, and International and others.

German Requirements

Chapter 10 of the RW MSB requires an EMC plan to prevent impermissible breakdowns and failures of safety-relevant system due to EMI. This plan must include information on the following:

- An assessment of the electromagnetic emissions environment under normal operating conditions. This may be location-dependent (for example, there will be localized emissions 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 proper operational states of the vehicle, wayside and signal and train control equipment.

Measurements and tests, as specified by the DIN-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.

DIN VDE 0228 - Measures Against Interference in Telecommunications Systems by Electric Power Installations provides a discussion of general principals, 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 AC and DC railroad electric traction systems.

E DIN 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	Tile 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	Parts 1,2,3	Electromagnetic compatibility for industrial process measurement and control equipment (equivalent to IEC 801)	General Industrial
DIN VDE	0847	Parts 2 and 4	Measurement methods for electromagnetic compatibility	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

Table 6.6 Safety Requirements for Functional Area 405 (Continued)

Electromagnetic Interference and Electromagnetic Compatibility (EMI and EMC)

Issuing Organization	Tile and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
FCC	47 CFR	Parts 15 and 17	Regulations regarding maximum acceptable levels of electromagnetic emissions	General
UMTA	MA-06-0153-85-8	-	Test procedures for rail vehicle inductive emissions from the electrical power subsystems	Mass Transit
UMTA	MA-06-0153-85-6		Test procedures for EMI from power supply substations and propulsion equipment	Mass Transit
UMTA	MA-06-0153 -85-11		Test procedures for broadband emissions of rapid transit vehicle (140KH2 - 400MHZ)	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	737-3 737-4		Application of thyristors in railway technology Measures for limiting the disturbance of light current installations by electric traction	Railroad

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

DIN VDE 0843 - Electromagnetic Compatibility for industrial-process measurement and control equipment is a comprehensive guide to the kinds of that can be expected in different operating environments, and EMI test procedures.

DIN 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.

DIN VDE 0873, Measures against radio interference from Electric Utility Plants and Electric Tractions 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 DIN particularly concentrates actions to reduce the level of EMI at source.

DIN 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 DIN correspond to legal limits for electromagnetic radiation from small power tools, household appliances and similar products.

U.S. Requirements

FCC Regulations, 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.

Several studies of electromagnetic interference have been conducted on urban rail transit systems to develop measurement techniques for EMI, as follows:

- 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. Note that 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 the propulsion equipment and substation, as well as the susceptibility of audio frequency rate coded signaling systems.

- 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.

International and Other Requirements

The UIC Codes 737-3 and 737-4 provide some general guidelines regarding methods both 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 also 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.

D. 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 DIN 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 DIN-VDE 0843, DIN-VDE 0847, and DIN 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. However, 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.

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.

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. It is understood that extensive literature exists on this subject.

E. Recommendations

The following recommendations are made for EMI/EMC safety requirements for high speed maglev operations in the United States.

- 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-born 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-born and wayside equipment. Tests should include those for both conducted and radiated emission, using established test techniques such as those given in the UMTA report and MIL-STD-462.

Further research into this subject is recommended, to review past research and testing of MEI in electric railroads to help establish guidelines regards the best ways of addressing EMI/EMC issues on a maglev system.

6.6 Functional Area 406 - Lightning Protection

A. Description of Functional Area

The possibility exists of the maglev vehicle, the guideway, or other maglev installations such as buildings, electric power substations, and 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.

B. 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.

C. Description of Existing Safety Requirements

Existing safety requirements relevant to this functional area are listed in Table 6.7 and described below by country of origin: Germany, U.S., and International and Other.

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-born 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 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/DIN 57185 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 the Transrapid organization regarding lightning protection. These reports are summarized below.

- "Analysis of lightning protection for the Transrapid Magnetic Railway" (Thyssen-Henschel, 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.

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
Federal Aviation Administration	14 CFR 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
ANSI/UL UL	96-1988 96A		Lightning Protection for Buildings and Structures	General Industrial

Table 6.7 Safety Requirements for Functional Area 406 (Continued)

Lightning Protection

Issuing Organization	Title and/or Reference Number	Part, Chapter, etc.	Title of Part, Chapter, etc.	Applicability or Intent
AAR	-	-	Signal Manual, 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 bibliography for full citation.

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.

U.S. Requirements

FAA requirements for transport category airplanes 14 CFR Part 25.581 Lightning Protection requires that airplanes must be protected against the catastrophic consequences of a lightning strike by appropriate electrical bonding of metallic components, and providing 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 provides a comprehensive guidance for the lightning protection of static buildings and equipment, but specifically exclude 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 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 tests is the basic requirement for the protection of electrical and electronic equipment, and for devices to provide this protection.

International and Other

No relevant International and Other requirements have been identified.

D. Comparison and Assessment

Available data indicates that there is a much higher incidence and strength of 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 DIN-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.

E. Recommendations

The following safety requirements are recommended for the protection of maglev vehicles and fixed installations against the adverse effects of lightning strikes.

In view of the potentially severe lightning environment in the United States, U.S.-based safety requirements for lightning protection should be used for maglev vehicles and installations in the U.S.

Specifically, these are as follows:

- 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 shall be provided with multiple conducting paths to the guideway (at least four) via support or guidance magnets or support skids. Although the vehicle is non-contacting, it is expected that lightning discharges will easily travel across the air gap of the magnets.

  Furthermore, the effects of lightning strikes on vehicle electrical and electronic equipment shall 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 shall 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.

7. Personnel, Operations and Emergency Preparedness

7.1 Functional Area 501 - Qualifications and Training

A. Description of Functional Area

This functional area addresses qualifications and training requirements for all personnel engaged in maglev operations and maintenance activities that may have some influence on the safety of the system. This includes 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.

Other functional areas which have an interface with this area are:

Functional Area 104, Quality Assurance, the requirements for which can be equally applied to O and M activities as to the manufacture of hardware.

Functional Area 209, which discusses technical maintenance and inspection requirements for vehicles.

Functional Area 302, which discusses technical maintenance and inspection requirements for the guideway.

Functional Area 402 which discusses technical maintenance and inspection requirements for operations control equipment.

Functional Area 502, Operating Rules and Practices, which specify procedures to be followed to ensure the safe operation of a maglev system, including staffing requirements for particular maglev operating functions.

Functional Area 504, Emergency Plans and Procedures, part of which addresses the training of staff with regard to emergency response.

B. Safety Baseline

All personnel engaged in maglev operations and maintenance activities must be adequately trained so that they can carry out their duties properly, and in a way that does not create a danger either for themselves or for co-workers, or for members of the public using the maglev system. To accomplish this objective, the maglev operating organization must carry out appropriate training and testing of all employees.

C. Existing Requirements

The existing requirements in this functional area are listed in Table 7.1 and described below by country of origin: German, US, and international and other.

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, Operations Control Equipment, Section 2.1.1.1, that the Operations Control Center must be continually occupied by professionally trained, suitable and competent personnel.

The MBO provides 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)
  - Must be qualified, trained and tested to ensure that they can satisfactorily perform their duties
- Section 4.2 contains staffing 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.

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.

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	MBO	Section 1.6 Section 4.2	General/Personnel Requirements of Railroad Operation - Preconditions for Personnel	Maglev
German Government	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 bibliography for full citation.

- Paragraph 48 defines health requirements, and specifies physical examinations to confirm that employees meet these requirements.

- Paragraphs 49 to 52 specify age, vision, and hearing requirements. Minimum age of 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.

US Requirements

The FRA railroad regulations, 40 CFR, Part 219, Control of Alcohol and Drug Use, 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.

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 training program and associated tests must be filed with the FRA.

Part 217, Paragraph 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 parts of the FRA regulations require that persons performing safety-critical duties have appropriate training and experience. These include:

- Part 213.7 in the Track Safety standards provides requirements for persons performing track inspections and supervising 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 locomotive inspections required by FRA regulations.

The FAA regulations 14 CFR contains the following requirements with respect to personnel concerned with the operation and maintenance of aircraft:

- Part 43 required 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 respectively 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.

<u>International and Other</u>

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.

D. Comparison and Assessment

With regard to 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 to each other. 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 employees in each occupation.

- The content and frequency of refresher training for existing employees.

With variation in detail, requirements covering these three points are contained in the MBO, EBO, FRA Regulations 49 CFR, Parts 213, 215, 217, 220 and 229, and the FAA Aviation Regulations. In the case of railroads, both in the US and in Germany, the exact content of training and tests are the responsibility of the railroad. 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 employees 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 US railroad regulations, although individual railroads may have such requirements.

Some maglev occupations require employees to be in good physical condition. For example, vehicle on-board employees may have to help passengers in an emergency. Vehicle operator and control center staff must have good vision. Therefore, employee 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 also discussed in Functional Area 502, Operating Rules and Practices, since it is an on-going activity as much as a qualification and training requirement.

E. Recommendations

The existing FRA regulations controlling alcohol and drug abuse by railroad employees, contained in 49 CFR, Part 219, are applicable to maglev personnel in the United States. In addition, consideration should be given to the following safety requirements based on the information presented and discussed above.

A maglev operator must establish formal qualification and training requirements for all personnel engaged in safety-critical activities. These will normally include

- On-board operating personnel
- Control center and dispatching personnel
- Inspection and maintenance personnel
  - Vehicles
  - Guideway structures
  - Electric power supply
- Supervisors and managers of operating and maintenance personnel

At a minimum the qualifications and training specifications must include:

- The specific content and duration of training for new personnel in each skill area, or existing personnel seeking to move to a different or more advanced skill level.
- Qualification tests for new personnel (written and practical) in each skill area. Preferably these will include simulated vehicle or system operations, including emergencies.
- Specific content and frequency of refresher training and tests to ensure 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 is required before they can be permitted to perform duties alone.

Minimum personnel health requirements must be specified by the maglev operator related to the physical demands of each occupation in normal operation and emergency conditions.

All personnel must 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.

7.2 Functional Area 502 - Operating Rules and Practices

A. 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 employees who are 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 will 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, are also part of the operations control process both in normal operations and after an accident or malfunction. Thus, operating rules include communication procedures.

Functional Area 501 covering requirements for personnel qualifications and training.

Functional Area 504, which discusses emergency plans and procedures.

B. 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 be 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. This includes procedures for work on or near the guideway, on vehicles away from a maintenance workshop, maintenance work on safety-critical systems, pre-departure checks, and for 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 employees. 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.

C. Description of Existing Requirements

Existing safety requirements in this functional area are listed in Table 7.2 and are described below by country of origin: German, US, and UIC and International.

German Requirements

The RW MSB is primarily concerned with the technical installations of a high-speed maglev system, and not with operations. However, because an interface exists between these technical installations and operating procedures, Chapters 4 and 9 of the RW MSB contain some relevant information.

Chapter 4 of the RW MSB, On Board Control System, specifies that the operators console on the vehicle should display all safety relevant vehicle status information such as of the vehicle levitation and guidance system, door opened or closed, etc. The operator is responsible for permanent or periodic monitoring 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, Operational Control System, specifies that vehicle movements may be permitted only if the following conditions are satisfied (Section 2.2.2).

- The guideway is not occupied by another vehicle

- Moveable elements of the guideway are set and secured in the correct position

- No other technical installation is intruding into the clearance required for the vehicle to move safely along the guideway

- The guideway is not operationally ready for another run, or is blocked for some other reason

Section 2.1.1.1 of Chapter 9 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.

Section 1.5 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 50 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.

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	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, 2nd Edition 1991			Railroad
UIC	Code	734 916 965	Adaptation of Safety Installation to High-speed Operations Measures to Promote Safety-Consciousness in Staff Instructions Governing the Behavior of Staff Working on the Track	Railroad

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

Chapter 1 of the 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 MBO, Requirements of Railroad Operations, 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, 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 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 provided doors are automatically operated, train control (ATC) is available, and the power controls have a dead man's handle.

US Requirements

Several parts of the FRA railroad safety regulations in 49 CFR contain requirements for operating rules.

- CFR 49, 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.

- CFR 49, 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.

- CFR 49, Part 219 requires that no employee engaged in railroad operations shall 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.

- CFR 49, Part 220 specifies procedures for radio voice communications in railroad operation, including those for train orders and other instructions for train and vehicle movements.

- CFR 49, Part 228 limits the maximum continuous hours of duty of selected 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.

- CFR 49, Part 232, in paragraphs 232.12 to 232.16 specifies terminal and running brake tests that must be performed to ensure that brakes have been properly connected and are operating throughout the train.

- FRA CFR 49, Part 236, paragraph 0 specifies the maximum speeds that may be operated as a function of signal system type. A block system is required for speeds of 97 km/h on any railroad line (60 mph) and above, and an automatic cab signal or equivalent for speeds of 129 km/h (80 mph) and above.

The Association of American Railroads' '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 or under the control of block and interlocking signals. Additionally, all railroads have location-specific operating requirements (maximum speeds, what equipment can operate where, etc.) embodied 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.

UIC and Other International Requirements

Three UIC codes cover specific aspects of operating safety:

- Code 734 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 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 discusses the contents of safety programs designed to keep employees aware of safety matters, including training, testing and media presentations.

Rules documents for individual high-speed and conventional operations on foreign railroads are not available at present.

D. Comparison and Assessment

The RW MSB, MBO, EBO, FRA and other railroad 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 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 MBO also specifies that speeds over 50 km/h must be supervised by an automated system.

Among conventional railroad requirements, the German EBO requires pre-departure brake tests, but otherwise focusses 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. These are summarized in Table 7.3 for each of the sources. 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.

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 km/h	-
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 brake tests, a requirement that is also found in the MBO and EBO.

As well as signal requirements, the UIC codes identified address safety of working on the guideway, and also, 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 caused 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. Recommendations are made in Section E below for the content of such rules.

E. Recommendations

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. Other than these individual requirements, the review of existing requirements and of the likely nature of maglev operations indicate that maglev operating rules should at a minimum include comprehensive rules and procedures for the following activities and situations:

- Specification of the maximum permitted speed of operation without a functioning ATP system.

- Requirements for maglev train movements under normal control, including pre-departure checks and other actions by both on-board and control center staff, including ATP and brake system tests.

- Requirements for maglev train movements under emergency manual control following a malfunction of train control or power supply systems, including maximum speed of operation.

- Requirements for the protection of staff working on or near the guideway and/or performing maintenance and inspection duties. In particular, the requirements must cover procedures for disabling any portion of the power supply, signal or communication systems, and for physical occupation of the guideway by equipment or personnel.

- Protection of a vehicle on which maintenance or inspection work is being performed outside the regular maintenance shop.

- Definitions of terminology used in maglev operations.

- Voice radio communication procedures, during normal operations, for manual operations, and in emergency situations.

- Maximum hours of service and minimum rest periods for operating staff.

- A timetable shall be prepared giving speed limits for all points on the network, and other location-specific operating requirements.

Further research to develop a model code of operating rules, equivalent function to the AAR code or the 'NORAC' rules is suggested, using existing rules and the above recommendations as a starting point.

Finally, consideration should be given to developing safety management guidelines, incorporating the recommendations of UIC Code 916. 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.

7.3 Functional Area 503 - Emergency Features and Equipment, including Access and Egress

A. 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, on-board systems such as ventilation and lighting may be affected, and it may be necessary to evacuate the vehicle at the first opportunity. These 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. They are:

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 requirement for fire detection and the numbers, types and locations of fire extinguishers. A fire is one of the most important types of emergency which might lead to vehicle evacuation.

Functional Area 504, 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.

B. Safety Baseline

Vehicle occupants must be provided with reasonable protection against adverse consequences of a fire or major maglev subsystem 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 that should be considered 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. This is a particular concern with elevated guideways.

- Adequacy of emergency exits for use by elderly and handicapped 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 and the 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.

C. Description of Existing Safety Requirements

The existing safety requirements in this functional area are listed in Table 7.4, and are described below by country of origin: German, U.S. and Other.

German Requirements

Chapter 1 of the RW MSB 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 capability of coasting to and stopping at a "designated stopping place" at all times. This requires the following capabilities:

- 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 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 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 coast to the next designated stopping place.

The reason for adopting the designated stopping place philosophy for emergencies is the difficulty of providing emergency access and egress from a vehicle on an elevated guideway.

Table 7.4 Safety Requirements for Functional Area 503

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	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
FAA	14 CFR 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

Table 7.4 Safety Requirements for Functional Area 503 (continued)

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
FTA	DOT-TSCA-UMTA-84-26 Recommended Emergency Preparedness Guidelines for Rail Transit Systems	Section 4 Section 5	Facilities and equipment. Vehicles	Mass Transit
	DOT-TSC-UMTA-89-4 Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers	Section 4 Section 5	Vehicles Facilities	
NFPA	130 Fixed Guideway Transit Systems	Chapter 3 Chapter 4 Section 4.5	Trainways Vehicles Emergency Egress	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 bibliography for full citation.

The RW MSB points out that this approach puts the maglev vehicle into the same situation as an airplane, where emergency access and egress can only be provided at an airfield.

RW MSB, Chapter 12 provides comprehensive requirements for emergency access and egress using designated stopping places as follows:

- 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 requirements for the vehicle. These 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.

  - For situations where no other means of exit is possible, one safety rope per exit must be provided for emergency egress away from a designated stopping point. This can only be used when the guideway top surface is less than 20m (66 ft) above ground. Rescue slides are an acceptable alternative, provided they can operate 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. This will normally be the primary communication system and an independent back-up.

  - 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. They should also 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. This requirement is needed to ensure that vehicles do not stop at locations where rescue is difficult. Paragraph 3.2 requires that the passengers are informed of the situation during an emergency by the vehicle operator or control center. A public address system is an obvious means of meeting this requirement, but is not specifically mentioned.

U.S. Requirements

Federal Railroad Administration (FRA) regulations 49 CFR Part 223.15 requires a minimum of four emergency exit windows in a passenger car. This is the sole FRA requirement for passenger car emergency features or equipment.

The Federal Aviation Administration (FAA) in 14 CFR Part 25 specifies emergency exits and other features for commercial aircraft as follows:

- Paragraph 807 specifies the numbers, types and locations of emergency exits required as a function of aircraft configuration and seating capacity. Approximately one exit is required for every 30-40 seats.

- Paragraph 809 specifies the characteristics of emergency exits. 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. Exits must also be safeguarded against accidental opening.

- Paragraph 803 states that tests must be performed to demonstrate that a fully occupied aircraft can be evacuated in less than 90 seconds through half the available exits.

- Paragraph 811 requires conspicuous marking of emergency exits with illuminated signs, and the posting of clear operating instructions.

- Paragraph 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.

- Paragraphs 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

- Paragraph 813 specifies minimum aisle widths as a function of aircraft seating capacity, and the width of unobstructed passageways to emergency exits. On aircraft with more than 20 seats, aisles must be 0.38 m (15 in) wide between floor level and 0.63 m (25 in) above floor, and 0.5 m (20 in) wide above this level.

- Paragraph 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.

- Paragraphs 1411 and 1423 require a public address system with microphones at flight attendant seats adjacent to emergency exits. The public address system must have an independent back-up power source capable of operating for at least 10 minutes.

- Paragraph 1561 requires that all safety features and equipment are clearly marked with operating instructions, and locker or compartments which contain safety and life-saving equipment should be marked accordingly.

The FTA has developed Emergency Preparedness Guidelines for rail mass transit systems. Section 5 of these guidelines recommends vehicle equipment and features for emergencies and emergency evacuation. The principal requirements can be summarized as follows:

- End doors capable of manual operation must be provided between vehicles.

- Side doors must be openable automatically from the operators cab, and manually from both inside and outside the vehicle.

- Emergency lighting with an emergency power supply independent of the regular lighting system shall illuminate at least all door locations and vestibules and the operators cab.

- Vehicle communications systems, both public address within the train and to an external control center, should be provided, and be connected to the independent emergency power supply.

- Ladders should be provided in each vehicle.

- Flashlights should be provided for the use of train operating personnel.

- All emergency equipment should be provided with suitable labels and instructions. Consideration should be given to using pictographic or multilingual signs as appropriate. A vehicle identification number should be displayed both inside and outside the vehicle.

- Controls to shut off of the ventilation system should be provided in the operator cab.

Sections 4.1 and 4.2 specify that emergency exits from stations and along the guideway must be clearly marked with distinctive lighted signs. Continuous emergency walkways alongside track are not a requirement for underground and elevated route segments, but every effort should be made to provide effective emergency exits. Where walkways are used, it is recommended that they be of vehicle floor height, have fixed railings, and on the side of the track away from the power supply third rail.

The Federal Transit Administration has also developed emergency preparedness guidelines for elderly and disabled rail transit passengers. These emphasize points that might be of special concern with elderly and disabled passengers. These are:

- Emergency egress through regular vehicle doors onto a platform at floor height is highly desirable. Reliance on steps or ladders, and emergency exit windows should be minimized in view of the difficulty elderly and disabled people may have in using them.

- Generous aisle widths and plenty of handholds should be provided to minimize the difficulty of moving about the vehicle for elderly and disabled people. Aisles should be sized for wheelchairs where required.

- Consideration should be given to improving the level of emergency illumination, both in general and of emergency exit signs, to improve visibility for people with impaired vision.

- Everything possible should be done to maximize the clarity of emergency related signs and graphics and of public address systems. It is also desirable to provide a means of passengers talking directly to train crew or the control center, for example through a two-way intercom system.

The NFPA 130 safety requirements for fixed-guideway mass transit system specify the following vehicle features and equipment, and provisions for emergency access and egress:

- Each vehicle shall have emergency exits on the sides or in the end(s).

- Means must be provided for passengers to evacuate a train at any point along the guideway and reach a safe area. System egress points shall be illuminated.

- Access to an elevated guideway for emergency vehicles shall be provided at maximum intervals of 762 m (2500 ft).

- Emergency lighting powered by storage batteries shall be provided with a capacity to operate the lighting for a minimum of one hour.

- A public address system is required whereby the train crew or control center may make announcements to passengers.

- Communication systems are required between the train and the operations control center and between train crew members. In the case of remotely controlled vehicles, means must be provided for passengers to communicate with the operations control center.

The Association of American Railroads Manual of Standards and Recommended Practices requires the following features and equipment on intercity and commuter passenger cars (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 this Amtrak document.

- 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 49 CF 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.

- Car windows are impact resistant polycarbonate plastic that cannot be broken. If access is required in an emergency, they have to be cut out by rescue services.

- Except for tunnels and bridges, there are no special 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 have to reflect the existing features of these structures.

Other Requirements

The provisions of UIC codes regarding emergency access and egress are as follows:

- UIC 560 requires that power operated doors to be manually operable from inside and outside the vehicle. This includes provision to de-activate automatic locks. More details are provided in Functional Area 206, Passenger Vehicle Doors.

- UIC 564-1 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 breaking the window with a special purpose hammer. UIC accepts the use of safety glass that can normally be broken in this way.

- UIC 651 requires that an escape door and passage to the opposite end of a locomotive or cab-car must 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, provides requirements for emergency egress in Section 12. The principal requirements are that all trains should have doors that can be used for emergency exit 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.

D. 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 walkway parallel to the guideway and stairs or other means to reach 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. In this instance, the vehicle would not be damaged, and occupants could await rescue without immediate risk but 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 is desirable for maglev operations in the U.S., at least until system reliability has been demonstrated in service. Specific recommendations are made in Section E 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 equipment. 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 emergency egress is through the regular vehicle doors. Separate emergency exits are not required. There are no detailed requirements regarding the operability of the doors in emergency conditions, for example in case of loss of power.

Complete reliance on regular vehicle doors for emergency egress is also a concern. Requirements for conventional rail vehicles (for example FRA 49 CFR 223.15, and UIC 564.1) provide for emergency exits through windows in case doors are inaccessible or inoperable. UIC 560 and the FTA also require 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 door failure.

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 FTA guidelines. The common ground covered by these requirements includes emergency signals for passenger operation, emergency lighting, signage, public address systems, and vehicle to operation 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. Specific recommendations, based on existing requirements, are made in Section E below.

E. Recommendations

Consideration should be given to the following safety requirements for emergency access and egress and other emergency equipment and features for U.S. maglev applications. Some of the requirements will also be addressed in FRA Emergency Preparedness guidelines that are currently in preparation.

<u>Emergency Access and Egress</u>

A high-speed maglev system should have the following features:

- One emergency exit per 40 seats should be provided other than those provided by regular vehicle doors, on each side of a vehicle or vehicle compartment. The minimum opening size shall be 0.6 m (24 in) x 0.45 m (18 in)(based on FRA requirement 49 CFR 223.15 for conventional rail vehicles and AAR requirements). Exits must be openable from inside and outside the vehicle.

- Regular doors must be provided with emergency manual means of opening from both outside and inside the vehicle (based on UIC 560, FTA guidelines).

- Adequate means must be provided for people to move away from a stranded vehicle in an emergency. Alternative means include:
  - Aircraft style emergency evacuation slides, provided they are compatible with elevated guideway height.
  - A continuous walkway at vehicle floor height parallel to the guideway.
  - 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. Until this is the case, this approach should be used only in combination with one of the other recommended alternatives.
  - Provision of permanently available mobile rescue platforms and stairs that could be bought to a disabled vehicle anywhere on the guideway, with using the roadway recommended below. Maximum time to reach a disabled vehicle has to be compatible with the 30 minute protection time afforded by fire barriers on the vehicle.
- 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).

Emergency Features and Equipment

The following are recommended based on the RW MSB and similar, or equivalent requirements in NFPA 130, FAA Commercial Aircraft Airworthiness Standards, FTA rail transit emergency preparedness guidelines, and the AAR passenger car requirements.

- Provision of a passenger emergency signal in each vehicle to alert the vehicle crew and/or the operations control center of an emergency. An intercom system for passengers to speak to crew and/or control center is also desirable.
- Emergency lighting having a one hour capability to be activated automatically if the regular lighting fails. This should provide general illumination, and illumination of emergency exits, safety-related signs, and the operators cabs.
- A public address system with an independent power source shall be provided for announcements to passengers by vehicle crew or operations control center staff.
- An emergency communication system, independent of the primary communication systems, and with an independent power supply, must be provided to ensure that train crew can communicate both with the maglev operations control center and with rescue service expected to respond to an emergency.

- One first-aid kit per vehicle shall be provided.
- Flashlights shall be provided for the use of train crew members.
- All emergency features and equipment shall have clear and unambiguous accompanying signs giving purpose and instructions for use.
- The needs of elderly and disabled passengers shall be given particular consideration in developing vehicle and guideway features in response to these requirements.

7.4 Functional Area 504 - Emergency Plans and Procedures

A. Description of Functional Area

A high-speed maglev system will need procedures for responding to any emergency that might develop on the system which threatens the safety of passengers, employees or others, or which might cause significant property damage.

The kinds of emergency which may arise 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 incidence 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 describes overall system safety approach applicable to high-speed maglev systems, including the roles of emergency plans and procedures.

Functional Area 205 discusses requirements to minimize the occurrence and severity of on-vehicle fires.

Functional Area 403 provides information and requirements for communication systems, including those for emergency communication.

Functional Area 503 addresses emergency access to and egress from a disabled maglev vehicle, and other emergency features and equipment required to aid emergency egress and to respond to on-board emergencies and malfunctions.

B. Safety Baseline

Emergency plans and procedures should address all preparations needed for an adequate emergency response, including the content of plans and procedures. These plans and procedures should include:

- Identification of the types of emergencies for which the plans and procedures have been prepared.
- Content of plans and procedures.
- Requirements for training, rehearsals and drills to familiarize maglev system staff 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.
- Requirements for lines of communication during an emergency, and responsibilities of vehicle crew, operations control center and other parties for emergency actions.

C. Description of Existing Safety Requirements

The existing safety requirements in this functional area are listed in Table 7.5 and described below. The descriptions are organized by country of origin: Germany, U.S. and Other.

German Requirements

Chapter 1 of the RW MSB, 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 2XX, Emergency Features and Equipment.

Chapter 12 of the RW MSB provides some detailed requirements regarding emergency plans and procedures. These are summarized as follows (Sections 12.6, 12.7, 12.8 and 12.9):

- The 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. Landing sites for helicopters should also be considered.
- 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.
- For a rescue operation between designated stopping places, planning of measures and execution must involve firefighting services.
- On-board conductors are required to be trained to provide passenger safety in the event of an emergency. In particular, they are required to (Section 12.8):
  - Be trained in first aid.
  - Be demonstrably and repeatedly trained in the use of rescue.

Table 7.5 Safety Requirements for Functional Area 504

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 12	Rescue Plan	Maglev
German Government	MBO	Chapter 3	Vehicle Para 3.4 Vehicle Compartments Para 3.7 Operator's Cab	Maglev
FTA	MA-06-0152-85-1 Emergency Preparedness Guidelines for Rail Transit Systems MA-06-0186-89-1 Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers			Mass Transit Mass Transit
Amtrak	Emergency Evacuation from Amtrak Trains NPRC 1910			Railroad
NFPA	130 Fixed Guideway Transit Systems	Chapter 3 Chapter 6	Trainway Emergency Procedures	Guided Transportation
BSI	6853 Fire Precautions in the Design and Construction of Railway Passenger Rolling Stock			Railroad

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

- Trained personnel must be available to operate means of rescue. In addition, brief and succinct operating instruction must be available.

Section 1.7 of the 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.

U.S. Requirements

Amtrak has developed a guide (NRPC 1910) for emergency evacuation from its intercity passenger trains. This guide 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 emphasize the following points:

- 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 this is impossible or there is reason to believe that a derailment or personal injury would result.

- Advance planning is essential to establish responsibilities and lines of communication between railroad officials, local emergency response authorities and train crews.

- Procedures are essential for isolating and/or avoiding accidental contact with high voltage equipment used by electric railroads.

The Amtrak document 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.

NFPA 130 for fixed guideway transit systems, Chapter 6, provides detailed recommendations for emergency plans and procedures. The NFPA definition of an emergency includes the following events:

- Fire in or near a train
- Collision or derailment
- Disabled trains
- Serious vandalism, criminal acts, or a terrorist threat
- Serious risk of structural failure
- Illness or injury of a passenger
- Disruption of operations caused by extreme weather (snow, flooding, high wind, extreme temperatures, etc.)

- Earthquake

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 staff shall 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," prepared for the FTA includes requirements for emergency response procedures. The guidelines include:

- A clear policy regarding emergency response needs and capabilities and coordination with community emergency response organizations.

- Definitions of different types and severities of emergencies.

- Responsibilities of train crew, operations control center and outside organizations for initiating and coordinating the emergency response.

- Criteria for determining the type and level of response in each situation.

- A thorough emergency response manual detailing the procedures.

- Suitable training, drills and exercises and reviews to ensure that the emergency response capability effectiveness is maintained over time.

The FTA has also prepared "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. This includes a review 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. 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.

Other Requirements

British Standard, BS6853, requires the 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.

D. Comparison and Assessment

In general terms, there is no significant conflict between the emergency procedures specified by the RW MSB, NFPA 130 and the FTA. All emphasize:

- The need for advance planning of emergency response. This includes 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 staff who may be involved in an emergency, and to carry out regular drills and exercises.

In addition, the FTA has developed guidelines for addressing the special needs of elderly and disabled passengers in an emergency. These or the FRA Emergency Guidelines currently in preparation should be adopted by a U.S. operator of maglev service.

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. Thus, only minimal means of egress from the vehicle are provided, using ropes for decent to the ground, and there is no requirement for vehicular access to the guideway other than at designated stopping places. This can be contrasted with NFPA recommendations for fixed guideway transit which 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 503 on emergency features and equipment, 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 attend to the emergency. Detailed plans should be included in the emergency planning document for attending to vehicles stranded away from a station or designated stopping place.

E. Recommendations

Consideration should be given to the following safety requirements for U.S. maglev operations in this functional area. These recommendations should be reviewed in the light of the FRA Emergency Guidelines which are current in preparation.

Written emergency plans should be prepared by a maglev operator, and revised from time to time as necessary to reflect both changes in the maglev system, and improvements to procedures found to be desirable as a result of drills and exercises, and operating experience. The plans should include at least the following:

- Definition of responsibilities and lines of communications between vehicle crew, maglev operations control center and local emergency services during an emergency. This includes responsibilities and communications between the control center and the scene of the emergency.

- The location and types of emergency equipment and vehicles on the maglev system.

- A point of contact with all organizations that may be affected or involved in an emergency. This includes local emergency service (fire, police, ambulance) utility companies, any other transportation companies with rights of way crossing or parallel to the maglev guideway, and local public works departments.

- Specific procedures to be followed in each type of emergency and for each location on the system.

- A requirement to carry out emergency drills and exercises at least twice a year.

- Procedures for the removal and restoration of electric power to the guideway and other maglev fixed facilities should this be needed in the course of the emergency response.

- The plan should specifically include emergency procedures for attending and evacuating occupants from a vehicle stranded away from a station or designated stopping place.

- The plan should include procedures and methods for attending to the special needs of elderly and disabled passengers in an emergency.

The particular procedures needed for emergency response to and evacuation from a maglev vehicle on an elevated guideway can be different from those for conventional railroad or rail transit vehicles. Some further research is recommended into the most appropriate procedures, and in particular how best to provide rescue services to a maglev vehicle stranded away from a stopping place.

Bibliography

Introduction

This bibliography lists the documents referenced in the RWMSB document "High Speed Maglev Trains: Safety Requirements", and the documents cited in the reviews of individual functional areas in this report. Most of the referenced requirements documents are Standards, Rules, Regulations or Codes issued by government departments, national standard-setting organizations, and industry associations, both in the United States and elsewhere. The general technical literature is also cited where appropriate.

The bibliography contains the following information about each document:

- Issuing Organization
- Reference number, part, etc.
- Full title
- Date of Issue
- Where cited by RWMSB (where applicable)
- Applicable Maglev Functional Areas or areas, as reviewed in this report
- Source of document
- Translation Status (where applicable)

Although not strictly biographical information, the last two items are added for the convenience of users of this report. Many of the requirements referenced are from foreign sources, and, of course, are originally published in German. Various commercial services can provide either translated or original documents, as well as the publishing organization. Those used for this report were:

Global/IHS	Microfilm library of DIN and DIN-VDE standards provided by Global Engineering Services in conjunction with Information Handling Service (IHS).
BSI	British Standards Institution, which publishes translations of selected technical standards originally published in languages other than English.
Beuth Verlag	A German commercial bibliographic search service and documents provider used to obtain mostly German standards, rules, and regulations unavailable through other sources.

VNTSC Library — The Volpe archives include a Maglev library of DIN's, DIN-VDE's and supplier documents which were made availble to ADL during the course of this study.

Issuing Org. — When the name of the issuing organization appears in the Source/Issuer column, the documents referenced were obtained directly from DIN, IEC, VDE, etc.

This information is only provided for documents published outside the United States.

Translation Status is provided for all documents originally published in a language other than English. Categories of Translation Status are shown below:

- Complete translation is available in English (FE).
- Partial translation is available in English (PE)
- Only currently available in the original language, usually German (FG)

The bibliography of technical requirements documents, standards, rules, regulations and codes is organized in alphabetical order by issuing organization. For each document series, the documents are listed in order of the issuing organization reference number.

References to the general technical literature are listed in a separate section, in order of publications starting with the most recent.

DIN (Deutsches Institut für Normung E.V.)
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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0109	Sheet 2	Driving Elements Centre for V-belt Drives	01-Jan-60	2.7	404	DIN	FE
1045		Structural Use of Concrete; Design and Construction	01-Jul-88	6.4.3, 7.2.2.1	301,101	Beuth Verlag	FE
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	201,202,301	Global Engi-neering	FE
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	Global Engi-neering	FE
1055	Part 3	Design Loads for Buildings; Live Loads	01-Jun-71	6.2.1	301	Global Engi-neering	FE
1055	Part 4	Design Loads for Buildings; Imposed Loads; Wind Loads on Structures Unsusceptible to Vibration	01-Aug-86	6.2.1	301	Global Engi-neering	FE
1055	Part 6	Design Loads for Buildings; Loads in Silo Bins	01-May-87	6.2.1	301	Global Engi-neering	FE

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(continued)

Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
1072		Road and Foot Bridges; Design Loads	01-Dec-85	5.5.0	301	Global Engi- neering	FE
1075		Concrete Bridges; Dimensioning and Execution	01-Apr-81	7.2.2.1, 7.4.0	301,201,302	Global Engi- neering	FE
1079		Steel Road Bridges, Principles for Structural Design	01-Sep-70	7.4.0	301,302,101	Global Engi- neering	FE
1084		Quality supervision in concrete and concrete reinforced construction		7.3.2, 7.4.0	105,301,302	Global Engi- neering	FE
4102	Part 2	Fire Behavior of Building Materials and Building Components	01-Sep-77	11.3.0	207	Global Engi- neering	FE
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	207	Global Engi- neering	FE

DIN (Deutsches Institut für Normung E.V.)
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Code of Technical Standards
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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
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	207	Globl Engi-neering	FE
4102	Part 6	Fire Behavior of Building Materials and Building Components; Ventilation Ducts; Definitions, Requirements and Tests	01-Sep-77	11.6.0	207	Global Engi-neering	FE
4149	Part 1	Buildings in German Earthquake Zones; Design Loads, Dimensioning, Design and Construction of Conventional Buildings	01-Apr-81	6.3.2	301	Global Engi-neering	FE
4227	Part 2	Prestressed Concrete; Partially Prestressed Structural Members	01-May-84	6.4.3, 7,2,2,1	101,301,103	Global Engi-neering	FE
4227	Part 3	Prestressed Concrete, Segmental Type Structural Components, Design and Workmanship of Joints	01-Dec-83	6.4.3, 7.2.2.1	301,101,103	Global Engi-neering	FE
4227	Part 4	Prestressed Concrete; Prestressed Lightweight Concrete Structural Components	01-Feb-86	6.4.3, 7.2.2.1	301,101,103	Global Engi-neering	FE

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(continued)

Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
4227	Part 5	Prestressed Concrete; Injection of Cement Mortar into Prestressing Concrete Ducts	01-Dec-79	6.4.3, 7.2.2.1	301,101,103	Global Engi-neering	FE
4227	Part 6	Prestressed Concrete; Structural Components With Unbonded Prestressing	01-May-82	6.4.3, 7.2.2.1	301,101,103	Global Engi-neering	FE
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	207,204,205	VNTSC Library	FE
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	207,204,205	VNTSC Library	FE
5510	Part 5	Preventative Fire Protection in Railway Vehicles; Electrical Operating Means; Safety Requirements	01-Oct-88	11.4.6, 11.6.0	207,101,100	VNTSC Library	FE
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	207,209,407	VNTSC Library	FE
18200		Inspection of Construction Materials, Structural Members and Types of Construction; General Principles	01-Dec-86	11.6.0	105,207	Beuth Verlag	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
18800	Part 1	Steel Structures; Design and Construction	01-Mar-81	6.4.1, 6.4.3	301,101	Global Engi-neering	FE
18800	Part 7	Steel Structures; Fabrication, Verification of Suitability for Welding	01-May-83	6.4.1, 6.4.3	301,101	Global Engi-neering	FE
24343		Hydraulic Fluid Power Systems 02d Components; List for Attendance and Inspection of Hydraulic Equipments	01-Feb-82	8.7.0	213,209	Global Engi-neering	FG
24346		Hydraulic Fluid Power; Hydraulic Systems; General Rules for Application	01-Dec-86 *Dec84?	9.7.0	213,209	Global Engi-neering	FE
29591		Aerospace; Examination of Welders; Welding of Metallic Components	01-Oct-86	*7.3.1.1. 3.1, 7.4	601,105,201	Global Engi-neering	FG
*31000		General Guide for Designing Technical Equipment to Satisfy Requirements - Safety Technology Concepts; Basic Concepts Safety	01-Dec-87	3.6.0	101,102	BSI	FE
33400		Ergonomic Principles in the Design of Work Systems; Terminology and General Guiding Principles	01-Oct-83	4.4.0	204,101	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
33401		Control Elements: Terms and Definitions, Suitability, Design Recommendation	01-Jul-77	4.4.0	204,101	DIN	FE
33402	Part 4	Human Body Dimensions; Principles of Dimensioning Passages and Accesses	01-Oct-86	4.4.0	204,101	Global Engi-neering	FE
33403	Part 1	Climate at Workplaces and in Working Environments; Basic Principles for Determining Climates	01-Apr-84	4.4.0	204,101	Global Engi-neering	FE
33413	Part 1	Ergonomic Aspects of Indicating Devices; Types, Observation Tasks, Suitability	01-Jun-84	4.4.0	204,101	Global Engi-neering	FE
33414	Part 1	Ergonomic Design of Control Rooms; Seated Work Stations; Terms and Definitions, Principles, Dimensions	01-Apr-85	4.4.0	204,101	Global Engi-neering	FE
40041		Reliability in Elec. Engineering; Terms and Definitions; General	01-Dec-90	0.5	102,100,101	DIN	Full Ger-man
40046		Environmental Tests for Electrical Technology		2.7.0	404,401		

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
40050		Degrees of Proetction Provided by Enclosures; Protection of Electrical Equipment Against Contact, Foreign Bodies and Water	01-Jul-80	3.6.0	101,301	Global Engineering	FE
50060		Testing of Burning Behavior of Materials and Products; Terms and Definitions	01-Aug-85	11.3.0	207	Global Engineering	Full German
54345	Part 1	Testing of Textiles; Electrostatic Behavior; Determination of Electrical Resistances	01-Jul-85	10.4.1	404,401	BSI	FE
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	404,401	BSI	FE
54345	Part 3	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Floor Coverings by Machine	01-Jul-85	10.4.3	404,404,401	BSI	FE
54345	Part 4	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Fabrics	01-Jul-85	10.4.1	404,404,401	BSI	FE
54345	Part 5	Testing of Textiles; Electrostatic Behavior; Determination of Electrostatic Charge of Textile Fabrics	01-Jul-85	10.4.3	404,404,401	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
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	404,101	BSI	FE
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	404,101	BSI	FE
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	404,401	BSI	FE
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 (VDE Spec)	01-Jun-81	2.7	404,401	BSI	FE
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	404,401	BSI	FE
0101		Erection of Power Installations with Nominal Voltage Exceeding 1 kV	01-May-89	2.3.2,2.7	404	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0105	V1	Operation of Electrical Power Installations; General Requirements	01-Jul-83	2.7.0	404		FE
0106	100	Protection Against Electric Shock; Location of Control Elements in the Vicinity of Shock-Hazard Parts	01-Mar-83	2.7.0	404	BSI	FE
108		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	BSI	FE
0109 =IEC 664	A1	Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment	01-Mar-89	2.7.0	404	IEC	FE
0109 =IEC 664	10	Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment	01-Sep-90	2.7.0	404	IEC	FE
0110	1	Insulation Coordination Within Low-Voltage Systems; Fundamental Requirements	01-Jan-89	2.5.3	404,400	BSI	FE
0115	1	Traction Systems; General Construction and Safety	01-Jun-82	2.3.1.1	209,208	BSI	FE
0115	2	Traction Systems; Particular Requirements for Vehicles and Their Equipment	01-Jun-82	2.7.0	209,208	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0115	3	Traction Systems; Particular Requirements for Stationary Installations	01-Jun-82	2.7.0	209,208	BSI	FE
0122		Electrical Equipment for Electric Trans-Energy Supply	01-Aug-86	3.4.2	700	VDE	FG
0141		Earthing Systems for Power Installations with Rated Voltages Above 1kV	01-Jul-89	2.5.4.2, 4.1	404,400	BSI	FE
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	301,404	BSI	FE
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	301,404	BSI	FE
0165	A1	Installation of Electrical Equipment in Potentially Explosive Atmospheres	01-Sep-86	3.4.2	207,404	BSI	FE
0185	1	Lightning Protection System; General with Regard to Installation (VDE Guide)	01-Jan-83	10.2.2.1	406,404,207	VDE	FE
0185	2	Lightning Protection System; Installation of Special Structures (VDE Guide)	01-Jan-83	10.2.2.1	406,404,207	VDE	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0228	1	Measures Against Interference in Telecommunication Systems by Electric Power Installations; General Principles	01-Oct-82	2.7.0	404	BSI	FE
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	404	BSI	FE
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	404	BSI	FE
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	404	BSI	FE
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_0/U 450/750 V	01-Mar-89	2.7.0	405,207	BSI	FE
0266	7	Halogen-Free Cables With Improved Characteristics in Case of Fire; Nominal Voltages U_0/U 0.6/1 kV	01-Feb-85	2.7.6,3.6	207,401,403	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0278	1	Power Cable Accessories with Rated Voltages U Up to 30kV; General (VDE Specification)	01-Jun-80	2.7	401,403	BSI	FE
0278	4	Power Cable Accessories with Rated Voltages U Up to 30kV; Sealing Ends for Indoor U_0/U above 0.6/1 kV (VDE Specification)	01-Oct-84	2.7	401,403	BSI	FE
0278	5	Power Cable Accessories with Rated Voltages U Up to 30kV; Sealing Ends for Outdoor Installations U_0/U above 0.6/1 kV	01-Jun-82	2.7	401,403	BSI	FE
0278	6	Power Cable Accessories with Rated Voltages U Up to 30kV; Plug-In Type or Screw Type Enclosed Cable Connections U_0/U above 0.6/1 kV	01-Aug-88	2.7	401,403	BSI	FE
0282	1	Rubber Cables, Wires & Flexible Cords for Power Installation	01-Apr-85	3.3.1	404,101,401	BSI	FE
0287		Technical Procedures for Determining the Conformity of Harmonized Cables and Cords	01-Apr-85	3.3.3.1	404,404,101	BSI	FE
0298	2	Application of Cables and Flexible Cords in Power Installations; Recommended Values for the Current Carrying of Cables with Rated Voltages U_0/U up to 18/30 kV; VDE Specification	01-Nov-79	2.7.0,3.6	404,403,401	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0298	3	Application of Cables and Flexible Cords in Power Installations; General Information on Cables	01-Aug-83	2.7.0,3.6	404,401	BSI	FE
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	404,403,401	BSI	FE
0472	1b	Recommendations for Testing Insulated Cables and Flexible Cords	01-Jan-74	2.7.0	404,401	VDE	FE
0510	2	Accumulators and Battery Installations; Stationary Batteries	01-Jul-86	3.4.2	200,215	BSI	FE
0532	1	Regulations for Transformers and Chokes; Transformers	01-Dec-78	3.4.2	301,401	BSI	FE
0532	1 Annex M	List of Important Deviations of VDE 532 Part 1 from IEC Publications 76 (1967)	01-Nov-71	3.4.2	301,401	BSI	FE
0532	2	Transformers and Chokes; Temperature Rise	01-Mar-82	2.7.0	301,401,404	BSI	FE
0558	1	Semiconductor Convertors; General Specifications and Particular Specifications for Line-Commutated Convertors	01-Jul-87	2.7.0	301,401,404	Global	FE
0558	5	Semiconductor Convertors; Uninterruptible Power Systems (UPS); Deviations from IEC 146-4	01-Sep-88	2.4.0	301,401,404	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0660	103	Switch Gear and Control Gear; High Voltage Alternating Current Contractors (Deviations to IEC 470)	01-Mar-84	2.7.0	301,303,401	BSI	FE
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	303,209	BSI	FE
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	301,401,404	DIN	FE
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	404,401,303	BSI	FE
0675	1	Guidelines for Over-Voltage Protection Appliances; Valve Type Lighting Arresters for AC Circuits	01-May-72	2.7.0	406,404,401		
0800	1	Telecommunications; Erection and Operation of Facilities	01-Apr-84	2.7.0	403,407	BSI	FE
0800	2	Telecommunications; Earthing and Equipotential Bonding	01-Jul-85	2.3.1	406,404,401	BSI	FE
0801		Principles for Computers in Safety -Related Systems	01-Jan-90	4.1.1	401,101,102	DIN	FE
0816		External Cables for Telecommunications Systems	01-Feb-79	2.7.0	403,407,401	BSI	FE
0831		Electrical Equipment for Railway Signalling (VDE Specification)	01-Jun-83	1.5.1,2.7.0	402,401,103	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0839	10	Electromagnetic Compatibility; Evaluation of Immunity from Conducted and Radiated Disturbances	01-Oct-87	10.1.0	405,404,401	IEC	FE
0843= IEC 801-1	1	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; General Introduction	01-Jan-84	10.2.0	405,404,401	IEC	FE
0843= IEC 801-2	2	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; Electrostatic Discharge Requirements	01-Apr-91	10.2.0	405,404,401	IEC	FE
0843= IEC 801-3	3	Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment; Radiated Electromagnetic Field Requirements	01-Jan-84	10.2.0	405,404,401	IEC	FE
0845		VDE Specification for the Protection of Telecommunications Systems Against Overvoltages	*01-Apr-76	2.7.0	401,403,404	BSI	FE
0847	2	Measuring Method for Evaluation of Electromagnetic Compatibility; Immunity from Conducted Disturbances	01-Oct-87	10.2.0	405,404,401	BSI	FE
0847	4	Procedures for Measurement of Electromagnetic Compatibility; Immunity Against Radiated Interference Variables	01-Jan-87	10.2.0	405,404,401	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
0870	1	Electromagnetic Interference (EMI) Terms	01-Jul-84		405	BSI	FE
0873	1	Measures Against Radio Interference from Electric Utility Plants and Electrical Traction Systems; Radio Interference from Systems Below 10kV and from Electric Trains	01-May-82	10.3.3	405,404,401	BSI	FG
*0873	2	Measures Against Radio Interference from Electric Utility Plants and Electrical Traction Systems; Radio Interference from Systems Below 10kV and from Electric Trains	01-Oct-88	10.3.3	405,404,401	VDE	FE
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	405,404,401	BSI	FE
0875	2	Radio Interference Suppression of Electrical Appliances and Systems; Radio Interference Suppression by Luminaires with Discharge Lamps (VDE Specification)	01-Nov-84	10.3.3	405,404,401	BSI	FE

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Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
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	405,404,401	BSI	FE
0888	1	Optical Waveguides for Telecommunication System; Definitions	01-Jun-88	2.7.0	401,403,404	DIN	FG
0888	2	Optical Waveguides for Telecommunication and Data Processing Systems; Fibres and Buffered Fibres	01-Aug-87	2.7.0	401,403,404	Beuth Verlog	FG
0888	3	Optical Waveguides for Telecommunication and Data Processing Systems; Outdoor Cables	01-Oct-89	2.7.0	401,403,404	Beuth Verlog	FG
0888	4	Optical Waveguides for Telecommunication and Data Processing Systems; Indoor Cable with One Optical Fibre	01-Aug-87	2.7.0	401,403,404	Beuth Verlog	FG
0888	5	Optical Waveguides for Telecommunication and Data Processing Systems; Outdoor Fan-Out Cables	01-Dec-87	2.7.0	401,403,404	Beuth Verlog	FG
31000	2	General Guide for Designing Technical Equipment to Satisfy Safety Requirements; Safety Technology Concepts; Basic Concepts	01-Dec-87	1.3.3.2	101,100	BSI	FE

Deutsche Bundesbahn (DS)
German Railways
Code of Technical Standards

Ref. #	Part	Title	Date of Issue	TüV Citation	Functional Areas	Source/ Issuer	Trans. Status
DS 804		Regulations for Railroad Bridges and Other Engineering Constructions (VEI)	01-Jan-83	3.4.4,5.5.0, 6.3.2	301,201	DB	FG
DS 804		[English Extract] Regulations for Railroad Bridges and Other Engineering Constructions (VEI)	01-Jan-83	3.4.4,5.5.0, 6.3.2	201,202	DB	PE
DS 899/35		Code of Practice for Testing the Burner Behavior of Solids	01-Dec-72	11.4.4,11.6.0	207,401	DB	FG
DS 899/59		Besondere Bestimmungen für Eisenbahnbrücken in Neubaustrecken (BesB) Special Provisions for Railroad Bridges on New Lines	01-Jan-85	5.5.0	301	DB	FG
Mü 8004		Grundsätze zur technischen Zulassung in der Signal- und Nachrichtentechnik - Signal and Train Control Standards	01-Jan-91	4.2	401,402	DB	FG

Deutscher Verband für Schweisstechnik, e.V. (DVS)
German Welding Association
Code of Technical Standards

Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
1603		Spot Welding of Steel in Railroad Rolling Stock Construction	01-Nov-64	7.3.1.1.3.1	201,601,102	DVS	FG
1604		Spot Welding of Aluminum and its Alloys in Railroad Rolling Stock Construction	01-Oct-66	7.3.1.1.3.1	201,601,102	DVS	FG
1608		Welding of Aluminum in Railroad Rolling Stock Construction	01-May-83	7.3.1.1.3.1	201,601,102	DVS	FG
1609		Spot Welding of Alloy Steel in Railroad Rolling Stock Construction	01-Feb-75	7.3.1.1.3.1	201,601,102	DVS	FG
1610		General Guidelines for Planning Molded Structure in Railroad Rolling Stock Construction	01-Jun-88	7.3.1.1.3.1	201,601,102	DVS	FG
1611		Radiographic Testing of Aluminum and Alluminum Alloy Molded Joints in Railroad Rolling Stock Construction	01-Apr-79	7.3.1.1.3.1	201,601,102	DVS	FG

International Standards Organization (ISO)
Code of Technical Standards
ISO 9000-90004 = BS 5750 Series

Ref. #	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
9000		Quality Management and Quality Assurance Standards — Guidelines for Selection and Use	01-Jan-87	7.3.1.1	105	BSI	FE
9001		Quality Systems — Model for Quality Assurance in Design/Development, Production, Installation and Servicing	01-Jan-87	7.3.1.1	105	BSI	FE
9002		Quality Systems — Model for Quality Assurance in Production and Installation	01-Jan-87	7.3.1.1	105	BSI	FE
9003		Quality Systems — Model for Quality Assurance in Final Inspection and Test	01-Jan-87	7.3.1.1	105	BSI	FE
9004		Quality Management and Quality Systems Elements — Guidelines	01-Jan-87	7.3.1.1	105	BSI	FE
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	201,105,301	ISO	FE

Additional German Standards
Code of Technical Standards

Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
AD		Codes of Practice			7.0		
BOSTRAB		Federal Gazette I, 1987 Ordinance on the Construction and ? Streetcars	01-Jan-87	1.3.4.2	207	Broker German	FG
EBO	BGB 1, II	Railroad Construction and Traffic Regulations	01-Jan-82	1.3.4,8.7	310,100,200	Maglev Library	FE
ESBO		Railroad Construction and Operation Ordinance for Narrow Gauge Railroads	21-Nov-83	8,7.0	310,101,401	Broker German	FG
ESO		Railroad Signaling Ordinance		8.7.0	401,402,403	Broker German	FG
MBO		Construction and Operating Code For Magnetic Levitation Rail Systems (draft)	21-Oct-88	1.5,8.7,11.2	207,404,101, 201,301	Maglev Library	FE
NTK/375/ 02187		Wind Tunnel Studies TROG II, Loads Caused by Crosswind	19-Mar-87	5.6	200,204,205	VNTSC	FE
Pehla		Test Guidelines for High Voltage Systems	01-01-77	2.7	401,404,101	Pehla	FG
TRB		Technical Regulations for Pressurized Containers -- Index		8.6,8.7	301,303,304	Broker German	FG
TRGL		Technical Regulations for High Pressure Gas Conduits -- Index		8.6,8.7	301,303,304	Broker German	FG

Additional German Standards
Code of Technical Standards

Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
TVE K/10000/2 /SS/2		Specification for the Vehicle of the TRANSRAPID Test Facility in Elmsland	12-Oct-84	5.7	201,202	Krauss Maffei	FE
TVE T 483004SS 02		Long Stator Cables		2.5.22	404		
VG 96900		Standard, Protect Against Electromagnetic Pulse NEMP & Light Standards; Survey		10.2.5	406,404,207		
VG 96901		Standard, Protect Against Electromagnetic Pulse NEMP & Light Standards; Survey		10.2.5	406,404,207		
VDMA 24169	1	Technical Guidelines for Explosion Protection in Fans Transporting Air Containing Combustible EPS, Steam, or Mist	01-Dec-83	3.4.2	207,211	Beuth Verlag	FG
VNP1	967	Long Stator Cable	01-June-84	2.5,2.2	404,400		FG
ZHI	153	Code of Practice for Selection and Installation of Force Opining Position Switches with Safety Function		8.7.0	303,301,101		FG
ZHI	200	Guidelines for Avoiding Detonation Hazards due to Electrostatic		10.4.1,10.4.3	405,404,401		FG

Additional International Standards
Code of Technical Standards

Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
ATS 1000.001		Airbus Industries - Fire, Smoke, Toxicity - Test Specification	01-Nov-89	11.6.0	207,101,404	Airbus Indus-tries	FE
BS 6853:1987		British Standards Institute - Fire Precautions in Design and Construction of Rail Passenger Rolling Stock	01-Jan-87		207,404	BSI	FE
IEC 502 CAT A, AMM2		International Electrotechnical Commission - Feeder & Long Stator Cable - Choosing Cable Voltage for Fault D	01-Jan-87	2.5.2	404,400	IEC	FE

International Standards
UIC - Union Internationale de Chemins de Fer
(International Union of Railways)
Code of Technical Standards

Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
515		Coaches - Running gear (with amendments)			210	UIC	FE
533		Protection by the earthing (grounding) of metal parts of vehicles (with amendments)			210	UIC	FE
540		Brakes - Air brakes for freight and passenger trains	01-01-82		209	UIC	FE
541		Brakes - Regulations concerning the construction of the various brake components	01-01-84		209	UIC	FE
541-3		Brakes, Disc Brakes and Linings, Amendment 6	07-01-91			UIC	FE
543		Brakes - Regulations relative to the equipment and use of vehicles (with amendments)	01-01-84		209	UIC	FE
544-1		Brakes - Braking power (with amendments)	07-01-85		209	UIC	FE
546		Brakes - High power brakes for passenger trains. New edition of 1-80 (with amendments)	01-01-80		209	UIC	FE
560		Doors, entrance platforms, windows, steps, handles and handrails of coaches and luggage vans	01-01-88		206	UIC	FE
564-1		Coaches - Windows made from safety glass	01-01-79		203	UIC	FE
564-2		Regulations relating to fire protection and fire-fighting measures in passenger-carrying railway vehicles or assimilated vehicles used on international services	07-01-82	11.6.0	207,101,204	UIC	FE

International Standards
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Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
566		Coaches - Load cases	01-01-84		201	UIC	FE
610		Rules for the testing of electric rolling stock on completion of construction and before entry into service	11-01-78		213	UIC	FE
617-4		Position of front and side windows and of other windows situation in the driving compartments of electric powered stock (with amendments)	06-01-82		202	UIC	FE
642		Special provisions concerning fire precautions and fire-fighting measures on motive power units and driving trailers in international traffic	01-01-83		207	UIC	FE
651		Layout of driver cabs in locomotive railcars, multiple unit trains and driving trailers	01-01-86	5.5.0	201,202,203	UIC	FE
711		Geometry of points and crossings with UIC rails permitting speeds of 100 km/h or more on the diverging track	12-01-84		301	UIC	FE
720		Laying and maintenance of track made up of continuous welded rails	01-01-86		301	UIC	FE
730-3		Automatic warning of track maintenance gangs	01-01-85		304,601,602	UIC	FE
731		Inspection of signalling installations	07-01-71		402	UIC	FE

International Standards
UIC - Union Internationale de Chemins de Fer
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Code of Technical Standards

Ref. # or Org. Name	Part	Title	Date of Issue	RW-MSB	Functional Areas	Source/ Issuer	Trans. Status
734		Adaptation of railway signalling systems to meet the requirements of high speeds	07-01-86		401	UIC	FE
737-3		Use of thyristors in railway technology: measures for the prevention of functional disturbance in signalling installations	07-01-85		405	UIC	FE
737-4		Measures for limiting the disturbance of light current installations	07-01-86		405	UIC	FE
738E, 2nd Ed.		The more important safety conditions to be observed in the use of electronic components in railway signalling techniques	01-01-90		101	UIC	FE
965		Instructions governing the behavior and safety of staff working on the track	01-01-80		304,601,602	UIC	FE
966		Measures intended to promote safety-consciousness in staff	01-01-80		601,602	UIC	FE

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