U.S. Department of Transportation

Federal Railroad Administration

Locomotive Crashworthiness and Cab Working Conditions

Report to Congress

Office of Safety Assurance and Compliance **September 1996**

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THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

September 18, 1996

The Honorable Albert Gore, Jr.
President of the Senate
Washington, D.C. 20515

Dear Mr. President:

I am pleased to submit the enclosed report prepared by the Federal Railroad Administration (FRA) on "Locomotive Crashworthiness and Cab Working Conditions," as requested by the Rail Safety Enforcement and Review Act, Public Law 102-365. This report responds to the congressional mandate to report on issues related to:

- health and safety of locomotive cab working conditions;
- effectiveness of Association of American Railroads (AAR) Specification S-580; and
- benefits and cost of additional locomotive crashworthiness features.

The report summarizes the findings of FRA's study, which included research on locomotive crashworthiness features, extensive consultations with a wide range of interested parties; and a field survey of actual locomotive working conditions. These findings indicate that a number of the crashworthiness features and working condition improvements identified in the Act merit further action by FRA in cooperation with the private sector. Identified priority safety improvements include implementation of stronger collision posts and full height corner posts, incorporation of a crash refuge, improved fuel tank design, and improved methods to control noise and temperature levels inside the locomotive cab.

Consistent with FRA's emphasis on promoting a collaborative approach to railroad safety, FRA will seek the participation of railroads, employee representatives, manufacturers and suppliers, and other interested persons in determining the specific actions that may be appropriate to advance the safety and health of railroad crew members, based on the results of this study and other information that the parties may make available. FRA expects to refer locomotive crashworthiness issues to the newly constructed Railroad Safety Advisory Committee. That committee will make recommendations on the best course of action to implement the recommendations of this report, including voluntary initiatives, and regulatory standards where appropriate.

The U.S. rail industry has experienced significant growth over the past 15 years. The railroads are using larger, heavier locomotives which are more effective and efficient than the locomotives they are replacing. This growth has already been accompanied by some improvements in locomotive design and crew working conditions. I am confident that further improvements will be forthcoming if those most affected work together toward specific objectives that they participate in defining.

I look forward to working with the Congress to advance our shared objective of improving safety in the railroad industry.

An identifical letter has been sent to the Speaker of the House of Representatives.

Sincerely,

Federico Peña

Enclosure

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WASHINGTON, D.C. 20590

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Executive Summary

INTRODUCTION

The Rail Safety Enforcement and Review Act (RSERA) mandated that the Secretary of Transportation conduct a proceeding to determine the need for action on locomotive crashworthiness and cab working conditions. This mandate followed frequent expressions of concern by employee organizations, congressional members, and recommendations of the National Transportation Safety Board.

The Federal Railroad Administration (FRA) convened public conferences and listening sessions, surveyed actual working conditions through field observations on a significant number of locomotive assignments, conducted research and analysis, and developed engineering concepts for further consideration and refinement. As a result of these efforts, FRA finds that, while locomotive cab crashworthiness has been significantly improved through the adoption of new industry standards, additional improvements in crew protection can be realized—and must be pursued. Implementation of selected measures including, but not limited to stronger collision posts, full height corner posts, creation of a crash refuge, and improved fuel tank design appear to be feasible options for future engineering improvements. Although locomotive cab working conditions are steadily improving, FRA finds that additional steps are warranted to safeguard the safety and health of crew members.

Recent accidents, both in the freight and commuter rail operating environments, have prompted a renewed interest and stimulated a heightened public awareness concerning locomotive design, crashworthiness, and railroad operating practices, and their associated roles in these accidents. This report addresses many of the specific issues that have been raised during the ongoing investigations of these accidents, and clearly establishes that alternatives for improvement exist and should be evaluated. FRA calls for a collaborative effort by rail labor, the railroad companies, the rail supply industry, and government to fully exploit the opportunities for further progress that are documented in this report.

THE STUDY

In September 1992, as a part of RSERA (Public Law 102-365), Congress required the Secretary of Transportation to conduct an inquiry into locomotive crashworthiness and the safety effects of locomotive cab working conditions on productivity. The Act required an investigation of health and safety working conditions in locomotive cabs, an evaluation of the adequacy of the Association of American Railroads (AAR) Locomotive Crashworthiness Requirement Specification S-580, and consideration of the benefits and cost of implementing additional locomotive crashworthiness features.

On behalf of the Secretary, FRA conducted an inquiry which included: discussions with rail management, labor, and suppliers; creation of a locomotive collision data base; development and validation of a computer model to predict the results of locomotive collisions; conceptual implementation of each of the crashworthiness features listed in the Public Law into the design of a locomotive; use of a computer model to predict the benefits of each crashworthiness feature listed in the public law; conduct of a field survey of working conditions—including temperature and noise measurements of cab air quality made in both lead and trailing locomotives of trains traversing the Cascade Tunnel; and review of human factors (ergonomic) guidelines for the evaluation of locomotive cabs.

FRA recommends that promising safety measures identified by this report be further developed in active consultation with all of FRA's customers.

LOCOMOTIVE CRASHWORTHINESS

FRA determined that AAR Specification S-580—which provides for improvements in collision posts, anticlimbing arrangements and other safety features—represents a significant step on the part of the railroad industry to improve crashworthiness. Research and analysis shows that AAR S-580 can be further improved to reduce causalities without significantly impacting locomotive design. Modifying front-end structural design to incorporate stronger collision posts, full height corner posts with increased strength, and utilization of roof longitudinal strength to support structural members from crushing may provide opportunities for additional protection for crew members. The potential exists to create a designated crash refuge within the space that these measures would help to protect. FRA believes that fuel tank design can be significantly improved to minimize the number and severity of future fuel spills from locomotives based on accident/incident experience with respect to the nature, location, and cause of fuel tank ruptures and recent advances in fuel tank design being undertaken by the industry. Additional concepts that appear to warrant further exploration include cab emergency lighting and more reliable means of rapid egress during derailments and collisions.

Concurrent with the efforts of the research program undertaken to respond to this Congressional mandate, FRA worked in partnership with Amtrak in the development of their design specification for the High Speed Trainset, specifically in the areas of safety and crashworthiness design. During this effort, FRA and Amtrak jointly developed minimum design parameters for the High Speed Trainset relating to locomotive cab crashworthiness and cab survivability that addressed features not specified for evaluation in the Congressional mandate—most notably, crash energy management. Crash energy management is a design technique in which a structure, such as a locomotive, is designed to crush and absorb energy in a controlled manner by "zones" when subjected to significant end loads in a collision. Designated sections in unoccupied spaces or lightly occupied spaces are intentionally designed to be weaker than heavily occupied spaces so that during a collision, portions of the unoccupied spaces will deform before the occupied spaces. This allows the occupied spaces of the locomotive initially to decelerate more slowly and minimize the uncontrolled deformation of occupied space. Modeling has shown that implementation of crash energy management design techniques offers significant benefits with respect to occupant survivability in the event of a collision. Amtrak incorporated such requirements in their procurement specification for the High Speed Trainset.

FRA also evaluated the crashworthiness of control cab cars used in commuter services. This evaluation clearly demonstrated that, in a head-on or offset collision with a freight locomotive, the control cab car experiences a significant loss of survivable space due to crushing at very low closing speeds. Further modeling shows that substantial increases in the strength of the control cab car structure yield only small improvements in protection of the crew in the case of a cab car-leading train-to-train collision. However, improvements in corner post strength warrant further exploration as a means to mitigate accidents at lower speeds or with objects of lesser mass, such as highway vehicles.

While this report details a number of specific safety features which would markedly improve locomotive crashworthiness, other initiatives would not yield the same positive benefits. After careful study, FRA recommends not pursuing further action on rollover protection, deflection plates, and uniform sill heights. Rollover protection costs would be substantial, and no material need for such protection is demonstrated by the accident data. Deflection plates cannot be designed to function practically within the design limitations of multi-use freight locomotives, and a successful deflection device would cause collateral safety problems. Uniform sill heights would not significantly reduce life threatening crash damage, would have a high cost, and any benefit would accrue only after an extended period which older standard locomotives would retire. The perceived benefits of uniform sill height might be more reliably achieved by improved anticlimbing arrangements, and this report proposes that development and evaluation of a design concept be explored.

Many of the proposed measures are practical for application only to newly constructed locomotives. Further, additional information and research is required to determine the cost-effective basis of these concepts, and the acceptance of these measures by locomotive crews. Crew members must have confidence in whatever protection is provided, rather than jumping from the locomotive which results in certain injury and possible death.

LOCOMOTIVE CAB WORKING CONDITIONS

FRA conducted a nationwide, 2-year study into the working conditions of locomotive crews. The investigation encompassed over 200 locomotives belonging to 13 Class 1 Freight Railroads and Amtrak. The study found that locomotive cab working conditions need improvement. Considerations of the report included crew hours, cab temperature, cab noise, cab air quality, cab sanitary facilities, cab ergonomics, and cab vibration.

The study found temperatures varied greatly, from 30 to 120 °F. During summer months, crews are required to work for long periods of time in an environment that would be expected to accelerate fatigue. Cab temperatures were greater than outside temperatures due to heat from the engine. Railroads and operational employees recognize that this environment is far from optimal, and efforts to alter the designs of new locomotives to prevent fatigue persist. In extreme hot weather, temperatures in a locomotive cab reach levels associated with the risk of heat exhaustion and reduced crew performance. High temperatures also cause train crews to open windows, which increases noise exposure and partially obviates the benefit of safety glazing. Current mandates require protection from excessively low temperatures. However, FRA's in-cab requirement of 50 °F is much lower than U.S. Military guidelines and other accepted standards.

FRA employed state-of-the-art electronic measurement equipment aboard approximately 350 locomotive assignments to conduct a noise survey. The noise level in many locomotives was sufficiently high to interfere with normal voice communication. A significant minority of locomotive cabs had noise levels high enough to contribute to long-term hearing loss after long-term repetitive exposure, and in the absence of personal protective equipment. Some companies have implemented rules requiring hearing protection and have instituted hearing conservation programs. However, these are not universal in the industry, and increased attention to the issue is warranted during the phase-in period of newer locomotives with quieter cabs.

Sanitary facilities in many locomotives are in deplorable condition. The industry needs to improve these conditions.

Other issues were identified that could potentially affect crew performance, and include vibration and ergonomic cab design. Continued attention to the maintenance of equipment, and engineering innovations for new locomotives, can offer assurance that these issues will be successfully addressed.

FRA's investigation does not indicate that locomotive crews are subject to any risk of exposure to airborne asbestos contamination. Modern locomotives are built without the use of asbestos. In older units, asbestos is believed to be limited to components housed in engine compartments and encapsulated in a manner not presenting a risk to operating employees. FRA will continue to respond to any concerns related by individual locomotive series, though prior complaint investigations have not indicated the presence of asbestos in the cab.

FRA's investigation was unable to determine—in any quantitative way—the effect of adverse locomotive working conditions, such as noise, temperature, vibration, or sanitary conditions on the productivity of crew members. However, it is reasonable to infer from the study findings and available literature that extreme conditions encountered in some locomotive assignments can adversely impact crew performance, and accordingly must be addressed to improve safety.

FINDINGS AND IMPLEMENTATION STRATEGY

Based on the study findings, several issues bearing on locomotive crashworthiness and working conditions clearly warrant further exploration. Responses to the findings of this inquiry will reflect the nature of the opportunity for further risk reduction, the ability of government to positively influence the subject matter, and the extent to which private parties initiate responsive action of their own. However, the findings also indicate the areas of uniform sill heights, deflection plates, and crew asbestos exposure do not warrant further action.

FRA will pursue opportunities for safety improvement in partnership with its customers. Since 1993, FRA has been taking action to promote earlier and more extensive participation by all interested parties in the agency's regulatory processes. In 1993, the Administrator initiated a series of roundtables on all aspects of FRA's safety program. In 1994, FRA initiated its first formal negotiated rulemaking on roadway worker safety.

During the same period that this study has been concluded, FRA has conducted outreach and a review of its regulatory program under the President's Regulatory Reinvention Initiative and the National Performance Review. FRA concluded that railroad safety will be best served if the agency moves from a traditional "hear and decide" regulatory paradigm to a new paradigm that is founded on consensus among those who are benefitted and burdened by the agency's regulations.

Implicit in this "paradigm shift" is the concept that decisions regarding the best approach to resolution of safety issues should be made with the full participation of all affected parties. Although FRA has included affected parties in the factfinding portion of this report, and has invited comment on the engineering research reported within these covers, this document is a status report regarding an ongoing activity. Accordingly, it contains some information and analysis not previously shared with interested parties. Dissemination of this report will set the stage for further conversation that will inform public and private actions over the next few years.

In order to promote productive conversation among interested persons, FRA has sought to avoid unilateral declarations that might create polarization and chill dialogue regarding appropriate options. However, where our study findings indicate that particular measures are clearly impractical or ineffective, we have so stated. By separating potentially helpful ideas from those that will not bear close scrutiny, we seek to focus future discussions on those measures that offer real promise for risk reduction.

FRA has established a Railroad Safety Advisory Committee (RSAC), which will provide a forum for consensual rulemaking and program development. The Committee includes representation from all of the agency's major customer groups, including railroads, labor organizations, suppliers and manufacturers, and other interested parties. FRA intends to task the Committee with consideration of the major issues identified in this report. Through appropriate working groups, the Committee will evaluate the results of this study, determine what additional facts or analysis may be required, consider relevant benefits and costs of alternative actions, and recommend an appropriate approach to address each area of concern. That action may take the form of continued implementation of existing measures, voluntary initiatives by individual parties, concerted voluntary initiatives by several parties, amendments to existing regulations, or new regulatory requirements, as appropriate.

ACTION PLAN

FRA will refer the issues identified in this report to the RSAC for consideration. The Committee will be asked to fashion a strategy with milestones for advancing locomotive crashworthiness and cab working conditions. Approaches to improved locomotive crashworthiness and cab working conditions may include cooperative projects involving the industry parties and FRA, development of voluntary industry standards, issuance of new or revised regulations, and further research. Through RSAC and other cooperative forums, FRA and our partners will identify the most useful approaches to meet particular needs and opportunities.

Next steps to advance resolution of these issues are as follows:

- o Disseminate report and seek initial action proposals from RSAC members.
- o Request that RSAC establish an informal working group to review and recommend actions and milestones for implementation, as appropriate, of recommendations identified in this report (done at July 1996 RSAC meeting).
- o Receive and act on recommendations for actions and milestones (October 1996).
- o Implement recommended actions according to the timetable determined with RSAC participation.
- o Initiate or complete research and development to:
    - improve and validate the analytical methods used in the study;
    - investigate the effectiveness of interlocking anticlimber designs, and
    - publish guidelines for the cab working environment.

The Mandate

Section 10 of the Rail Safety Enforcement and Review Act (Public Law 102-365; September 3, 1992), entitled "Locomotive Crashworthiness and Working Conditions," provides as follows:

Section 202 of the Federal Railroad Safety Act of 1970 (45 U.S.C 431), as amended by this Act, is further amended by adding the following new subsection:

"(t) LOCOMOTIVE CRASHWORTHINESS AND WORKING CONDITIONS.--

"(1) The Secretary shall, within 30 months after the date of enactment of this subsection, complete a rulemaking proceeding to consider prescribing regulations to improve the safety and working conditions of locomotive cabs. Such a proceeding shall assess--

"(A) the adequacy of Locomotive Crashworthiness Requirements Standard S-580, or any successor standard thereto, adopted by the Association of American Railroads in 1989, in improving the safety of locomotive cabs; and

"(B) the extent to which environmental, sanitary and other working conditions in locomotive cabs affect productivity, health and the safe operation of locomotives.

"(2) In support of the proceeding required under paragraph (1), the Secretary shall conduct research and analysis, including computer modelling and full scale crash testing, as appropriate, to consider--

"(A) the costs and benefits associated with equipping locomotives with--

"(i) braced collision posts;

"(ii) rollover protection devices;

"(iii) deflection plates;

"(iv) shatterproof windows;

"(v) readily accessible crash refuges;

"(vi) uniform sill heights;

"(vii) anticlimbers, or other equipment designed to prevent overrides resulting from head-on locomotive collisions;

"(viii) equipment to deter post-collision entry of flammable liquids into locomotive cabs;

"(ix) any other devices intended to provide crash protection for occupants of locomotive cabs; and

"(x) functioning and regularly maintained sanitary facilities; and

"(B) the effects on train crews of the presence of asbestos in locomotive components.

"(3) If on the basis of the preceding required under paragraph (1) the Secretary determines not to prescribe regulations, the Secretary shall report to Congress on the reasons for that determination".

CHAPTER 1

Introduction

In response to the mandate of Section 10 of Public Law 102-365, the Federal Railroad Administration (FRA) prepared a plan of action and milestones for the research and analysis necessary to determine (a) the health and safety effects of locomotive cab working conditions, (b) the effectiveness of Association of American Railroads (AAR) Specification S-580, and (c) the benefits and costs of additional locomotive crashworthiness features. In an effort to fully address the broad range of issues presented in the Act, FRA outlined a multi-faceted approach that included the following:

- *conduct of an industry-wide public meeting to gather information from all segments of the industry regarding the areas of concern identified in the Act;*
- *establishment of a comprehensive locomotive collision data base based on detailed accident information gathered during actual collisions;*
- *establishment of a research contract to develop and verify a computer model capable of predicting how each of the crashworthiness features in AAR S-580 and in the Act affect the collision dynamics and probability of crew injury; and*
- *conduct of a detailed survey of the locomotive crew's cab working conditions and environment.*

This report presents the results of the above research and analysis on locomotive crashworthiness and locomotive cab working conditions, and lays out an implementation strategy to address each of the issues raised by the Act.

In response to the mandate of Section 10 of Public Law 102-365, the Federal Railroad Administration (FRA) prepared a plan of action and milestones for the research and analysis necessary to determine:

- health and safety effects of locomotive cab working conditions;
- effectiveness of Association of American Railroads (AAR) Specification S-580; and
- benefits and cost of additional locomotive crashworthiness features.

The research and analysis done focuses on the cost and benefits of changes to conventional locomotives operating at speeds of less than 80 mph. The work done to meet the requirements of the Act is not intended to address safety concerns unique to high speed rail transportation. FRA addresses high speed rail safety concerns through a cooperative effort with Amtrak to procure high speed trainsets and through the development of a set of high speed passenger trainset safety standards.

The Starting Point

As part of the information gathering process to prepare the research and analysis plan, FRA determined that the following factors needed to be considered at the outset of the effort:

- Very little quantitative information has been recorded on the effect of cab working conditions on crew health or productivity.

- Accident/incident statistics do not explicitly show cab working conditions to be the cause of, or a contributing factor to railroad accidents.

- Efforts to correlate the working environment to health or productivity in other industries invariably resulted in qualitative rather than quantitative links that lead to wide interpretation and controversy.

- Current FRA research budgets are limited and will not support the cost of full scale crash locomotive testing as contemplated by the Act.

- Analysis by computer modeling and small scale component tests will be the only means available to predict the benefits and costs of the locomotive crashworthiness features enumerated in the Act.

- Past accident investigations and reports of locomotive collisions do not contain the precise information necessary for the accident to be used as a validation scenario for a computer model to predict the results of locomotive collisions.

- A widely accepted, validated analysis tool (computer model) to predict the results of locomotive collisions based on input parameters characterizing the collision must be developed.

- Research done by the automobile industry on the motion of the human body and the injuries caused by impact have the potential to be adapted to predict injuries to crew members in a locomotive cab.

- To predict the benefits and costs of the crashworthiness features listed in the Act, requires each of the features to be conceptually designed into the structure of an existing locomotive and then the locomotive must be subjected to one or more computer modeled collision scenarios with and without the crashworthiness feature included in the design.

The Plan

The plan FRA developed to comply with the Act includes several-time consuming tasks needed to build the data base and the tools necessary to perform the in-depth analysis required to predict costs and benefits. The need to build the data base and the analysis tools, and the need to stretch out limited research budgets and limited FRA resources forced FRA to develop a plan that meets the intent, but not the schedule, required by the Act.

FRA planned a two-phase effort. This report is the culmination of the first, or research and analysis phase. The plan laid out in Figure 1.1 shows that FRA completed the detailed research and analysis phase within the 30-month schedule mandated by the Act. Drafting and approval of the report, which addresses each issue raised by the Act and additional safety concerns identified by FRA, extended beyond the 30-month schedule.

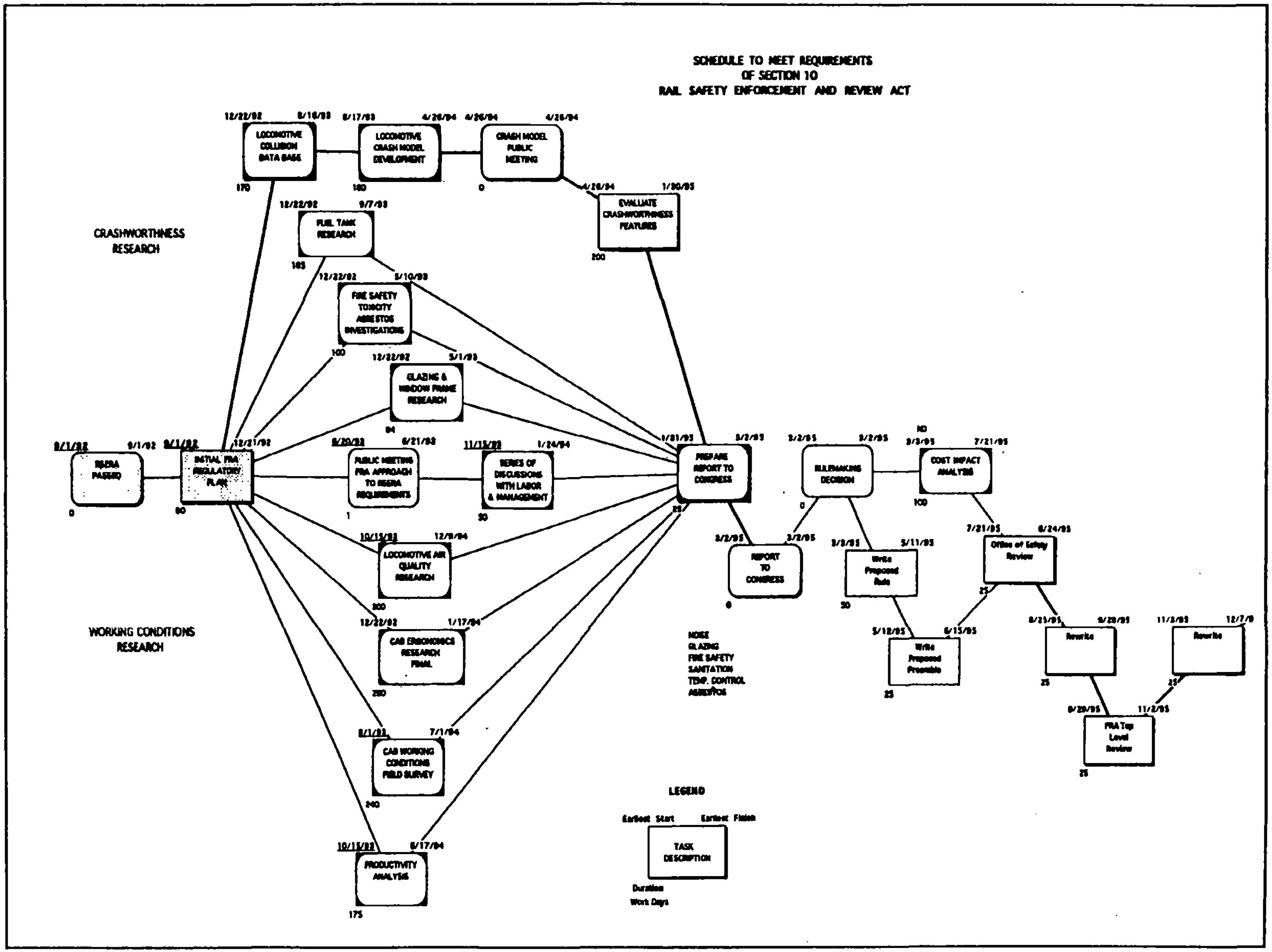
As noted in the Executive Summary, FRA has determined that further development of these issues can best be managed within a very inclusive consensus process that taps the knowledge and energies of a wide range of interested parties. Acting through a new Railroad Safety Advisory Committee, FRA and these customer groups will chart a program for completion of the work contemplated by the Congress. The results of the research and analysis phase forms the foundation for the second—rulemaking and guideline development—phase of the effort.

This report gives a plan and description of the rulemaking and guideline phase in Chapter 12.

As shown in Figure 1.1, the research and analysis follows two separate paths, one for cab working conditions and one for locomotive crashworthiness. The main body of this report to Congress is organized along these lines; it reports—in separate chapters—the results of the research and analysis on locomotive crashworthiness and on locomotive cab working conditions.

Railroad Industry Meetings

Meetings with all segments of the railroad industry formed an essential part of FRA's plan to meet the requirements of the Act. FRA held an industry wide-public meeting on June 23, 1993 to gather information from the industry on each of the areas of concern identified in Section 10 of the Act and to inform the industry of FRA's approach. This meeting was well attended by all segments of the rail industry, including rail labor, freight railroads, locomotive builders, Amtrak and commuter railroads.


SCHEDULE TO MEET REQUIREMENTS
OF SECTION 10
RAIL SAFETY ENFORCEMENT AND REVIEW ACT
CRASHWORTHINESS
RESEARCH
WORKING CONDITIONS
RESEARCH
RSERA
PASSED
INITIAL FRA
REGULATORY
PLAN
LOCOMOTIVE
COLLISION
DATA BASE
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CRASH MODEL
DEVELOPMENT
CRASH MODEL
PUBLIC
MEETING
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CRASHWORTHINESS
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CAB ERGONOMICS
RESEARCH
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COST IMPACT
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Office of Safety
Review
Rewrite
Rewrite
FRA Top
Level
Review
NOISE
GLAZING
FIRE SAFETY
SANITATION
TEMP. CONTROL
ASBESTOS
LEGEND
Earliest Start
Earliest Finish
TASK
DESCRIPTION
Duration
Work Days

Figure 1.1

1-4

Rail labor emphasized the importance of improved working conditions within the cab. Rail management argued that cab working conditions are not a safety issue and that improvements in crash avoidance technology should be pursued in lieu of improved crashworthiness features. Amtrak and commuter railroads expressed their desire to discuss their views in a smaller forum not dominated by freight railroads.

Several participants in the public meeting expressed an opinion that a series of smaller, informal meetings with the separate segments of the rail industry would provide more detailed information regarding locomotive crashworthiness and cab working conditions. As a result, FRA held such meetings with the following organizations:

- General Electric Company (GE);
- Electromotive Division of General Motors (EMD);
- Morrison Knudsen (MK);
- E.I. Dupont De Nemours and Company (glazing);
- Sierracin Transtech (glazing);
- Amtrak;
- Brotherhood of Locomotive Engineers (BLE);
- United Transportation Union (UTU);
- Association of American Railroads (AAR);
- American Short Line Railroad Association (ASLRA);
- American Public Transit Association (APTA); and
- Burlington Northern (BN).

These meetings generated considerable discussion about the topics listed in Section 10 of the Act. During the meetings, FRA requested specific cost or test data to support the positions taken by the various organizations. Some supply industry organizations were forthcoming with this data, while other organizations were apparently unable or unwilling to respond.

The industry representatives provided several recommendations regarding locomotive crashworthiness and cab working conditions including:

- Several segments of the industry expressed concern over the adequacy of current glazing requirements. Specific concerns included a perceived need to improve the anti-spalling characteristics of glazing and to test the glazing and its frame as a system. The current glazing standards allow glazing manufacturers to do a one-time test of their own products to ensure compliance with FRA rules. The industry questioned the wisdom of this practice. Several organizations recommended that all glazing manufacturers be required to periodically have an independent testing organization recertify their products. For front facing glazing, the concept of adopting a multi-tiered glazing standard based on train speed is generally accepted within the industry.

- Labor organizations strongly emphasized the potential for adverse cab working conditions to cause medical damage to crew members. In their view, improvements in cab working conditions should be an immediate and high priority effort. Specifically, labor identified the inclusion of, or improvements in cab air conditioning systems as a primary concern with respect to the safety and health of locomotive crews. Direct anticipated benefits of cab air conditioning include increased protection from airborne objects, improved cab air quality, and reduced cab noise levels.

- Further, reduced noise levels in the cab directly impact communications between crew members and dispatchers, increasing the probability of receipt and correct execution of instructions. Labor organizations also believe that cab air conditioning could significantly reduce the number of medical claims relating to hearing damage that constitute a large financial expense to many railroads. Other safety benefits which are not easily quantified may be derived from improved cab working conditions, such as reduced stress and increased attentiveness of the crew resulting from a more comfortable working environment.

- Locomotive manufacturers currently offer higher quality, more reliable air conditioning systems as options on new locomotives. As a matter of policy, many major railroads are now procuring new locomotives with these systems. Manufacturers estimate that more than 50 percent of new locomotives are currently ordered with air conditioning. Maintenance of these units is a major problem, but is improving.

- Locomotive manufacturers fear design solutions will be legislated in response to the list of crashworthiness features contained in Section 10 of the Act. The builders strongly prefer that any new regulations identify performance parameters which define a measure of when a design solution is adequate, while leaving the specific design solution to the discretion of the designer. The manufacturers offered no specific suggestions for the type performance requirements that they favor.

FRA held a second public meeting in August 1994 to present the preliminary results of the locomotive crashworthiness computer model development effort to the industry. Arthur D. Little Inc. briefed industry representatives on how they put the model together, locomotive collision scenarios used to validate the model, a comparison of results of a collision predicted by the model to results of real collisions and preliminary computer predictions of the effectiveness of crashworthiness features added to the design of the locomotive. Industry representatives asked questions but had little reaction—either supportive or critical—of the work done or methods used.

Definitions

Confusion over the meaning of terms used in the Act and used to describe locomotive crashworthiness and working conditions arose during the meetings with industry organizations. To help alleviate this problem, Appendix A gives definitions of terms used in this report that may be unclear or subject to more than one interpretation.

Locomotive Collision Data Base

To compensate for the fact that earlier locomotive collision accident reports did not contain the data necessary to support crash modeling, in December 1992 FRA instructed field inspectors to investigate—without regard to monetary damage thresholds—all accidents involving either a collision of two trains or a collision of one train with an object weighing ten tons or more. FRA placed special emphasis on the investigation of accidents involving trains including one or more locomotive(s) that comply with AAR Specification S-580. These locomotives—built after August 1, 1990—are equipped with some of the crashworthiness features that are of Congressional interest. For comparison purposes, accidents assigned for investigation by FRA involving only locomotives built prior to specification S-580 taking effect that meet the collision of two trains or collision of one train with a ten ton or greater object criteria are also included as part of this data collection survey.

Locomotive collisions provide an unfortunate target of opportunity to partially compensate for the inability to perform full-scale locomotive crash tests. Detailed full-scale crash information is required to determine the effectiveness of AAR Specification S-580 and to validate computer models that predict the results of locomotive collisions. FRA accident investigators collected and documented detailed information, including photographs, on the results of over 30 accidents involving collisions of locomotives. The results focused on the parameters of the collision, the damage to the locomotives involved and the circumstances and extent of injuries to crew members. Chapter 2 reports the detailed analysis of these accidents.

Locomotive Crashworthiness Research Contract

Through the Volpe National Transportation System Center (VNTSC), FRA contracted with Arthur D. Little Inc. (ADL) to predict the benefit, if any, of each of the locomotive crashworthiness features listed in Section 10 of the Act in providing additional protection to personnel in locomotive cabs under realistic collision conditions. The contract called for ADL to approach the problem in the following steps or tasks:

- o Analyze the data compiled for each accident reported for entry to the data base taking into account the dynamics of each situation to estimate:
  - the total energy of the collision;
  - how the energy was dissipated;
  - the peak forces reached in the control cab area;
  - how and why structural damage occurred;
  - how and why crew members were injured; and
  - what existing features provided crew protection, and how.
- o Use the analysis of the collision data to develop a computer model to correlate crew injury probability to the dynamic parameters of the collision. The model should avoid unnecessary complexity to make first order predictions on how changes to the locomotive structure change the dynamics of the collision and thus affect the probability of crew injury.
- o Verify the computer model by using it to predict the results of accidents contained in the data base. Compare the computer prediction to the real data. Adjust the parameters of the model to make the predictions as accurate as possible.
- o Use the model to predict how each of the locomotive crashworthiness requirements of American Association of Railroads (AAR) Specification S-580 affects the collision dynamics and probability of crew injury.
- o Determine a means to conceptually implement each of the locomotive crashworthiness features listed in section 10 of the "Rail Safety Enforcement Act" into the design of a locomotive including an estimate of the cost of implementation.

- o Use the model to predict how each of the locomotive crashworthiness features listed in Section 10 of the "Rail Safety Enforcement Act" affects the collision dynamics and probability of crew casualties.

- o Estimate the cost of implementation of each crashworthiness feature.

Chapter 3 reports the details of the procedures used for and the results of each these tasks. Chapter 3 also explains how National Transportation Safety Board (NTSB) recommendations concerning locomotive fuel tanks, locomotive crash refuges and locomotive corner posts are addressed by the locomotive crashworthiness research.

Locomotive Cab Working Conditions

FRA planned a detailed survey of the locomotive crew's cab working conditions and environment to meet the requirements of the Act. FRA inspectors travelled for long periods of time aboard more than 230 locomotives, under a variety of ambient environmental conditions, making observations and taking measurements to determine if working conditions impair the crews':

- o vigilance;
- o coordination;
- o timing behavior;
- o visual perception;
- o cognitive functions;
- o speech or ability to communicate;
- o hearing; or
- o ability to operate the locomotive safely.

The locomotive cab working conditions survey draws on field data and information gathered by field professionals, and sources within the railroad and railroad supplier industries. During the past five years, FRA investigated more than 100 complaints alleging poor locomotive working conditions and received reports of several thousand injuries or illnesses caused by locomotive cab working conditions. Chapter 4 presents this data and reports the details of the procedures used for, and the results of, these locomotive working condition surveys.

The meanings of the cab working conditions survey results and the conclusions drawn by FRA from the results are discussed by individual working condition factor or effect in the following chapters of this report:

- Cab Temperature - Chapter 5
- Cab Noise Level - Chapter 6
- Cab Air Quality - Chapter 7
- Cab Sanitary Facilities - Chapter 8
- Cab Layout (Ergonomics) - Chapter 9
- Other Factors Affecting Cab Working Conditions - Chapter 10
- Effect of Cab Working Conditions on Locomotive Productivity - Chapter 11

Chapter 12 summarizes FRA findings and lays out an implementation strategy to address each of the crashworthiness features and working condition improvements covered by the Act. Additional supporting information and suggested guidelines for industry action are given in appendices to this report.

CHAPTER 2

Locomotive Collision Data

Prior to enactment of RSERA, the collision data base used by FRA was not designed to fully support locomotive crashworthiness analysis, and shortcomings in this data base made it impossible to accurately evaluate the effectiveness of the crashworthiness features identified by Congress. As a result, FRA developed a group of accident report forms to be used as a guide by accident investigators to collect the necessary information relating to locomotive crashworthiness and associated parameters following a collision. FRA accident investigators provided 30 complete reports for inclusion in the locomotive crashworthiness data base used for this report.

As the locomotive crashworthiness data base established in response to RSERA described above is very limited in scope, FRA also researched trends in train collisions and associated fatalities and injuries to railroad personnel over the 10-year period covering 1983 to 1992.

Establish Collision Data Base

Following the enactment of Public Law 102-365, the Rail Safety Enforcement and Review Act (RSERA), the Federal Railroad Administration (FRA) initiated an effort to develop a detailed data base containing information relating to locomotive crashworthiness acquired from investigations of train collisions. Locomotive collisions provide an unfortunate target of opportunity to collect full-scale crash information. Of particular interest were collisions involving locomotives built after August 1, 1990. These locomotives comply with the Association of American Railroads (AAR) Specification S-580 (see Appendix B), which calls for some of the same crashworthiness features specifically addressed by the Act.

FRA directed its inspectors to investigate—without regard to monetary damage thresholds[1]—all collisions involving either (a) two trains, or (b) one train with an object weighing ten tons or more, having one or more locomotives built in compliance with AAR S-580. In an effort to ascertain the effectiveness of AAR S-580, FRA also investigated collisions involving locomotives built prior to S-580 that met the above criteria.

[1]Typically, a railroad company must report all accidents involving on-track equipment resulting in $6300 or more damage to railroad property to the FRA. Reportable damages include the cost of labor and the cost of repairing (or replacing in kind) damaged on-track equipment, track, track structures, or roadbed.

FRA developed a group of accident report forms to be used as a guide by the accident investigators to collect information relating to locomotive crashworthiness. FRA instructed accident investigators to record all required information on these forms, take photographs of the collision site, and comment on the perceived effectiveness (or lack thereof) of crashworthiness features included on the locomotives involved in the collision. Figures 2.1 through 2.3 illustrate the Locomotive Crashworthiness Data Collection Forms provided to the investigators.

The data base used by FRA prior to the creation of the data base described above was not designed to fully support locomotive crashworthiness analysis. Numerous key collision parameters were not included, the description of structural damage to the locomotives was incomplete, and the injury and fatality data included passengers. These shortcomings in the prior data base had to be corrected to evaluate the crashworthiness features specified by Congress.

Analysis of Data Base

FRA accident investigators provided 30 complete reports for inclusion in the locomotive crashworthiness data base for this report. These accidents have been divided into five distinct groupings by accident type as follows:

- head-on collisions involving two trains—with both trains in motion at impact;
- head-on collisions involving two trains—with one train stationary at impact;
- rear end collisions involving two trains;
- head-on collisions with one train and another vehicle at a highway-rail grade crossing; and
- collisions of two trains at a railroad grade crossing.

Table 2-1 summarizes the collisions included in the data base.

ACCIDENTS INVOLVING ONE TRAIN
(Form A)

FRA INSPECTOR:	A1:	LOCATION OF ACCIDENT:	A2:
DATE OF ACCIDENT:	A3:	DATE OF INVESTIGATION:	A4:

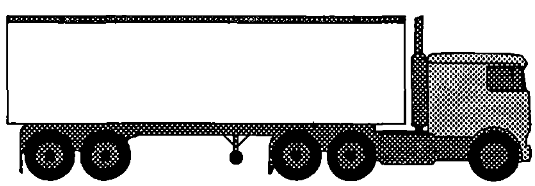
Operating Railroad:	A5:	Type Train: (Pass., Coal, Grain, etc)	A6:
Tonnage Including Locos:	A7:	Number of Cars:	A8:
Slack Action***:	A9:	Direction of Travel:	A10:
Speed at Impact:	A11:	Track Curvature:	A12:
Track Grade: (% Ascend/Descend)	A13:	Type Collision: (Head-On, Side, Rear)	A14:
Total Number of Locos:	A15:	Number of Crashworthy* Locos:	A16:

	ID Number	Built Date:	Manufacturer	Model or Type	Crashworthy*	Damaged**	Operating Direction
Lead Loco	A17:	A18:	A19:	A20:	A21: Yes No	A22: Yes No	A23: Forward Reverse
Second Loco.	A24:	A25:	A26:	A27:	A28: Yes No	A29: Yes No	A30: Forward Reverse
Third Loco.	A31:	A32:	A33:	A34:	A35: Yes No	A36: Yes No	A37: Forward Reverse
Fourth Loco.	A38:	A39:	A40:	A41:	A42: Yes No	A43: Yes No	A44: Forward Reverse
Fifth Loco.	A45:	A46:	A47:	A48:	A49: Yes No	A50: Yes No	A51: Forward Reverse

* Crashworthy means Locmotives Built in Accordance with AAR Specification S580

** Complete a separate Summary of Locomotive Damage form for each damaged Locomotive.

*** Slack Action is the total change in length of the train from compression to tension.



OBJECT OF COLLISION

Type Object:	A52:	Weight:	A53:
Direction of Travel:	A54:	Speed at Impact:	A53:
Distance Moved by Train:	A56:		

Figure 2.1

ACCIDENTS INVOLVING TWO TRAINS

(FORM B)

FRA INSPECTOR NO.: B1:

LOCATION OF ACCIDENT:[1] B2:

DATE OF ACCIDENT: B3:

DATE OF INVESTIGATION: B4:

First Train

Operating Railroad:[1] B5:

Type Train: (Pass., Coal, Grain, etc) B6:

Tonnage Including Locos: B7:

Number of Cars: B8:

Slack Action***: B9:

Direction of Travel:[1] B10:

Speed at Impact:[1] B11:

Track Curvature:[1] B12:

Track Grade:[1] (% Ascend/Descend) B13:

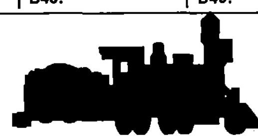
Type Collision:[1] (Head-On, Side, Rear) B14:

Total Number of Locos: B15:

Number of Crashworthy* Locos: B16:

	ID Number	Built Date:	Manufacturer	Model or Type	Crashworthy*	Damaged**	Operating Direction:****
Lead Loco	B17:	B18:	B19:	B20:	B21: Yes No	B22: Yes No	B23: Forward Reverse
Second Loco.	B24:	B25:	B26:	B27:	B28: Yes No	B29: Yes No	B30: Forward Reverse
Third Loco.	B31:	B32:	B33:	B34:	B35: Yes No	B36: Yes No	B37: Forward Reverse
Fourth Loco.	B38:	B39:	B40:	B41:	B42: Yes No	B43: Yes No	B44: Forward Reverse
Fifth Loco.	B45:	B46:	B47:	B48:	B49: Yes No	B50: Yes No	B51: Forward Reverse

Second Train



Operating Railroad:[1] B52:

Type Train: (Pass., Coal, Grain, etc) B53:

Tonnage Including Locos: B54:

Number of Cars: B55:

Slack Action***: B56:

Direction of Travel:[1] B57:

Speed at Impact:[1] B58:

Track Curvature:[1] B59:

Track Grade:[1] (% Ascend/Descend) B60:

Type Collision:[1] (Head-On, Side, Rear) B61:

Total Number of Locos: B62:

Number of Crashworthy* Locos: B63:

	ID Number	Built Date:	Manufacturer	Model or Type	Crashworthy*	Damaged**	Operating Direction:****
Lead Loco	B64:	B65:	B66:	B67:	B68: Yes No	B69: Yes No	B70: Forward Reverse
Second Loco.	B71:	B72:	B73:	B74:	B75: Yes No	B76: Yes No	B77: Forward Reverse
Third Loco.	B78:	B79:	B80:	B81:	B82: Yes No	B83: Yes No	B84: Forward Reverse
Fourth Loco.	B85:	B86:	B87:	B88:	B89: Yes No	B90: Yes No	B91: Forward Reverse
Fifth Loco.	B92:	B93:	B94:	B95:	B96: Yes No	B97: Yes No	B98: Forward Reverse

* Crashworthy means Locmotives Built in Accordance with AAR Specification S580

** Complete a separate Summary of Locomotive Damage form for each damaged Locomotive.

*** Slack Action is the total change in length of the train from compression to tension.

**** Forward means the normal or short hood end of the locomotive is leading. Reverse mans the long hood end is leading.

1 Use same codes as Accident/Incident Report or Inspection Report.

Figure 2.2

SUMMARY OF LOCOMOTIVE DAMAGE
(FORM C)
(Complete one summary form for each locomotive damaged in the accident.)

Locomotive ID No.: C1: ____ **Type:** C2: ____ **Manufacturer:** C3: ____ **Built Date:** C4: ____ **Crashworthy*?:** C5: Yes No

	CIRCLE	DESCRIPTION	Photo Numbers
C6: Short End Facing Damage	C7: None Moderate Slight Extensive	C8: Describe Damage:	C9:
C10: Collision Post Damage	C11: None Moderate Slight Extensive	C12: Describe Damage:	C13:
C14: Control Cab Damage	C15: None Moderate Slight Extensive	C16: Describe Damage:	C17:
C18: Glazing Damage	C19: End Facing	C21: None Cracked Shattered Spalled Caused Injury	C23:
	C20: Side Facing	C22: None Cracked Shattered Spalled Caused Injury	
C24: Sill Height	C25: Uniform Not Uniform	C26: Damage Due to Non-Uniform Sills:	C27:
C28: Did Over Ride Occur?	C29: Yes No	C30: Describe Role Anti-Climbers Played:	C31:
C32: Did Rollover Occur?	C33: Yes No	C34: Describe Damage Due to Rollover:	C35:
C36: Did Side Impact Occur	C37: Yes No	C38: Describe Damage Due to Side Impact:	C39:
C40: Did a Fuel Tank Rupture?	C41: Yes No	C42: Fuel Tank Capacity & Extent of Spill:	C43:
C44: Did a flammable liquid Other than fuel spill?	C45: Yes No	C46: Fluid Spilled & Extent of Spill:	C47:
C48: Did a Fire Occur?	C49: Yes No	C50: Consequence of Fire:	C51:
C52: Was a Fuel Tank Design Weakness Revealed?	C53: Yes No	C54: Describe Weakeness:	C55:
C56: Did a Crew Casualty Occur?	C57: Yes No	C58: Location When Injured:	NO PHOTOGRAPHS REQUIRED
		C59: Extent of Injury:	

***Crashworthy means the locomotive was built in accordance with AAR Specification S580.**

Figure 2.3

HEAD ON COLLISIONS - TWO TRAINS, BOTH IN MOTION AT IMPACT

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN (INCL LOCOS) (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL.	MNF	YR BLT	S-580 COMPL-IANT	WG HT. (TONS)
B-02-93 01/20/93	BN	17	1753	416	9	9.4862	2.2512	BN 7072	SD40-2	EMD	1978	NO	208
								BN 7180	SD40-2	EMD	1979	NO	208
	SP	RVCHX-14	9262	887	21	272.879	26.133	SSW 9710	GP 60	EMD	1990	NO	143.25
								CSX 8444	SD40-2	EMD	1990	NO	195
								CSX 6077	GP40-2	EMD	1972	NO	138.75
								SP 9287	SD45T-2	EMD	1973	NO	205
								SP 9346	SD45T-2	EMD	1975	NO	205
B-03-94 02/26/94	IC	MENL-26	6829	396.1	25	285.1437	16.5391	IC 6152	SD40-2	EMD	1976	NO	208
								IC 6061	SD-40	EMD	1966	NO	188.1
	IC	BRME-25	8847	396.1	34	683.2515	30.5907	IC 6131	SD40-2	EMD	1976	NO	208
								IC 6033	SD-40	EMD	1975	NO	188.1

TABLE 2-1

HEAD ON COLLISIONS - TWO TRAINS, BOTH IN MOTION AT IMPACT

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN (INCL LOCOS) (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL-IANT	WGHT. (TONS)
B-11-91 08/30/91	BN	602	2533	530.77	18	54.8286	11.4889	BN 2275	GP38-2	EMD	1973	NO	133.25
								BN 8009	SD40-2	EMD	1977	NO	206.35
								BN 6909	SD40-2	EMD	1973	NO	191.17
	BN	603	8048	915.34	35	658.644	74.9109	BN 6905	SD40-2	EMD	1973	NO	191.17
								BN 6901	SD40-2	EMD	1973	NO	191.17
								BN 2287	GP38-2	EMD	1973	NO	133.25
								BN 2283	GP38-2	EMD	1973	NO	133.25
								BN 2274	GP38-2	EMD	1973	NO	133.25
								BN 2289	GP38-2	EMD	1973	NO	133.25
B-12-91 09/17/91	NS	629L4	12566	526	26	567.506	23.7552	NS 6207	SD40-2	EMD	1980	NO	195
								NS 8642	C39-8	GE	1986	NO	195
								NS 4636	GP59	EMD	1989	NO	136
	NS	227L4	1256	195	35	102.7904	15.9587	NS 6134	SD40-2	EMD	1975	NO	195

NOTES:
1) * INDICATES THE PRE-COLLISION KINETIC ENERGY OF THE TRAIN OR LOCOMOTIVE CONSIST
2) WHERE LOCOMOTIVE WEIGHTS WERE NOT PROVIDED IN ACCIDENT REPORTS, BASELINE CONFIGURATION WEIGHTS PROVIDED BY THE MANUFACTURERS WERE USED

HEAD ON COLLISIONS - TWO TRAINS, ONE STATIONARY AT IMPACT

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL-IANT	WGHT. (TONS)
??? 02/12/94	CSXT	R122-12	4006	483.75	6-8	13.114	1.5836	CSX 5813	B36-7	GE	1985	NO	140
								CSX 6300	GP40-2	EMD	1980	NO	138.75
								CSX 7663	CW40-8	GE	1991	YES	205
	CSXT	U599-10	11632	615	0	0	0	CSX 7576	C40-8	GE	1989	NO	205
								CSX 7632	C40-8	GE	1990	YES	205
								CSX 7717	CW40-8	GE	1991	YES	205
C-72-93 10/01/93	UP	CJRBD-30	???	400	24	UNKNOWN	15.3925	UP 9504	C41-8W	GE	1993	YES	200
								UP 9502	C41-8W	GE	1993	YES	200
	UP	CRDJR-27	???	405	0	UNKNOWN	0	UP 9391	C40-8	GE	1990	NO	205
								UP 9420	C41-8	GE	1990	YES	200
B-01-91 01/19/91	CSX	R 691-17	3836	548.75	35	313.9362	44.9094	CSX 7564	C40-8	GE	1989	NO	205
								CSX 7627	C40-8	GE	1990	YES	205
								CSX 6648	GP-40	EMD	1969	NO	138.75
	CSX	U 115-15	2658	615	0	0	0	CSX 8475	SD-40-2	EMD	1966	NO	210
								CSX 8618	SD-50	EMD	1985	NO	195
								CSX 8103	SD-40-2	EMD	1980	NO	210

HEAD ON COLLISIONS - TWO TRAINS, ONE STATIONARY AT IMPACT

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL-IANT	WGHT. (TONS)
C-40-91 03/28/91	UP	GJNSM-26	4608	390.25	40	492.56	41.7147	CR 6726	SD-50	EMD	1983	NO	195
								CR 6719	SD-50	EMD	1983	NO	195.25
	UP	FKCGI U-27	3069	399.5	0	0	0	SP 6833	SD45T	EMD	1988	NO	205
								DRGW 5321	SD-45	EMD	1967	NO	194.5
C-58-91 04/21/91	CSX		411	411	18	8.8964	8.8964	CSX 5816	B-36-7	GE	1985	NO	411 (TOTAL)
								CSX 5883	B-36-7	GE	1985	NO	
								CSX 5863	B-36-7	GE	1985	NO	
	CSX		546	546	0	0	0	CSX 5723	U-36-B	GE	1970	NO	546 (TOTAL)
								CSX 5898	B-36-7	GE	1985	NO	
								CSX 5878	B-36-7	GE	1985	NO	
								CSX 6134	SD40-2	EMD	1975	NO	
B-8-91 07/30/91	BN		9950	288	34	768.4359	22.2422	LMX 8518	D8-40B	GE	1987	NO	144
								LMX 8568	D8-40B	GE	1988	NO	144
	BN		840	138.75	0	0	0	BN 3502	GP40	EMD	1988	NO	138.75

REAR END COLLISIONS - TWO TRAINS

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL -IANT	WGHT. (TONS)
??? 03/28/94	CR	COBU-8	10995	400	30-32	705.9035	25.6809	CR 6207	C-40-8	GE	1993	YES	205
								CR 5573	SD60	EMD	1993	YES	195
	CR	VAT-13	7473	UNKNOWN	0	NOT APPLICABLE		NOT INVOLVED IN COLLISION					
??? 07/23/93	CSX	T541-23	13545	557.5	16	231.6571	9.5348	CSX 6448	GP40-2	EMD	1981	NO	138.75
								CSX 6824	GP40	EMD	1967	NO	138.75
								CSX 5520	B30-7	GE	1978	NO	140
								CSX 5554	B30-7	GE	1980	NO	140
	CSX	V501-23	13137	UNKNOWN	0	NOT APPLICABLE		NOT INVOLVED IN COLLISION					
C-71-92 10/28/92	SOO	6019 E	4764	390	34	367.9225	30.1196	SOO 6019	SD60	EMD	1986	NO	195
								SOO 6026	SD60	EMD	1989	NO	195
	SOO	6001 E	7019	UNKNOWN	0	NOT APPLICABLE		NOT INVOLVED IN COLLISION					

REAR END COLLISIONS - TWO TRAINS

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPLIANT	WGHT. (TONS)
C-13-92 03/22/92	NW		13103	614	20	350.1527	16.408	NS 3963	U23B	GE	1977	NO	132.5
								NS 3951	U23B	GE	1975	NO	132.5
								BN 7021	SD-40-2	EMD	1978	NO	208.5
								BN 4106	B30-7A	GE	1982	NO	140.5
	NW		19640	390	1	1.3121	0.0261	NS 8566	C-39-8	GE	1985	NO	195
						NOT INVOLVED IN COLLISION		NS 8672	C-39-8	GE	1986	NO	195
B-04-93 02/26/93	SP	EUCLX-K24	6032	978.75	52	1089.6693	176.8093	SP 6793	SD45-T2	EMD	1987	NO	210
								SP 9250	SD45-T2	EMD	1972	NO	210
								SP 7431	SD40-2	EMD	1980	NO	210
								SP 6826	SD45T	EMD	1987	NO	210
								DRGW 3144	GP40	EMD	1968	NO	138.75
	SP	RUGJM-23	6149	UNKNOWN	0	NOT APPLICABLE		NOT INVOLVED IN COLLISION					
C-80-92 12/02/92	CR	WITH-05	390	120	40	41.688	12.8271	CR 1655	GP-15-1	EMD	1979	NO	120
	CR	UAM-34	18500	410	0	NOT APPLICABLE		CR 6098	C40-8	GE	1990	NO	205
						NOT INVOLVED IN COLLISION		CR 6035	C40-8	GE	1989	NO	205

HEAD ON COLLISIONS - ONE TRAIN AND ANOTHER VEHICLE AT A GRADE CROSSING

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL-IANT	WG HT. (TONS)
??? 11/04/93	AT SF		7209	416.5	60	1733.8209	100.1715	ATSF 7414	B40-8	GE	1988	NO	141.5
								ATSF 336	GP60-B	EMD	1991	YES	139.2
								ATSF 3822	GP50	EMD	1981	NO	135.8
	N/A	TRACTOR TRAILER	62.4	NOT APPLICABLE	10	0.4169	NOT APPLICABLE	NOT APPLICABLE					
??? 01/04/94	SP		5169.5	840	44	668.6219	108.6454	SP 7809	B30-7	GE	1978	NO	140
								SSW 7776	B30-7	GE	1980	NO	140
								SSW 7797	B30-7	GE	1980	NO	140
								SP 7754	B36-7	GE	1984	NO	140
								SP 7762	B36-7	GE	1984	NO	140
								SSW 7784	B30-7	GE	1980	NO	140
	N/A	LOGGING TRUCK	40	NOT APPLICABLE	10-12	0.3233	NOT APPLICABLE	NOT APPLICABLE					
??? 01/06/94	BN	93457-06	1193	127	45	161.3958	17.1813	BN 2906	GP39E	EMD	1990	YES	127
	N/A	DUMP TRUCK	UNKNOWN	NOT APPLICABLE	15	UNKNOWN	NOT APPLICABLE	NOT APPLICABLE					

HEAD ON COLLISIONS - ONE TRAIN AND ANOTHER VEHICLE AT A GRADE CROSSING

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL	MNF	YR BLT	S-580 COMPL-IANT	WG HT. (TONS)
C-16-93	ATK	350	339.7	131	60	81.7005	31.5065	ATK 370	F40PH	EMD	1981	NO	131
03/09/93	N/A	TANK TRUCK	18.4	NOT APPLICABLE	10	0.1229	NOT APPLICABLE	NOT APPLICABLE					
??? 12/16/93	SP	ASSRQ-15	7718	UNKNOWN	23	272.7641	UNKNOWN	SP 7826		GE	1979	NO	
								NOTE: 5 OTHER LOCOS INVOLVED BUT NOT IDENTIFIED					
	N/A	OVSZ TRUCK	AUTH 120	NOT APPLICABLE	0	0	NOT APPLICABLE	NOT APPLICABLE					
C-82-93	ATK	P088	592	131	78	240.6233	53.246	ATK 306	F40PH	EMD	1979	NO	131
11/30/94	N/A	TRACTOR TRAILER	146	NOT APPLICABLE	0	0	NOT APPLICABLE	NOT APPLICABLE					
C-41-93	ATK	305	300	131	35	24.5518	10.721	ATK 279	PF40PH	EMD	1977	NO	131
06/28/93	N/A	TR.TLR	38	NOT APPLICABLE	0	0	NOT APPLICABLE	NOT APPLICABLE					
??? 06/06/94	ATK	364	298.6	131	60	71.8156	31.5065	VIA 6445	F40PH2	EMD	1989	NO	131
	N/A	DUMP TRUCK	26	NOT APPLICABLE	2	0.0069	NOT APPLICABLE	NOT APPLICABLE					
??? 01/31/94	ATK	520	N/A	UNKNOWN	60	UNKNOWN	UNKNOWN	ATK 802	8-40BP	GE	1993	YES	
	N/A	TR.TLR	28	NOT APPLICABLE	5	0.0468	NOT APPLICABLE	NOT APPLICABLE					

TWO TRAINS - COLLISION AT GRADE CROSSING

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL.	MNF	YR BLT	S-580 COMPL-IANT	WGHT. (TONS)
C-68-92 10/03/92	CGA	198A5	6528	405	16	111.6469	6.9266	SOU 6625	SD-60	EMD	1986	NO	195
								NW 8512	C36-7	GE	1982	NO	210
	CSX	X11401	2358	410	24	90.7388	15.7713	CSX 7593	8-C40	GE			205
								CSX 7624	8-C40	GE			205
C-1-93 01/03/93	BN	0120-28	3418	UNKNOWN	43	422.217	UNKNOWN	BN 3131	GP 50	EMD	1985	NO	
								BN 3127	GP 50	EMD	1985	NO	
	MNA		8600	832.5	0	0	0	GATX 3075	GP 40	EMD	1969	NO	138.75
								GATX 3083	GP 40	EMD	1969	NO	138.75
								UP 510	GP 40-L	EMD	1968	NO	138.75
								UP 507	GP 40	EMD	1968	NO	138.75
								GATX 3081	GP 40	EMD	1969	NO	138.75
								UP 501	GP 40	EMD	1968	NO	138.75
B-3-93 02/21/93	BN	01-175-19	3188	420	40	340.7729	44.8948	ATSF 5861	SD45-2	EMD	1973	NO	210
								ATSF 5961	SDF-45	EMD	1968	NO	210

TWO TRAINS - COLLISION AT GRADE CROSSING

ACCIDENT # DATE	RR	TRAIN #	WEIGHT OF TRAIN INCL. LOCOS (TONS)	WEIGHT OF LOCO CONSIST (TONS)	SPEED AT IMPACT (MPH)	KINETIC ENERGY* ENTIRE TRAIN (MILLIONS OF FT-LBS)	KINETIC ENERGY* LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	LOCOMOTIVE INFO					
								ID	MDL.	MNF	YR BLT	S-580 COMPL-IANT	WGHT. (TONS)
B-3-93 02/21/93	AT SF	G-ENH O1-19	10803	630	0	0	0	ATSF 5343	SD-45	EMD	1966	NO	210
								ATSF 5098	SD40-2	EMD	1979	NO	210
								ATSF 5176	SD40-2	EMD			210
C-50-93 08/08/93	AT SF	188-05	6715	628	18	145.3509	13.5935	ATSF 852	C-40-8 W	GE	1992	YES	205
								ATSF 4019	GP60	EMD	1988	NO	135
								ATSF 7441	B40-8	GE	1989	NO	144
								ATSF 7434	B40-8	GE	1989	NO	144
	AT SF	SLACH 8-07	6266	UNKNOWN	0	0	0	ATSF 891	NOT APPLICABLE - NOT INVOLVED IN COLLISION				
								ATSF 829					
								ATSF 511					
								ATSF 573					
11/22/91	BN	87-RC2 63-22	1926	405	5	3.2168	0.6764	BN 5054	C30-7	GE	1980	NO	210
								BN 7258	SD40-2	EMD	1980	NO	195
	SO O	201		UNKNOWN	0	0	0	CNW 6934	NOT APPLICABLE - NOT INVOLVED IN COLLISION				
								SOO 753					
								UNIDEN					

The sample size of locomotives built in accordance with AAR S-580 involved in collisions to date is small. Only 12 of the 122 locomotives (9.8 percent) identified in the data base are known to comply with AAR S-580. Additionally, only four of these 12 (33 percent) locomotives were located in the lead position of the consist. It is interesting to note that of the nine locomotive consists involved in collisions which had locomotives compliant with AAR S-580, five of these consists (56 percent) had a locomotive that was compliant with AAR S-580—and presumably better equipped to survive a collision—following another locomotive in the consist which did not necessarily incorporate the crashworthiness features specified in AAR S-580. While sufficient information is not yet available to determine whether it would be cost effective to require that an AAR S-580 compliant locomotive be placed in the lead position of the consist (if one is part of the train), it would appear that this is a common sense approach to improve occupant survivability in the event of a collision that should be considered by the railroads as an internal operating procedure to be employed whenever possible.

A total of six fatalities and 14 injuries (of varying severity) were reported for the four head-on collisions with both trains in motion at impact. Eighteen of these casualties resulted from the three collisions with closing speeds above 50 miles per hour (mph). It is very interesting to note that of these 18 people, a total of 14 (78 percent) jumped from the locomotive prior to impact. This indicates that occupants of the locomotive cab have little or no confidence in the ability of a locomotive to withstand a collision at these speeds. Further, this shows that in most cases when a collision is known to be imminent, locomotive crew members have some amount of time in which to evaluate options and react. This supports the feasibility of creating some form of a crash refuge in the locomotive cab, in which occupants may protect themselves from the decelerations and secondary impacts resulting from collisions.

In the four locomotive consists with an AAR S-580 compliant locomotive in the lead position involved in a collision, two of nine crew members jumped prior to the point of impact. These two crew members sustained serious injuries, while the seven crew members who remained in the cab reported minor or no injuries. However, the injuries sustained in any collision are a function of numerous varying factors and conditions of that particular accident, including closing speed, the type of accident, and whether or not a fire ensued among others. Accordingly, it should not be implied that the two crew members who jumped and sustained serious injuries would have fared better by staying in the cab during the collision. Photographs of the accident scene following the subject collision indicate that survivability in the lead locomotive would have been improbable, as the cab structure was crushed by a loaded coal car that came to rest on the roof as a result of the impact.

An understanding of how the energy is dissipated during a collision is a vital part of understanding and predicting occupant survivability. Table 2-2 provides several parameters associated with the kinetic energy of trains involved in head-on collisions, both before and after impact.

HEAD ON COLLISIONS - BOTH TRAINS IN MOTION AT IMPACT

ACCIDENT # DATE	SPEED AT IMPACT (MPH)	WEIGHT OF LOCOMOTIVE CONSIST (TONS)	PRE-COLLISION KINETIC ENERGY OF LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	PRE-COLLISION TOTAL KINETIC ENERGY LOCOMOTIVE CONSISTS (MILLIONS OF FT-LBS)	VELOCITY OF INDIVIDUAL TRAIN TO GENERATE SAME TOTAL KINETIC ENERGY (MPH)	CLOSING SPEED (MPH)	TOTAL ENERGY ABSORBED IN COLLISION (MILLIONS OF FT-LBS)	POST-IMPACT VELO-CITY (MPH)
B-2-93 1/20/93	9 21	416 887	2.2512 26.133	28.3842	32.0 21.9	30	17.0271	11.4
B-3-94 2/26/94	25 34	396.1 396.1	16.5391 30.5907	47.1298	42.2 42.2	59	46.0581	4.5
B-11-91 8/30/91	18 35	530.77 915.34	11.4889 74.9109	86.3998	49.4 37.6	53	63.0472	15.5
B-12-91 9/17/91	26 35	526 195	23.7552 15.9587	39.7139	33.6 55.2	61	35.3648	9.5

ASSUMPTIONS:
1) STRUCTURES OF BOTH VEHICLES POSSESS TOTALLY PLASTIC MATERIAL PROPERTIES IN THE REGION WHERE CRUSH OCCURS
2) COLLINEAR VEHICLE IMPACT
3) VEHICLES REMAIN IN CONTACT AFTER COLLISION AND ACQUIRE A COMMON, POST-IMPACT VELOCITY
4) NEGLECT ENERGY DISSIPATED BY FRICTIONAL FORCES

TABLE 2-2a

HEAD ON COLLISIONS - ONE TRAIN STATIONARY AT IMPACT

ACCIDENT # DATE	SPEED AT IMPACT (MPH)	WEIGHT OF LOCOMOTIVE CONSIST (TONS)	PRE-COLLISION KINETIC ENERGY OF LOCOMOTIVE CONSIST (MILLIONS OF FT-LBS)	PRE-COLLISION TOTAL KINETIC ENERGY LOCOMOTIVE CONSISTS (MILLIONS OF FT-LBS)	VELOCITY OF INDIVIDUAL TRAIN TO GENERATE SAME TOTAL KINETIC ENERGY (MPH)	CLOSING SPEED (MPH)	TOTAL ENERGY ABSORBED IN COLLISION (MILLIONS OF FT-LBS)	POST-IMPACT VELO-CITY (MPH)
 2/12/94	7 0	483.75 615	1.5836 0	1.5836	7.0 6.2	7	0.8864	3.08
C-72-93 10/1/93	24 0	400 405	15.3925 0	15.3925	24.0 23.9	24	7.7441	11.93
B-1-91 1/19/91	35 0	548.75 615	44.9094 0	44.9094	35.0 33.1	35	23.733	16.5
C-40-91 3/28/91	40 0	390.25 399.5	41.7147 0	41.7147	40.0 39.5	40	21.1017	19.77
C-58-91 4/21/91	18 0	411 546	8.8964 0	8.8964	18.0 15.6	18	5.0757	7.73
B-8-91 7/30/91	34 0	288 138.75	22.2422 0	22.2422	34.0 49.0	34	7.2316	22.95

ASSUMPTIONS:
1) STRUCTURES OF BOTH VEHICLES POSSESS TOTALLY PLASTIC MATERIAL PROPERTIES IN THE REGION WHERE CRUSH OCCURS
2) COLLINEAR VEHICLE IMPACT
3) VEHICLES REMAIN IN CONTACT AFTER COLLISION AND ACQUIRE A COMMON, POST-IMPACT VELOCITY
4) NEGLECT ENERGY DISSIPATED BY FRICTIONAL FORCES

TABLE 2-2b

In general, transport vehicle kinetic energy is dissipated during an accident by means of mechanical and frictional work. For wheel-on-rail vehicles, this energy is consumed by the following physical processes:

- o controlled vehicle structural deformations (i.e., crush without buckling and/or fracture);
- o structural buckling;
- o sliding/rolling (e.g., vehicle wheels cutting through track ties, ballast, surrounding roadbed surfaces, etc.); and
- o impacts with wayside structures.

While only a few percent of the kinetic energy of a collision can be absorbed by the vehicle structures in a reasonable crush distance, an accurate representation of the *potential* damage that can be inflicted on vehicles by a collision may be shown through calculation of the total energy dissipated in the two vehicles during the crash as a result of permanent deformation of their structures. This parameter can be approximated through application of two fundamental physical concepts that govern the overall response of vehicles involved in a collision: the laws of conservation of momentum and conservation of total energy. Appendix C shows the derivation of the parameter of total energy dissipated by vehiclestructures in collisions using these fundamental physical laws for the case of collinear impact[2] between two ground vehicles.

The derivation of the total energy dissipated in the two vehicles during the crash as a result of permanent deformation of their structures provided in Appendix C illustrates many interesting relationships regarding collisions in general. It is shown that the masses of the trains involved play an important role, as there will be less energy available to damage the trains for the case where one or both trains are lightweight compared to the case where both are heavy[3]. It is also shown that the final common velocity of the two vehicles after impact and the associated kinetic energy that must be dissipated in both vehicles is determined only by the masses and pre-collision velocities of the two vehicles, and are totally independent of their individual crush characteristics. This relationship clearly demonstrates that the *management* of energy, along with designing for structural protection at higher closing speeds, is a key parameter in designing for crew survivability within the cab of a locomotive.

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[2]A collinear intervehicular impact is one in which the longitudinal axes of both vehicles are aligned along the same straight line at the moment of impact. Examples of such crash configurations are a head-on frontal collision and an aligned, front-to-rear impact.

[3]Computer modeling developed by Arthur D. Little (as detailed in Chapter 3) shows that when trailing cars have lower crush strength than the locomotives, trailing vehicles (nonlocomotives) and the effects of derailment are minor with respect to the additional energy generated that must be dissipated, and need not be modeled to predict the crush response of the lead locomotives. Accordingly, in the derivation of total energy absorbed in a collision, only the mass of the locomotive consist is considered.

For every collision, there is a fixed magnitude of kinetic energy that can be absorbed by the two vehicle structures. How this energy is distributed between them depends on the structural design and material used in their construction.

FRA has attempted to correlate this parameter of total energy absorbed in a collision to actual results from accident investigations included in the data base to show that a direct relationship exists. This is a very complex relationship that is affected by numerous external parameters that cannot be quantified via accident reports. Due in part to the complexity of this relationship, and in part to the limited data available from accident reports, FRA has not yet defined such a correlation.

As the locomotive crashworthiness data base established in response to RSERA is very limited in scope, Figures 2.4 through 2.15 are provided to illustrate trends in train collisions and associated fatalities and injuries to railroad personnel over the 10-year period covering 1983 to 1992. These figures reveal the following information regarding general trends over the past 10 years:

- o Figures 2.4 through 2.9 provide data for all types of train collisions, including head-on, rear end, side, raking, broken train, and highway crossing collisions. Figure 2.4 shows that the total number of train collisions per year has decreased by nearly 30 percent over the past 10 years. This decline can be attributable to a combination of many factors, including more capable signal systems, tighter operating rules, computer-aided dispatching (CAD), improved voice radio communication, reductions in the use of alcohol and drugs, and increased professionalism of railroad operating employees. Accordingly, Figures 2.6 and 2.7 show that the number of casualties (injuries and fatalities) to crew members and passengers has decreased by over 40 percent in the same time period. While this progress is noteworthy, these numbers indicate that room exists for additional technological improvements to further reduce the number of collisions and casualties.

- o Figure 2.9 clearly shows that a large percentage of train collisions occur at very low closing speeds, likely within yard limits. While these collisions do not typically result in major injuries and/or fatalities, there have been collisions investigated that resulted in override of one locomotive onto another at these low closing speeds. Chapter 3 will show that collisions, even at moderate (i.e., 30 mph) closing speeds, generate very large amounts of kinetic energy and impact forces that can lead to massive structural collapse and serious and/or fatal injuries to crew members. The crashworthiness features evaluated in this report address the threat posed by increasing train speeds, and the ability of these proposed designs to protect cab occupants in these collision scenarios.

- Figures 2.10 through 2.12 indicate that head-on and rear end collisions, and the associated crew and passenger casualties, have also decreased over the 10-year time period reviewed. Again, this improvement can be directly related to various technological advances listed previously, but implementation of additional measures as identified in Chapter 3 will allow these numbers to decrease further.

- Figures 2.13 through 2.15 illustrate the 10-year trends for highway crossing collisions only. This collision scenario is typically much less severe for the locomotive due to the large differential in pre-collision kinetic energy developed by the train as compared to the highway vehicle. It is somewhat alarming that, while all other collision types have decreased significantly over the 10 year period examined, highway-rail crossing collisions have increased slightly. The Department of Transportation (including the Federal Highway Administration, the National Highway Traffic Safety Administration, the Federal Transit Administration, and FRA) is currently addressing this area of concern through improved warning systems, heightened public awareness and education, more effective law enforcement, and other initiatives.

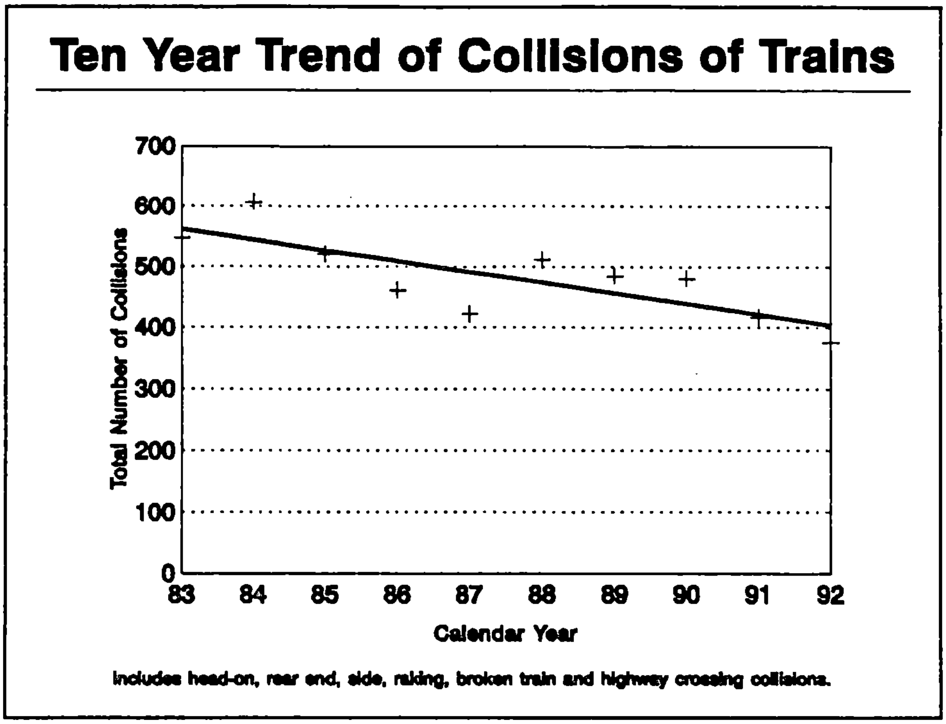

Figure 2.4

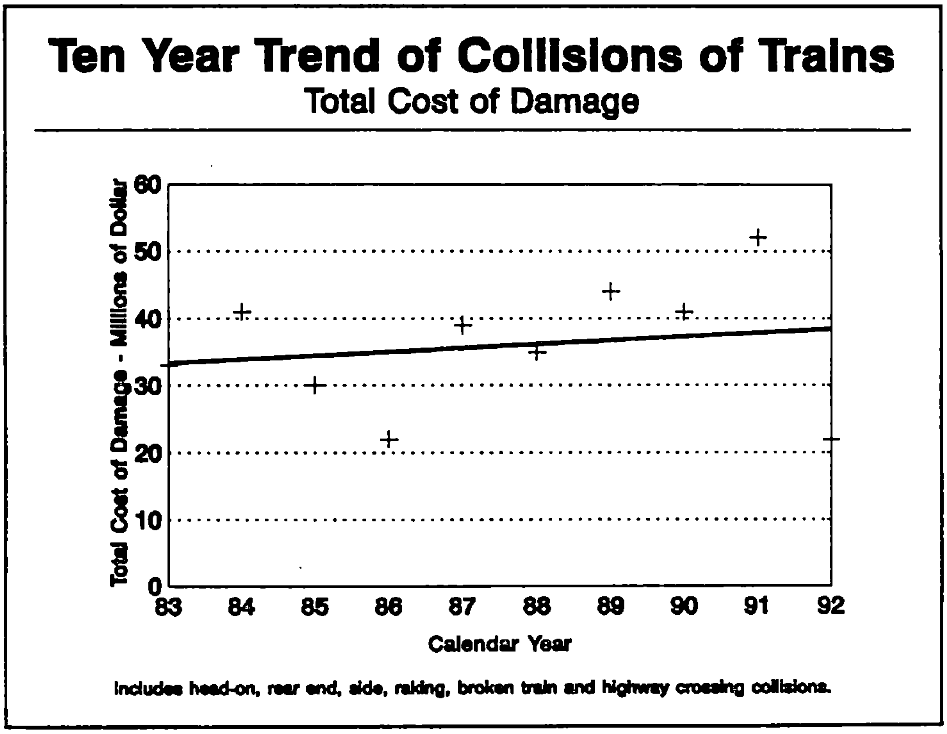

Figure 2.5

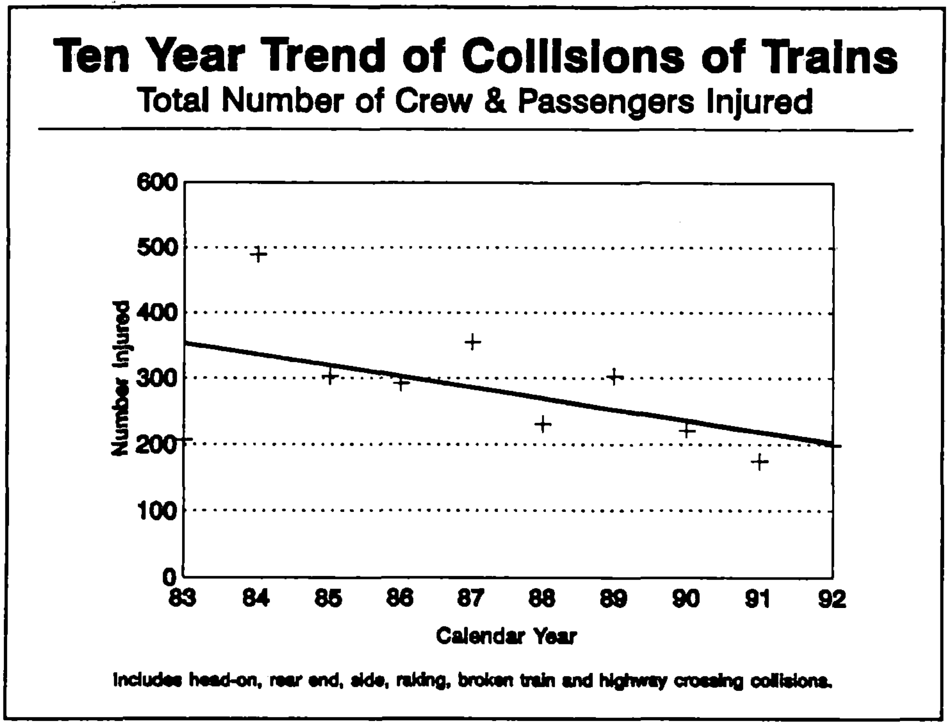

Figure 2.6

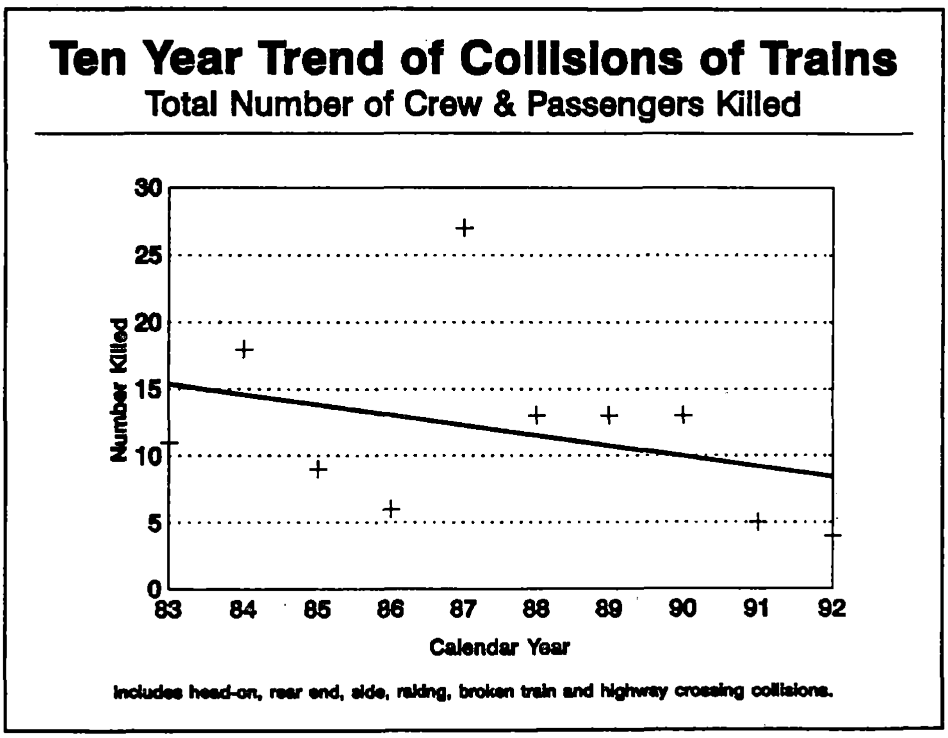

Figure 2.7

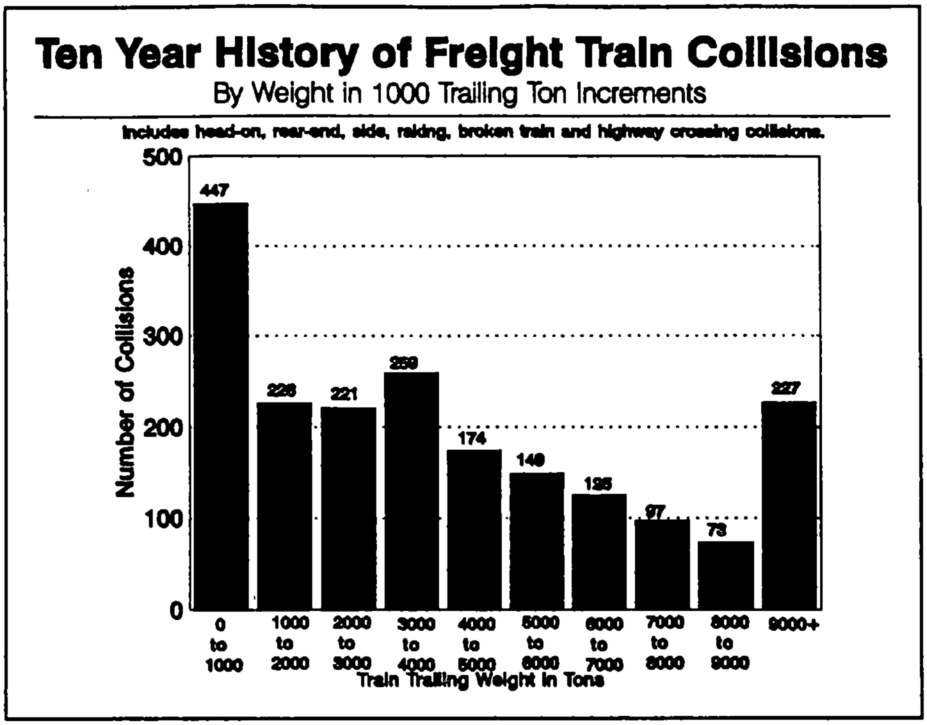

Figure 2.8

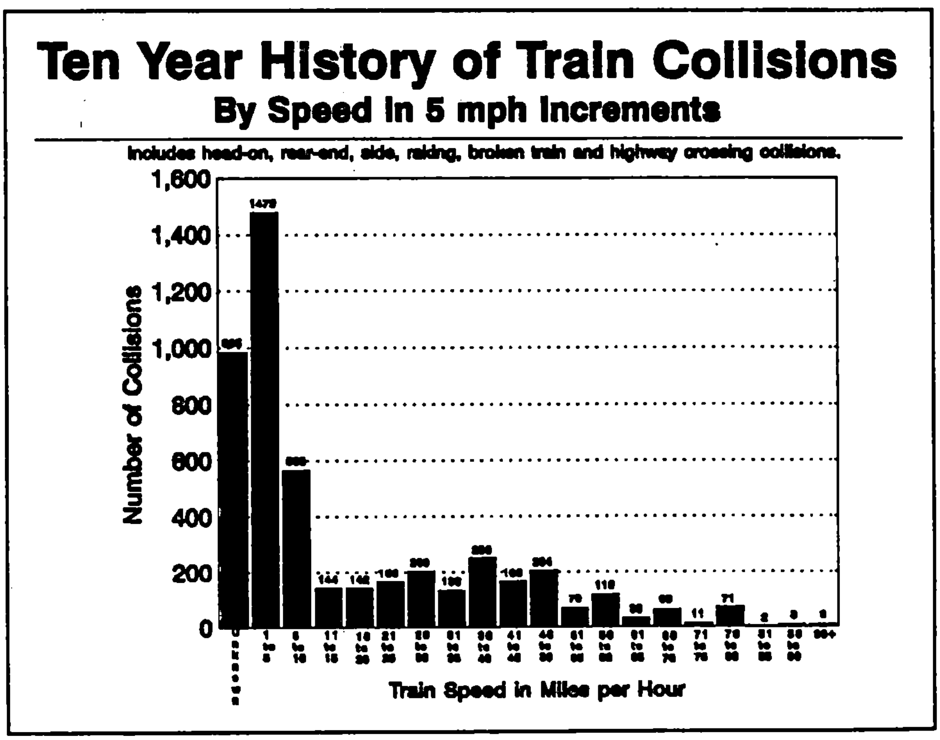

Figure 2.9

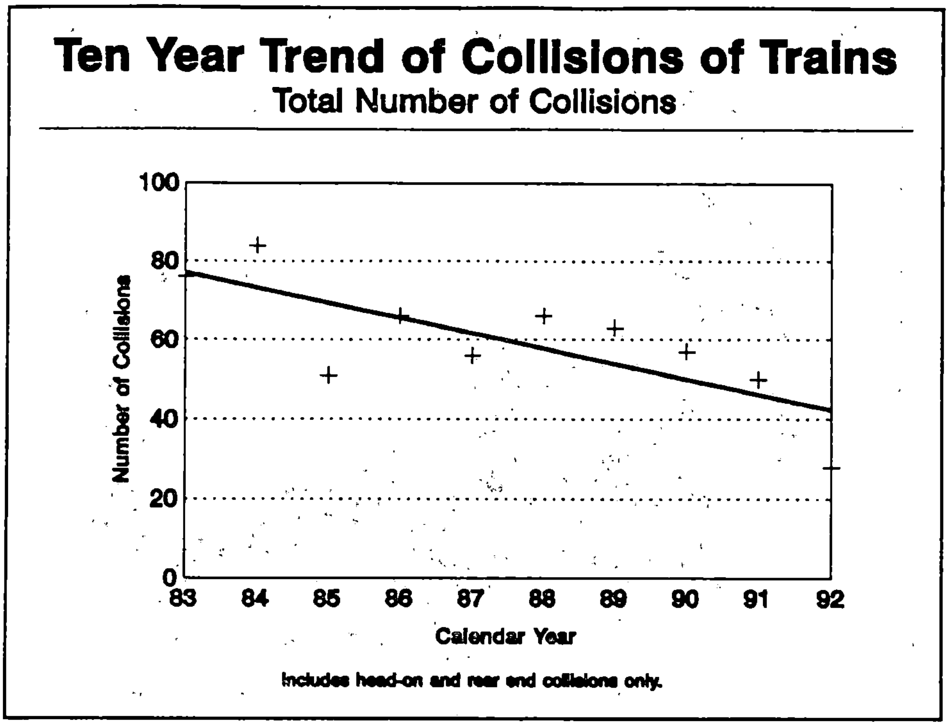

Figure 2.10

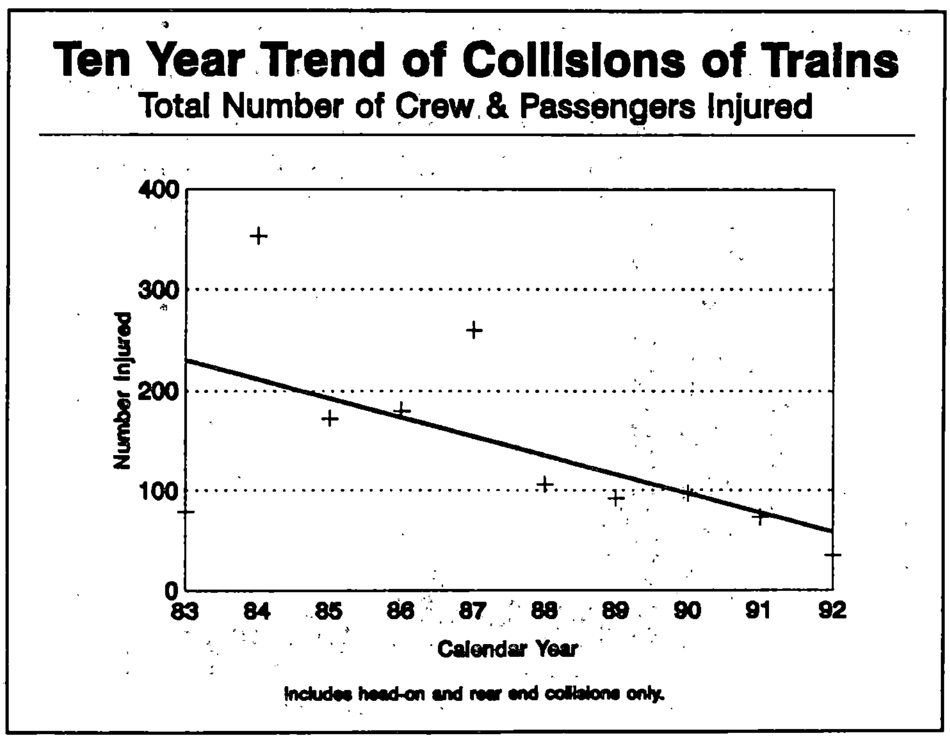

Figure 2.11

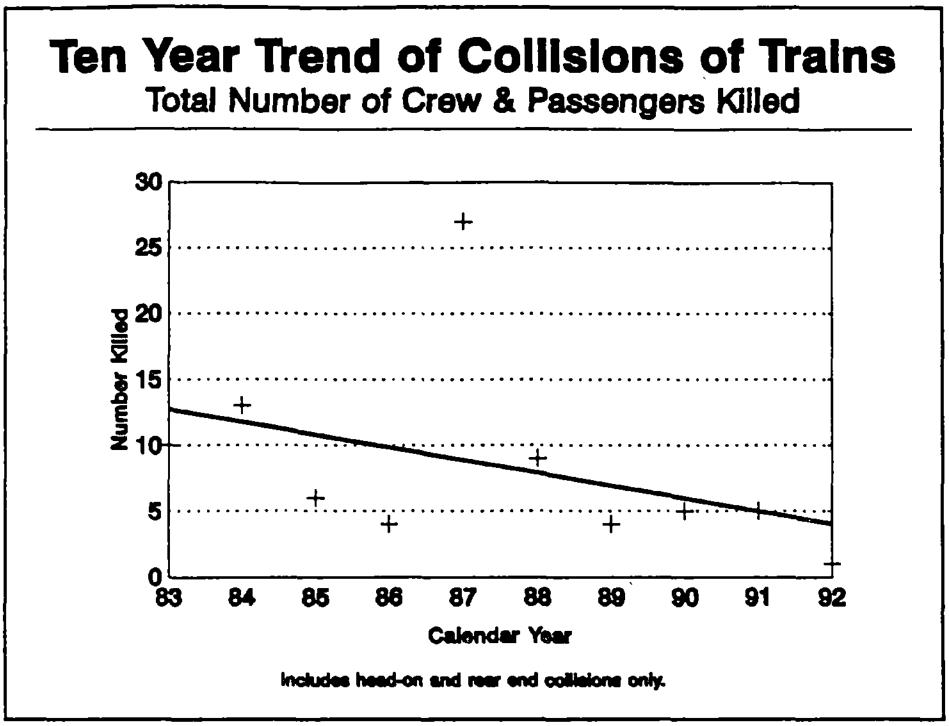

Figure 2.12

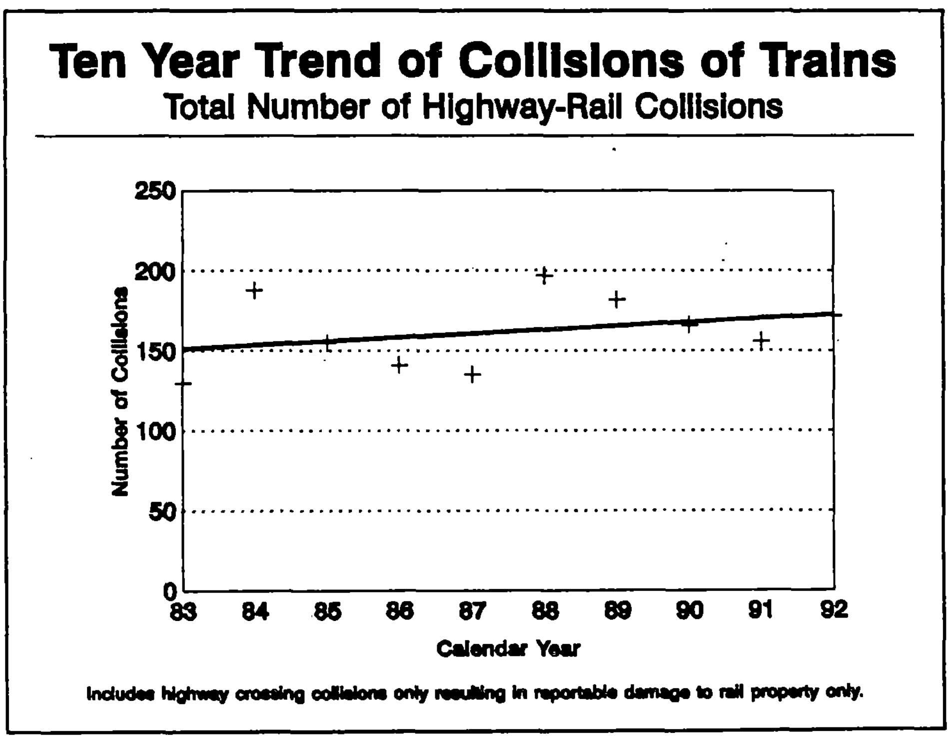

Figure 2.13

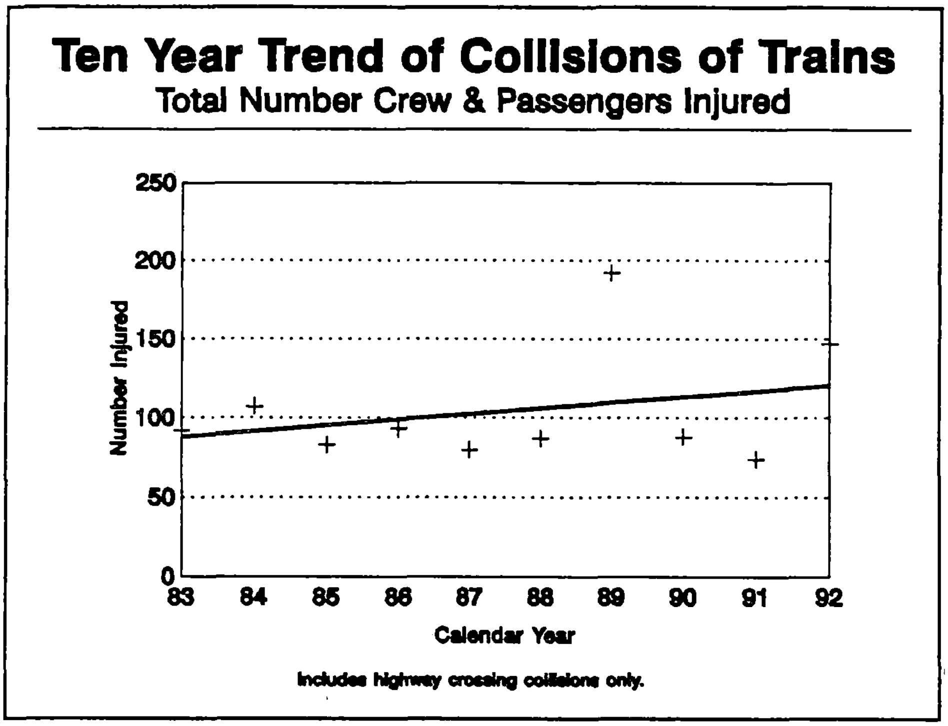

Figure 2.14

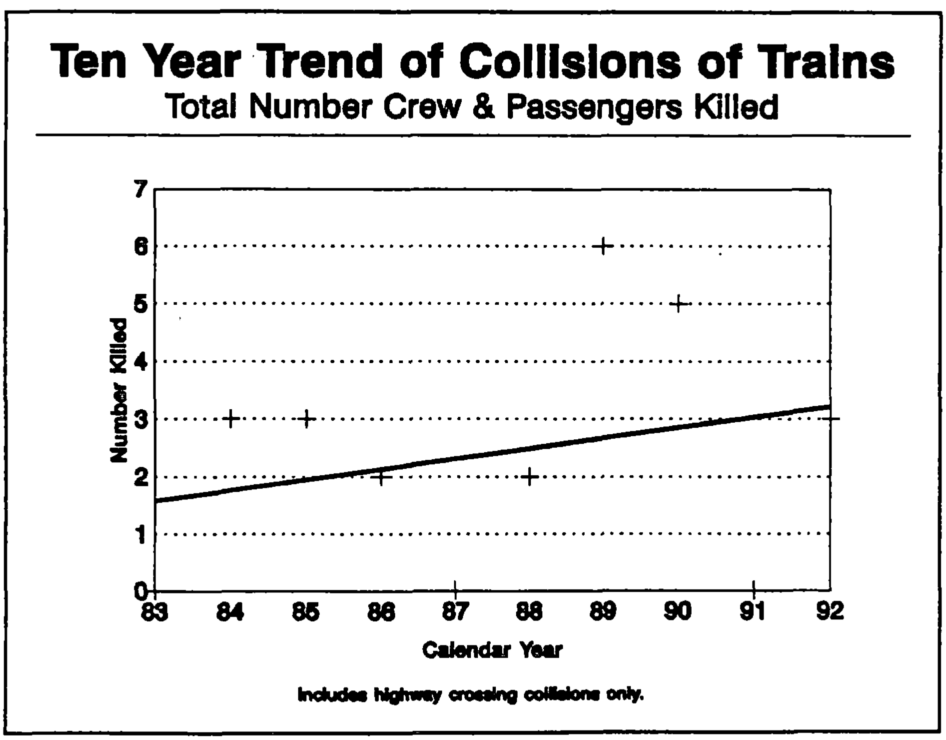

Figure 2.15

CHAPTER 3

Locomotive Crashworthiness

Section 10 of the Act required FRA to conduct research and analysis, including computer modeling and full scale crash testing, as appropriate, to determine the benefit, if any, of each of the listed locomotive crashworthiness features in providing additional protection to personnel in locomotive cabs under realistic collision conditions. Full scale crash testing to determine the benefits of the crashworthiness features listed in Section 10 of the Act is unduly expensive. As such, FRA conducted a research and analysis program that consisted of (a) review of recommendations made by the National Transportation Safety Board (NTSB) regarding locomotive crashworthiness, (b) review of previous studies on the subject, (c) establishment and review of the data base discussed in Chapter 2, and (d) execution of a research contract to develop and validate a computer model used to predict the results of locomotive collisions.

FRA determined that AAR Specification S-580 represents a significant step on the part of the railroad industry to improve the crashworthiness of locomotives. However, research and analysis has shown that S-580 may be improved to further reduce casualties in locomotive collisions without major impact on the design of future locomotives. This chapter provides a comprehensive evaluation of each of the features identified in the Act, including, but not limited to the following: braced collision posts, rollover protection devices, deflection plates, shatterproof windows, readily accessible crash refuges, uniform sill heights, anticlimbers, and fuel tank design. A review of the current industry and/or Federal practice, a description of a proposed concept generated through the modeling effort, and a technical evaluation of that concept is provided for each feature.

The evaluation process clearly indicates that implementation of selected crashworthiness features identified in the Act—including incorporation of stronger collision posts, creation of a crash refuge, and design of a positive engaging anticlimber or other means to prevent override—can significantly improve crew survivability in the event of a collision. However, most of these measures are practical for application only to locomotives of new construction. Additional information and research is needed to determine whether these concepts can be implemented on a cost-effective basis. In addition, other concepts to improve crew survivability, including mandated uniform sill height and deflection plates at the front of the locomotive, were evaluated and found to be impractical or without significant safety merit.

The railroad industry is fundamental to our Nation's transportation system. Our economy relies on railroad shipment and freight delivery, and intercity travelers in many portions of the country count on Amtrak for their transportation needs. We depend on the railroads to be reliable; but, most importantly, they must be safe. Chapter 2 showed that while train-to-train collisions have decreased steadily over the past 10 years, the number of locomotive crew member and passenger fatalities has not reached the desired goal—zero fatalities. Even at moderate impact speeds, collisions can generate extremely high kinetic energy levels and impact forces that produce massive structural collapse, and subsequently lead to serious and fatal injuries to the train crew and passengers. This chapter focuses on possible improvements in the crashworthiness design of locomotives that will ensure a safe environment for its occupants during the crash-related events that occur in a given accident scenario.

FRA recently reported to Congress on the status of advanced train control systems (ATCS), and specifically positive train control (PTC)[1], as a valid means of enforcing speed and movement restrictions on the railroads, potentially eliminating injuries and deaths caused by train-to-train collisions. FRA's analysis clearly indicates that the cost of universal implementation of PTC is not justified at this time based on accident avoidance alone. Further, PTC strategies are not yet available to address collisions between trains and heavy vehicles at highway/rail grade crossings. As such, pursuit of continual improvements in locomotive crashworthiness, and consequently crew survivability should a collision occur, has been a long standing National Transportation Safety Board (NTSB) concern and is an ongoing FRA priority.

Section 10 of the Rail Safety Enforcement and Review Act (RSERA), enacted September 3, 1992, requires the Secretary of Transportation to "complete a rulemaking proceeding to consider prescribing regulations to improve the safety and working conditions of locomotive cabs." Specifically with respect to locomotive crashworthiness, this mandate requires the following:

- o an evaluation of the adequacy of Locomotive Crashworthiness Requirements Standard S-580, or any successor standard thereto, adopted by the Association of American Railroads (AAR) in 1989, in improving the safety of locomotive cabs; and

- o conduct of research and analysis, including computer modeling and full-scale testing, as appropriate, to consider the costs and benefits associated with equipping locomotives with:

  - braced collision posts;

  - rollover protection devices;

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[1] *Railroad Communications and Train Control* (Report to Congress pursuant to the Rail Safety Enforcement and Review Act, Public Law 102-365 - Federal Railroad Administration, Office of Safety, July 1994)

- deflection plates;
- shatterproof windows;
- readily accessible crash refuges;
- uniform sill heights;
- anticlimbers, or other equipment designed to prevent overrides resulting from head-on locomotive collisions;
- equipment to deter post-collision entry of flammable liquids into locomotive cabs; and
- any other devices intended to provide crash protection for occupants of locomotive cabs.

Due to the high cost of full scale testing and the limited funding available to perform this research and analysis, FRA did not undertake full scale crash testing of locomotives. FRA's efforts focused on using information gathered from locomotive collision investigations to develop a computer model to predict the benefits—if any—of the locomotive crashworthiness features specified in the Act. The costs associated with implementation of each of the crashworthiness features were also estimated in an effort to determine whether identified changes would be economically practical.

Background

National Transportation Safety Board (NTSB)

Consideration of the recommendations made by the National Transportation Safety Board (NTSB) on locomotive crashworthiness forms an important part of the analysis done to support the Act. NTSB's interest in locomotive crashworthiness dates to 1970, and NTSB has made several safety recommendations to FRA and the industry concerning increased protection for the crew members in the cab.

- On September 8, 1970, a collision between an Illinois Central (IC) and an Indiana Harbor Belt (IHB) train occurred at Riverdale, Illinois. The collision caused the IC caboose to override the heavy underframe of the IHB locomotive demolishing the control cab of the locomotive. Two following cars continued in the path established by the caboose completing the destruction of the locomotive cab. The IHB engineer was found dead in the wreckage. NTSB recommended that FRA and the industry expand their cooperative effort to improve the crashworthiness of railroad equipment (NTSB Safety Recommendation R-71-44).

- An accident on October 8, 1970, involving a Penn Central Transportation Company freight train and a passenger train near Sound View, Connecticut, again demonstrated the weakness of the locomotive crew compartment. This collision caused NTSB to reiterate its recommendation to improve the crash resistance of locomotive cabs (NTSB Safety Recommendation R-72-005). This recommendation was ultimately classified as "Closed—No Longer Applicable" following the issuance of Safety Recommendation R-78-27, which addressed the same issue.

- The investigation of the collision of three freight trains near Leetonia, Ohio on June 6, 1975, again prompted the safety board to recommend increased cab crashworthiness, including consideration of a readily accessible crash refuge (NTSB Safety Recommendation R-76-009). This was classified as "Closed—Acceptable Action" on August 6, 1978, following FRA's assurance that studies were continuing in this area.

- On September 18, 1978, a Louisville and Nashville (L&N) freight train collided head-on with a yard train inside yard limits at Florence, Alabama. The lead unit of the yard train overrode the lead unit of the freight train. The cab provided no protection for the head brakeman and engineer, who jumped but were run over by their train.

- On August 11, 1981, a Boston and Maine Corporation freight train and a Massachusetts Bay Transportation Authority commuter train collided head-on near Prides Crossing, Beverly, Massachusetts. The lead car of the commuter train overrode the freight locomotive pushing components of the locomotive into the cab killing three people.

NTSB's investigations of the above accidents resulted in recommendations to FRA regarding crashworthiness protection to the locomotive operating compartments (NTSB Recommendations R-77-37, R-78-27, R-79-11, and R-82-34). As a result of the FRA-sponsored report, "Analysis of Locomotive Cabs"[2], NTSB classified these four recommendations "Closed—Acceptable Action" on November 24, 1982.

- A rear end collision of two Burlington Northern (BN) freight trains occurred near Pacific Junction, Iowa on April 13, 1983. The operating compartment of the lead locomotive on BN train 64T85 was overridden by the caboose of train 43J05 when the trains collided. The locomotive operating compartment was crushed. In general, when a locomotive strikes a caboose or a light freight car, the lighter vehicle overrides the locomotive—frequently with devastating results. As a result of this accident, NTSB issued a recommendation that FRA initiate and/or support a design

[2] *Analysis of Locomotive Cabs* (Report No. DOT/FRA/ORD-81/84, National Space Technology Laboratories, September 1982)

study to provide a protected area in the locomotive operating compartment for the crew when a collision is unavoidable (NTSB Recommendation R-83-102). This recommendation was subsequently classified as "Closed—Unacceptable Action/Superseded" based on a future investigation that reiterated similar concerns regarding locomotive crashworthiness.

- On July 10, 1986, Union Pacific (UP) freight train CLSA-09 struck a standing UP freight train near North Platte, Nebraska, at a speed of approximately 32 mph. Three locomotives and 11 cars from both trains were derailed, and the accident resulted in one fatality and three injuries. This accident, in which the locomotive cab section of train CLSA-09 was destroyed on impact, probably would have resulted in fatal injuries to the engineer and head brakeman of train CLSA-09 had they not jumped from the cab prior to the collision. As a result, NTSB issued Safety Recommendation R-87-23, which recommends that FRA:

  > Promptly require locomotive operating compartments to be designed to provide crash protection for occupants of locomotive cabs.

NTSB firmly believes that locomotive collision investigations continue to demonstrate that improvements are needed in the crashworthiness design standards of locomotives. This recommendation is currently classified as "Open—Acceptable Response" based on the adoption of AAR Specification S-580 for road locomotives built after August 1, 1990, and the work being done in the area of locomotive crashworthiness for this study.

NTSB has also issued recommendations in other areas addressed in the Act as follows:

- A head-on collision between Iowa Interstate Railroad Limited freight trains Extra 470 West and Extra 406 East on July 30, 1988 within the yard limits of Altoona, Iowa resulted in the derailment of all five locomotive units and 14 cars, including two tank cars containing denatured alcohol. The denatured alcohol was ignited by the fire resulting from the collision of the locomotives. Both crewmembers of Extra 470 West were fatally injured, and the two crewmembers of Extra 406 East were slightly injured. The covered hopper car behind unit 470 apparently elevated on impact, slipped by the standard type E (nonshelf) coupler and overrode the short hood of the locomotive, completely destroying the cab area. As a result of this accident, and in light of a 1982 study prepared for FRA[3] which identified the installation of shelf couplers on locomotives as one possible means of mitigating the problem of override, the NTSB issued Safety Recommendation R-89-51, which recommends that FRA:

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[3] *Analysis of Locomotive Cabs* (Report No. DOT/FRA/ORD-81/84, National Space Technology Laboratories, September 1982)

Promulgate regulations requiring that locomotives be equipped with shelf couplers compatible in strength with the main frame sill of the locomotive.

- On June 15, 1987, Southern Pacific Transportation Company (SP) freight train Extra 7791 West collided head-on with SP freight train Extra 7267 East near Yuma, Arizona, resulting in the death of the engineer of Extra 7267. The locomotive control compartment of Extra 7267 East was crushed and pushed rearward about 22 feet by impact forces. NTSB determined that all occupiable space was eliminated, thus rendering the accident unsurvivable from any position within the locomotive control compartment. It is NTSB's position that the sill is the strongest section in the structural design of a locomotive, and as such, there should be a Federal standard governing locomotive sill height. Accordingly, NTSB issued Safety Recommendation R-88-20 which recommends that FRA:

    Modify Title 49 Code of Federal Regulations Part 229 to require compatible main frame sill height standards.

- On January 18, 1993, Northern Indiana Commuter Transportation District (NICTD) eastbound commuter train 7 and NICTD westbound commuter train 12 collided in a corner-to-corner impact in Gary, Indiana, resulting in seven passenger fatalities and 95 injuries. The damage that both trains sustained after the initial impact resulted from the action of dynamic forces that caused the left front corner and sidewall of the passenger compartment of each car to experience a complete structural failure and intrude inward. Because no structure was available in the corner post areas to successfully absorb the crash forces of the collision, the substantial car body intrusion into each car left no survivable space in the left front areas of either car. Consequently, NTSB issued Safety Recommendation R-93-24, which recommends that FRA:

    In cooperation with the Federal Transit Administration and the American Public Transit Association, study the feasibility of providing car body corner post structures on all self-propelled passenger cars and control cab locomotives to afford occupant protection during corner collisions.

While the above recommendation specifically addresses self-propelled passenger cars and control cab locomotives—and not freight locomotives—current freight locomotive cab structures are similarly vulnerable to corner impacts.

NTSB has become increasingly concerned about the potential for diesel fuel fires resulting from collisions and derailments of locomotives, and the subsequent potential for these fires to fatally injure trapped crew members, consume cargo, contribute to hazardous materials fires in the train, and endanger nonrailroad property near the accident site. As a result of three accidents investigated by NTSB involving diesel fuel fires during 1990, NTSB issued the following Safety Recommendations to FRA:

Safety Recommendation R-92-10: Conduct, in conjunction with the Association of American Railroads, GE, and EMD, research to determine if the locomotive fuel tank can be improved to withstand forces encountered in the more severe locomotive derailment accidents or if fuel containment can be improved to reduce the rate of fuel leakage and fuel ignition. Consideration should be given to crash or simulated testing and evaluation of recent and proposed design modifications to the locomotive fuel tank, including increasing the structural strength of end and side wall plates, raising the tank higher above the rail, and using internal tank bladders and foam inserts.

Safety Recommendation R-92-11: Establish, if warranted, minimum performance standards for locomotive fuel tanks based on the research called for in recommendation R-92-10.

Past Studies of Locomotive Crashworthiness

Boeing Vertol

In the 1970's, the Boeing Vertol Company conducted two study programs for FRA[4] which included work related to the protection of crew members in locomotive cabs. The first study was conducted in three phases to evaluate and improve the crashworthiness of passenger-carrying vehicles in intercity service. Phase I surveyed the accident data and identified those areas responsible for the majority of accidents involving human injury. Phase II extended the structural survey to the caboose and the locomotive cab. Phase III developed a preliminary design for a crash-survivable locomotive cab and included both static and dynamic analyses of crash scenarios.

Boeing Vertol analyzed the structure of a GP40 locomotive in Phase II of the study. The analysis showed that the cab and superstructure of the locomotive were understrength compared to the structure of an overriding vehicle whether it be another locomotive or a freight car. This led to the examination of ways to increase the resistance of the cab to crushing. The model used for analyzing collision effects included representation of the couplers, draft gear, and trucks. The superstructure was represented by several lumped masses.

Phase III of the program involved a detailed study of the locomotive cab. It included the design of a deflection shield, a cab protective superstructure, and the forward section of the underframe. The work included analytical studies to establish the crash environment and to develop a simple dynamic analysis of the collision.

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[4] *A Structural Survey of Classes of Vehicles for Crashworthiness* (Edward Widmayer, Report No. FRA/ORD-79-13, Boeing Vertol Company, September 1979)

The summary report presented a sketch of a proposed structural arrangement for the front end of a locomotive which would protect the occupants of the cab in almost all accident situations. The proposed structural arrangement was a radical departure from present design practice and included heavy structural members around the cab.

The second study concerned itself with the safety aspects of the interior environment of rail vehicles and addressed the problem of secondary impact effects on the occupants of locomotives, cabooses, and passenger cars. This study also included an analysis of railcar accidents including passenger railcar collisions, derailments, and motions causing occupant injuries.

As a result of these studies, locomotive manufacturers in the U.S. and Canada worked closely with the Locomotive Control Compartment Committee (LCCC) to develop and test mock-ups of locomotives that incorporated improved structural protection for crew members in the event of a collision. The LCCC is a group that was formed in June 1971, consisting of representatives from FRA, AAR, UTU, and BLE, whose stated purpose is to:

> "explore the possibility and/or feasibility of effective improvements in the design, location, and construction of locomotive control compartments to enhance the safety of cab occupants in the event of collisions or derailments, and to achieve an optimum environment under normal operating conditions."

With support from the LCCC, this work by locomotive manufacturers to develop improved locomotive designs—prompted by both the NTSB recommendations regarding improved crashworthiness and the findings of the subject Boeing reports—led to the adoption of AAR S-580 in September 1989.

IIT Research Institute (IITRI)

Under support from FRA, IITRI analyzed head-on collisions between various combinations of two types of locomotives—a General Motors Corporation Electro-Motive Division model SD60M and a General Electric Company model C40-8[5]. The locomotives were assumed to be equipped with the crashworthiness features specified by AAR Specification S-580. The collision of single locomotives, three locomotive unit consists, and three locomotive, 100 loaded car trains were analyzed. The analyses were used to establish the speeds at which one locomotive would be expected to override the other and penetrate the cab of the overridden locomotive. Results of the analyses indicated that override and cab crush could occur in a head-on collision

[5] *Assessment of Crashworthiness of Locomotives* (Milton R. Johnson, IIT Research Institute Project V06200, September 1993)

between freight trains at closing speeds as low as 22 mph in selected collision scenarios.

Additional analyses were conducted to determine the effects on collision phenomena of raising the peak collision force that could be tolerated and the absorption of more energy. Results showed that if protection is to be afforded to cab occupants in the relative collision speed range of 60 to 80 mph, major structural modifications would be required. These modifications would have to provide design features which would allow colliding locomotives to pass by one another, either side-to-side or by override, and yet maintain the structural integrity of the cab space.

Peer review of this research indicated disagreement regarding its immediate applicability to development of performance criteria, and led to development of the more detailed research design discussed below.

Approach

To meet the crashworthiness investigation requirements of the Act, FRA planned a further research and analysis program consisting of the following tasks:

Establish and maintain a locomotive collision data base. The need for this data base and its uses are discussed in Chapter 2.

Analyze the data compiled for each accident reported for entry into the data base, taking into account the dynamics of each situation to estimate:

- o the total energy of the collision;
- o how the energy was dissipated;
- o the peak forces reached in the control cab area;
- o how and why structural damage occurred;
- o how and why crew members were injured; and
- o what existing features provided crew protection and how.

Develop a computer model using the analysis of collision data to correlate crew injury probability to the dynamic parameters of the collision. The model should avoid unnecessary complexity to make first order predictions on how changes to the locomotive structure change the dynamics of the collision and thus affect the probability of crew injury.

The model shall predict the dynamic motion and structural response of locomotives to the forces developed during collisions. The model shall account for how all the kinetic energy of the train(s) involved in the collision is dissipated. Using only that portion of the kinetic energy that is transmitted to the structure of each locomotive involved in the collision, the model shall predict the structural damage to each locomotive as a result of the collision.

Verify the computer model by using it to predict the results of accidents contained in the data base. Compare the predicted motion and structural damage to the motion or position of the locomotives after the collision and the structural damage actually observed as part of the accident investigation. Adjust the parameters of the model to make the predictions as accurate as possible.

Determine the effectiveness of AAR Specification S-580. Through evaluation of accident reports used in the formation of the data base, assess the effectiveness of each of the locomotive crashworthiness requirements of AAR Specification S-580 in lessening the effects of collision dynamics and decreasing the probability of crew injury or fatality.

Model crashworthiness features specified in Section 10 of RSERA. Determine how to practically and economically implement each of the listed crashworthiness features into the design of a locomotive. Sketches and conceptual specifications must be developed to describe how each feature is incorporated into the structure of the locomotive. How a crashworthiness feature is implemented into the design of a locomotive strongly influences how effective that feature will be in providing additional protection to cab occupants. As such, a balance of effectiveness against cost and practicality of implementation must be established for each crashworthiness feature modeled.

Predict how crashworthiness features affect structural damage. The model shall predict and compare the structural damage, particularly in the cab area, for locomotives equipped with each crashworthiness feature to the baseline case of the same locomotive without the feature included.

Prediction of additional protection provided to cab occupants. A means to predict the extent of injury likely to occupants of the locomotive cab based on the structural damage to the cab and the accelerations imparted to cab occupants due to forces generated during a collision will be established. The model shall predict and compare the likelihood and extent of injury for cab occupants for the baseline cases to the likelihood and extent of injury predicted for locomotives equipped with each of the crashworthiness features in the Act.

Prioritization of features and recommended future locomotive design. Based on the potential to provide additional protection to cab occupants as shown by the results of the modeling, estimated cost to implement, and practicality to implement, a prioritized list of crashworthiness features and specific recommendations for future locomotive design requirements will be established.

FRA established and maintains the locomotive collision data base described above. FRA contracted the other tasks to Arthur D. Little, Inc. (ADL).

Model Development

FRA did not conduct full-scale crash testing of locomotives due to its prohibitive cost. A single crashworthiness test using two structurally modified locomotives tested at two crash speeds (35 mph and 50 mph) is estimated to cost between 1.5 and 2 million dollars. This estimate does not include possible representative scale testing used to simulate crash scenarios. For these reasons, the primary function of the collision data base became to provide a means to validate the accuracy of computer models developed by ADL to predict the results of collisions in terms of damage to the locomotives and injuries to crew members.

The development of a computer model and the choice of accident types to which it should be applied was guided by many aspects of train collisions, including the possible and likely collision modes, locomotive structural design, and considerations on how colliding locomotives interact. Three primary types of collisions between two trains exist: (1) head-on; (2) rear-end; and (3) side impact. Of these, the head-on collision represents the greatest threat to the locomotive crew. Grade crossing accidents and rear-end collisions in which a lead locomotive is involved also challenge the front end, but less seriously than in a head-on collision. The AAR S-580 specification, with its emphasis on front-end components, is clearly directed toward protection against the head-on collision. For these reasons, the head-on collision scenario was selected as the primary crash scenario type with which to evaluate crashworthiness design concepts.

Three different computer models were developed to evaluate the effectiveness of the various crashworthiness features identified in the Act. The **structural damage model** generates the load-crush curves for the important front-end structural components. These curves are used as input to the lumped mass **collision dynamics model**, which calculates the amount of cab crush and the cab acceleration vs. time, also called the crash pulse. The crash pulse is the primary input to the **occupant survivability model** that determines accelerations that a simulated occupant could experience. Each of these three models must be exercised to predict the results of a given collision scenario. A brief description of each of the above models is provided as follows:

- o **Structural Damage Model.** The structural damage model is based on elastic-plastic finite element analyses carried out using the commercially available computer program ABAQUS[6]. Analyses were conducted for three sets of components: (1) the draft gear support structure/underframe; (2) the anticlimber/underframe; and (3) the short hood structure/collision posts. Analyses included the effects of plastic deformation and elastic and plastic buckling with crush values in excess of one to eight feet. Analyses made for actual components used on currently manufactured locomotives showed that the strength requirements of AAR Standard S-580 for anticlimbers and collision posts are substantially exceeded.

- **Collision Dynamics Model.** The collision dynamics model is a lumped mass model carried out using the commercially available computer program ADAMS[7]. Each locomotive in the consist is modeled as having three masses: the body and two trucks. These masses are connected by springs and dampers that include, for example, the effects of lift-off from the trucks during an override. The lead locomotives in the model include three impact elements to represent the important structural elements described in the previous paragraph.

  An important feature of the collision dynamics model is that override is purposely initiated by including a ramp on one of the lead locomotive anticlimbers. This is based on the assumption that, given sufficient collision force, the asymmetric deformation of components that occurs on impact leads to initiation of override. However, in the model as developed, override arrest will be predicted as long as the structural energy absorption capability exceeds the energy available to be absorbed.

  For most of the calculations, motion is restricted to a vertical plane that includes the track; that is, no lateral motion is allowed. Separate calculations made by ADL in the study show that lateral buckling or derailment of trailing vehicles has little effect on the crush and crash pulse of the lead locomotive. However, such a derailment has a substantial effect on dissipating the energy of trailing vehicles and is nearly always associated with head-on collisions of significant closing speed. Separate calculations in this study also showed it was not necessary to include non-locomotive trailing vehicles in the collision dynamics model to predict the collision effects to the lead locomotive.

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[6] ABAQUS. Hibbitt, Karlsson & Sorensen, Inc., 1080 Main St., Pawtucket, RI 03860

[7] ADAMS, Solver Reference Manual, Mechanical Dynamics, Inc., 2301 Commonwealth Blvd., Ann Arbor, MI 48105, 1993

- **Occupant Survivability Model.** The occupant survivability model is based on the commercially available program ATB[8] (Articulated Total Body). The occupant is simulated by a set of connected lumped masses designed to represent anatomical behavior of a 50th percentile male. For most of the analyses, the occupant was modeled as lying face down, transverse to the direction of travel, and in the rear of the cab to ride down the collision. The cab surfaces modeled included two seats with posts, two side-walls and a front panel with an opening to represent the stairs down to the nose of the hood. The model uses the crash pulse as input and calculates the trajectory of the occupant and various force and acceleration values to which the occupant is subjected as he/she impacts various surfaces.

Occupant Survivability Measures

The potential benefit of the crashworthiness design features examined required definitive measures and standards by which occupant injury potential in a train accident could be evaluated. Such methods and criteria, however, have yet to be formulated for occupied rail (and, in general, all guided ground transportation) vehicles. Consequently, selected protocols which assess occupant survivability in other types of civilian passenger transport vehicles were employed for this purpose.

Three occupant survivability measures were used to evaluate the relative risk of injury or fatality: cab crush, the Head Injury Criterion (HIC), and the Resultant Chest Acceleration (C_R). A crush of 6 feet beyond the tip of the short hood was taken as the value that would eliminate survivable space in the cab. This value corresponds approximately to crush up to the front console; however, it was assumed that for this crush, the debris forward of the console would be pushed into the cab, eliminating the survivable space.

As no secondary impact measures have been adopted for guided ground transportation, two quantitative injury-indicator parameters widely accepted for use in analyzing highway accidents were employed: (1) an acceleration-based algorithm called the Head Injury Criterion (HIC), and (2) the resultant translational acceleration of the center of gravity of the chest (C_R). Table 3-1 defines these measures and specifies commonly accepted thresholds that should not be exceeded. Both measures are currently prescribed in the U.S. Department of Transportation (DOT)/National Highway Traffic Safety Administration (NHTSA) as part of Federal Motor Vehicle Safety Standard (FMVSS) 208[9]. This standard includes a

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[8] Obergefell, L.A., Gardner, T.R., Kaleps, I., and Fleck, J.T., *Articulated Total Body Enhancements, Volume 2, User's Guide*, Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH, Report No. AAMRL-TR-88-043, January 1988

[9] Title 49, Code of Federal Regulations: Part 571

Body Region	Requirement
Head	The resultant acceleration at the center of gravity of the head shall be such that the expression (the Head Injury Criterion, HIC): $$\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5} (t_2 - t_1)$$ shall not exceed 1,000, where a is the resultant translational acceleration expressed as a multiple of g (the acceleration of gravity), and t_1 and t_2 are any two points in time during the crash of the vehicle which are separated by not more than a 36 millisecond time interval and which maximizes the integral
Chest (Thorax)	The resultant translational acceleration at the center of gravity of the upper thorax shall not exceed 60 g's, except for intervals whose cumulative duration is not more than 3 milliseconds

Table 3-1 Selected Biomechanical Measures of Occupant Survivability

rigorous full-scale crash test of a vehicle into a flat, rigid barrier at 30 mph. Body region accelerations recorded by instrumentation embedded in two front-seated dummies are used to calculate the HIC and C_R. All small-cabin volume motor vehicles and certain classes of buses must demonstrate compliance with FMVSS 208 in order to be sold and allowed to operate on U.S. roadways. The DOT/Federal Aviation Administration (FAA) also utilizes the HIC as part of its injury criteria for the occupants of various civil aircraft under applicable Federal Aviation Regulations[10]. The HIC acceptance value for both NHTSA and FAA is 1000, as this is the level above which serious injury will likely occur. As stated above, similar acceptance measures have not been developed for guided ground transportation modes, and FRA currently has no regulations regarding acceptable levels of occupant injury potential. Although there exists some controversy regarding the meaning and utility of the HIC and the C_R measures, they appear to constitute the best available means of quantifying the severity of typical secondary-contact type injuries that could occur in the cab of a locomotive.

It should be noted that the maximum allowable thresholds listed in Table 3-1 actually represent a single coordinate on a specific injury risk function curve. Various injury risk functions exist; they are derived using inputs from biomechanical test data and accident statistical analyses and reflect a prescribed Abbreviated Injury Scale (AIS) classification. As such, they define the full range of injury probability over a continuum of index values

[10] Title 14, Code of Federal Regulations: Parts 23, 25, 27, and 29

ranging from nearly zero to well beyond the maximum human tolerance limits stipulated in Table 3-1. Risk functions were employed in this program to compute the probability of moderate or serious injury to the cab occupant corresponding to calculated HIC and C_R values provided by ATB.

The risk function selected for assessment of possible head injury is depicted in Figure 3.1. It relates the magnitude of the HIC to the probability of sustaining a minimum AIS ≥2 level (moderate) injury, i.e., the occurrence of linear skull fracture and/or a state of unconsciousness lasting less than one hour. Examination of this curve indicates that 90 percent of the general population would *not* be expected to sustain such injury (i.e., only 10 percent would be expected to incur AIS ≥2 trauma) if the HIC did not exceed 262. In the context of the tolerance limit defined in Table 3-1, a 1000 HIC is associated with a 44 percent probability that the general population would be likely to suffer injuries of this nature.

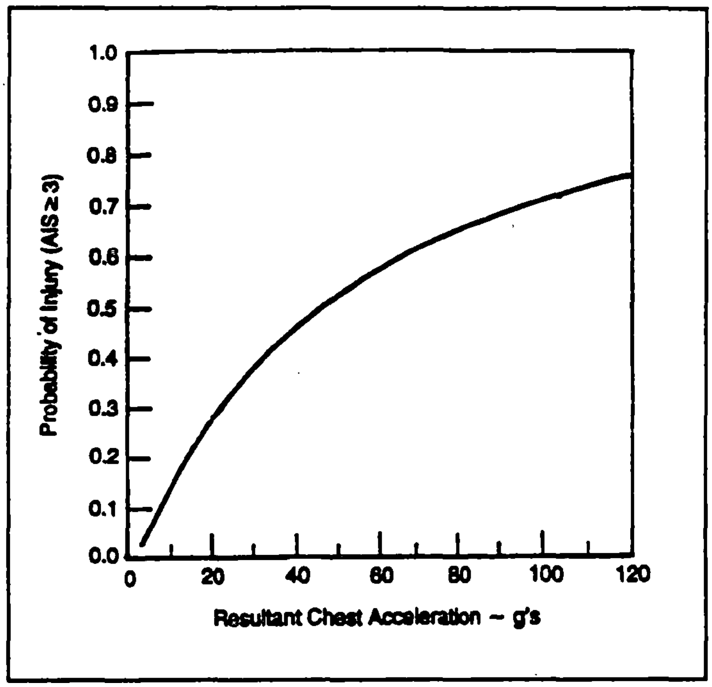

Figure 3.2 Probability of Thoracic Trauma as a Function of Resultant Chest Acceleration

Figure 3.2 shows the risk function selected for evaluation of possible chest injury. It relates the magnitude of C_R to the probability of sustaining a minimum AIS ≥3 level (severe) general thoracic trauma, i.e., the occurrence of various rib fracture mechanisms with or without hemothorax or pneumothorax. This curve indicates that 90 percent of the general population would *not* be expected to be injured in this manner (i.e., only 10 percent would be expected to suffer such trauma) if the C_R remained below 8 g's. Inspection of this profile shows that there is a 57 percent probability that the general population would be likely to incur this type of injury if subjected to the 60 g C_R tolerance limit noted in Table 3-1.

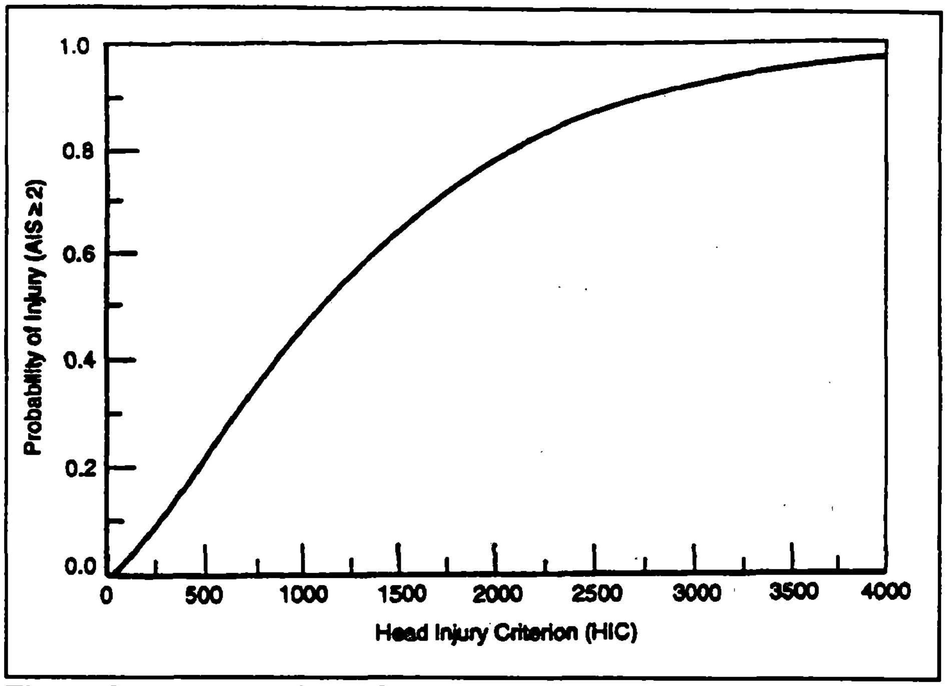

Figure 3.1 Probability of Head Trauma as a Function of the Head Injury Criterion

Probability curves are available for other injury, or AIS, levels. However, the AIS ≥2 level for HIC and AIS ≥3 for C_R were chosen because they seemed to best correspond to the onset of "serious" injury. Table 3-2 illustrates the relationships between the AIS Code, the HIC value, and the C_R value as they relate to specific injuries.

For modeling purposes, it is very difficult to specify a typical initial baseline occupant configuration and position in the cab, as unrestrained occupants of the cab have the freedom and space to do virtually anything just prior to a head-on collision. A "defensive" mode, which modeled the occupant lying on the floor near the rear of the cab in a lateral, prone, face-down posture, with outstretched arms, was selected for this purpose. Preliminary exploratory analyses demonstrated that the injury indicating parameters generated by ATB were sensitive to the exact location of the occupant relative to cab interior systems such as seats and the front walls. Consequently, ATB was exercised with four different lateral occupant positions in the cab in an effort to obtain an average and range of calculated survivability measures.

Table 3-2 AIS Code, HIC, and C_R Relationships

AIS Code	HIC	Head Injury	Chest Deceleration (C_R)	Chest Injury
1	135 - 519	Headache or dizziness	17 - 37 g's	Single rib fracture
2	520 - 899	Unconscious less than 1 hour; linear fracture	38 - 54 g's	2 to 3 rib fractures; sternum fracture
3	900 - 1254	Unconscious 1 to 6 hours; depressed fracture	55 - 68 g's	4 or more rib fractures; 2 to 3 rib fractures with hemothorax or pneumothorax
4	1255 - 1574	Unconscious 6 to 24 hours, open fracture	69 - 79 g's	greater than 4 rib fractures with hemothorax or pneumothorax; flail chest
5	1575 - 1859	Unconscious more than 24 hours; large hematoma	80 - 90 g's	Aorta laceration (partial transection)
6	> 1860	Fatality	> 90 g's	Fatality

- In two of these simulations, the occupant was positioned to ensure that head and/or upper torso contact with some part of the engineer's seat assembly would occur during crash ridedown. In one, the occupant was nearly touching the wall, while in the other, the occupant was positioned 10.5 inches forward of the wall.

- The other two baseline simulations were conducted with the occupant positioned near the center of the cab to avoid head and torso contacts with the seats in the cab. The same spacings described above were used in these runs.

Model Validation

ADL selected three head-on collisions from the FRA collision data base for comparison to results generated by the computer models. To the extent possible, actual masses and component strengths were used for the specific locomotives involved in the accidents. Comparison of the model predictions to the actual observations for the three accidents chosen demonstrate a high degree of similarity, and are in good agreement with respect to the extent of longitudinal crush and crash pulse for overridden locomotives.

(A) **FRA Report C-58-91.** This accident was a head-on collision between a stationary train and another moving at 18 mph. The stationary consist had three locomotives and the moving consist only one. None of the locomotives satisfied AAR S-580. The collision, for which there are no photos available, resulted in only minor damage to the front-end components. There was no override and no injuries.

The results from the ADAMS model are similar to the observations for this accident. The model predicted less than 1 inch of crush in the draft gear support structure at the point of maximum crush.

(B) **FRA Report B-02-93.** This accident was a head-on collision of two trains, the first with two locomotives traveling at 9 mph and the second with five locomotives traveling at 21 mph for a closing speed of 30 mph. Again, none of the locomotives satisfied the requirements of AAR S-580. The collision resulted in override of the lead locomotive of the 9 mph train onto the lead locomotive of the other train causing substantial crush to the cabin and an occupant fatality.

The ADAMS model predicts override and substantial crush of the short hood structure and cab. The model predicts approximately 10 feet of crush beyond the tip of the short hood, compared to approximately 7-8 feet actually observed from examination of photographs of the accident.

(C) **FRA Report C-10-94.** This accident was a head-on collision between a single locomotive consist traveling at a speed of 25 mph colliding with a three locomotive consist traveling at 18 mph for a closing speed of 43 mph. The lead locomotive of the 18 mph consist, which was built in early 1991 and satisfied the requirements of AAR S-580, was overridden but the collision posts were effective in arresting the override. There were only minor injuries as a result of the accident. From photographs, it appears that the short hood has been crushed about 2 feet.

The model results show that override is expected to occur, and the predicted crush of the short hood/collision post structure is about 4.5 feet.

An important result of the model validation simulations is the prediction of complete failure of the draft gear support structure of the overriding locomotive. This failure is largely responsible for enabling complete override to occur, since the anticlimber/underframe of the overridden locomotive encounters no resistance below the underframe of the overriding locomotive since the trucks are not secured to the underframe. Side view photographs of the overriding locomotives in representative accidents also show complete failure of the draft gear support structure.

In general, both model results and photographs from the three chosen accidents show that the anticlimber of the overridden locomotive is not challenged vertically during the head-on collision. Rather, it is crushed and then sheared by the opposing anticlimber/underframe structure. This suggests that the anticlimber is not effective in preventing override, and is confirmed to some extent by examining two head-on collisions studied by ADL in which override occurred at medium (30 and 43 mph) closing speeds. However, the anticlimber is probably very effective in preventing the rise of debris from grade crossing type accidents.

Baseline Crash Scenario

ADL used an actual head-on collision (accident (B) as described above) as a basis to model a "baseline" crash scenario—one that predicts the amount of cab crush and the loss of survivable space for a locomotive just meeting the requirements of AAR Standard S-580. In this collision, a train with two locomotives and 15 trailing vehicles traveling at a speed of 9 mph collided head-on with a train with five locomotives and 92 trailing vehicles traveling at a speed of 21 mph giving a closing speed of 30 mph. In this collision, the lead locomotive of the 21 mph train was overridden by the lead locomotive of the 9 mph train resulting in one fatality in the overridden locomotive due to about 10 feet of cab crush. Although the lead locomotive did not strictly satisfy the requirements of AAR Standard S-580—its anticlimber at the short hood end did not extend across the entire width of the locomotive—calculations suggest that the resulting crush would have been comparable had the lead, overridden locomotive satisfied AAR S-580. This is primarily due to the assessment presented in the previous paragraph that the anticlimber as specified by AAR S-580 is ineffective in preventing override.

Summary of Results

Effectiveness of AAR Specification S-580

In 1989, AAR adopted Specification S-580 which defined minimum standards for collision protection on new road locomotives built after August 1, 1990. The specification requires that all road locomotives built after this date be equipped with the following crashworthiness design elements:[11]

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[11]AAR Specification S-580 is provided in its entirety in Appendix B.

- o An anticlimber arrangement attached to the short hood end of the locomotive designed to withstand a minimum of 200,000 pounds without exceeding the ultimate strength of the material, when applied vertically and uniformly between the center sill webs under the anticlimbers of the locomotive. This anticlimber arrangement is attached to the underframe end plate in line with the center sill webs..

- o A minimum of two collision posts, located on the underframe longitudinals (center sills), designed to withstand a longitudinal force of 200,000 pounds each at 30 inches above the deck and 500,000 pounds each at the underframe deck without exceeding the ultimate strength of the material.

- o A short hood end-facing skin consisting of the equivalent of 1/2-inch steel plate with a 25,000 psi yield strength.

Throughout the informal industry meetings, each of the locomotive manufacturers (General Electric (GE), General Motors Electro-Motive Division (EMD), and Morrison Knudsen (MK)) clearly stated that they felt AAR S-580 is effective in improving locomotive crashworthiness. The manufacturers did not, however, substantiate this with post-accident evaluations or analytical comparisons to pre S-580 locomotive designs. As noted in Chapter 2, crash data is very limited for locomotives built in compliance with the requirements of AAR S-580. Because of this limited data sample, a clear evaluation of the level of effectiveness of the crashworthiness features implemented via this standard is difficult. In the limited number of collisions involving locomotives built to AAR S-580, these locomotives have demonstrated improved protection to crew members over previous designs.

While the adoption of AAR S-580 requirements in locomotive design is a definite improvement over previous designs, this report identifies both strengths and weaknesses in the specification as currently written. Specifically:

- o The anticlimber described in AAR S-580 provides effective protection only at very low speeds. The computer model shows that the anticlimber of an overridden locomotive is not challenged vertically during the head-on collision. Rather, it is crushed and then sheared by the opposing anticlimber/underframe structure. While the present anticlimber design may be effective in limiting the damage sustained in grade crossing type accidents, improved anticlimber designs are needed if they are to aid in protection of the crew in head-on collisions.

- o The collision posts, with strength as stipulated in AAR S-580, have proven to be beneficial with respect to protecting crew members. However, this report will clearly show that collision posts can easily be made stronger and more effective with minimal cost and weight penalties.

- o The short hood steel plate has been effective, in part, in preventing the entry of flammable liquids spilled as a result of a collision or derailment into the locomotive cab.

FRA followed a three step process described below to compare the effectiveness of AAR S-580 and the specific crashworthiness features identified in the Act.

- o FRA applied the baseline crash scenario used to validate the model to a locomotive simulated to just satisfy the requirements of AAR S-580. From this, a measure of the cab crush and the predicted loss of survivable space was determined for the locomotive just meeting AAR S-580.

- o Subsequently, a collision of a locomotive equipped with one of the crashworthiness features listed in the Act, in addition to just satisfying the requirements of AAR S-580, was modeled and evaluated to determine the measure of cab crush and the predicted loss of survivable space. This was done separately for each of the crashworthiness features specified in the Act.

- o The values obtained for cab crush and loss of survivable space for implementation of each of the crashworthiness features were compared to the corresponding values for the baseline condition of the locomotive which just satisfied the requirements of AAR S-580.

Application of the baseline crash scenario described previously to a locomotive simulated to **just** satisfy the requirements of AAR S-580 yielded the following measures of crashworthiness:

- o Total short hood/collision post crush of 8 feet. This exceeds the estimate identified earlier that a crush of 6 feet beyond the tip of the short hood is taken as the value that would eliminate survivable space in the cab. This value of 6 feet corresponds approximately to crush up to the front console; however, it was assumed that for this crush, the debris forward of the console would be pushed into the cab, eliminating the survivable space.

- o Peak cab acceleration of 11 g's. This peak acceleration, illustrated in the locomotive crash pulse in Figure 3.3, occurs early in the collision due to the stiff draft gear support structure.

o Secondary impact[12] measures as follows, and as detailed in Table 3-3:

- HIC values ranged between 11 and 260 for the four simulations run using different occupant positions as described previously, with an average value of 159. This average HIC value of 159 corresponds to a less than 5 percent probability of moderate head injury for the simulated occupants.

- C_R values ranged between 16 and 27 for the same four simulations, with an average value of 20. This average level of acceleration is associated with serious thoracic trauma for about 27 percent of the simulated occupants.

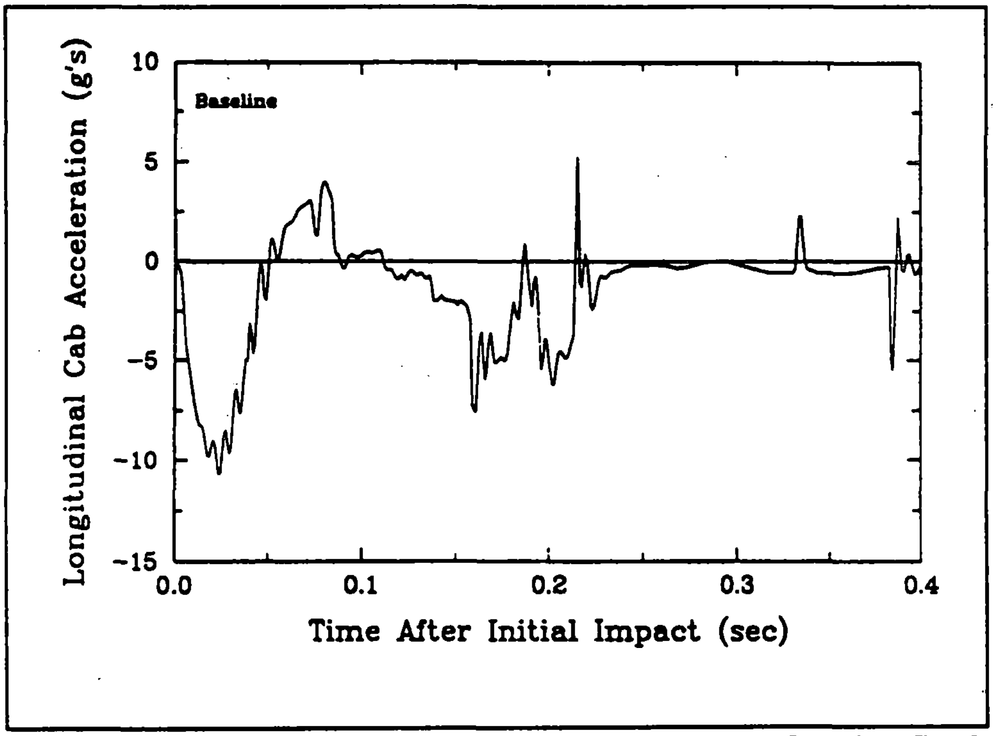

Figure 3.3 The Locomotive Cab Crash Pulse for the Baseline Crash Scenario

[12] These secondary impact measures are provided to illustrate that such a collision may be survivable if cab crush can be prevented. However, as cab crush of 8 feet is predicted for this collision, the secondary impact measures become irrelevant as the survivable space in the cab is eliminated thereby crushing cab occupants.

Table 3.3. **Locomotive Cab Occupant Response to the Baseline Crash Scenario**

Occupant Position in Cab	Head Response - HIC	Torso Response - C_R (g's)
Behind engineer's seat, against rear wall	260	16
Behind engineer's seat, forward of rear wall	11	18
Center of cab, against rear wall	166	18
Center of cab, forward of rear wall	197	27

These HIC and C_R values are directly influenced by the location, nature, and timing of multiple body region contacts with cab interior surfaces. The four simulations indicated that a variety of direct and indirect impacts (i.e., contact cushioned by an arm) could occur. Head contacts were made with the floor, engineer's seat support, and front cab wall. Torso contacts were made with the floor, underside and exterior (unpadded) back surface of the engineer's seat, and front cab wall.

The occupant survivability measures calculated for this baseline case, while demonstrating some probability of severe injury, generally suggest the crew remaining in the cab in this collision could have survived had override and substantial crush not occurred.

Braced Collision Posts

Collision posts are members of the end structure projecting upward from the underframe to which they are securely attached, and provide protection of occupied compartments from penetration during a collision.

Current Practice AAR Specification S-580 requires that collision posts have an ultimate strength of 500,000 lbf each for a longitudinal load applied at the deck level and an ultimate strength of 200,000 lbf each for a longitudinal load applied 30 inches above the deck. Current freight locomotives in the United States achieve these strengths by utilizing a solid plate element welded to the underframe in some manner. The plate material is an alloy steel ranging in yield strength from 50 ksi or higher. Calculations suggest that the ultimate load carrying capacity of currently employed posts exceeds the S-580 requirement by more than a factor of two. For example, Canadian National requires that each post sustain a longitudinal load of at least 800,000 lbf at 30 inches above the deck. This is achieved by using high strength material with conventional geometry. The posts currently used (two per locomotive) are estimated to weigh between 600-900 pounds each depending on the manufacturer and model.

Concept Description The collision post geometry selected for analysis and modeling is illustrated in Figure 3.4. It is tapered in the vertical direction with a cross section that resembles a structural wide flange beam, and has a total height of 71 inches. This represents a significant increase over the current AAR S-580 requirement of 30 inches. It appears feasible to fix this revised post in the same location as the current posts—it would also be welded to the short hood structure. This geometry was found to provide a good balance between minimum weight and maximum load carrying capacity. The tapered geometry takes advantage of the need for greater bending resistance at the base than at the point of load application. The same 50 ksi yield strength material used for the baseline case was used in this geometry. The post was designed to provide the same weight as the collision post analyzed for the baseline scenario.

Various forms of collision posts were considered before selecting the geometry shown in Figure 3.4. These included posts of similar geometry made of higher strength materials, posts of similar materials with cross sections providing larger plastic bending strengths, and multiple posts to even out the load crush curve and provide a deliberate ramping action for a potentially overriding locomotive.

Details for the method of welding such a post to the underframe were not investigated. However, one possibility is to weld the proposed web directly over the web of the primary underframe beams and to carry the post flanges through the deck for welding along the web of the underframe beam webs. Some builders are currently using such attachment methods for collision posts.

Quotes obtained from vendors for the welded collision post structural shapes suggest a price of about $500/post. An estimate of the differential cost over current designs, including welding to the underframe, is about $1,000 for both posts.

As a note, there is a strength limit for the collision posts beyond which bending of the underframe, rather than the posts, will occur. This limit is about 1,500,000 lbf per post at 30 inches above the deck.

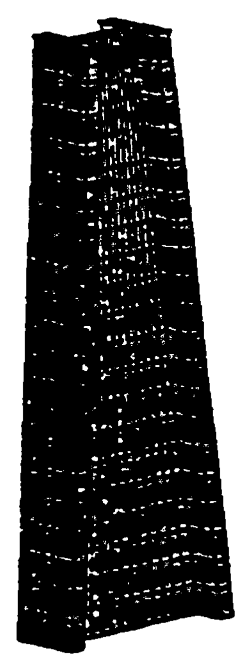

Figure 3.4 Finite Element Mesh Depiction of the Concept Collision Post

Evaluation The load-crush curve for the concept collision posts is shown in Figure 3.5, indicating that the ultimate strength is 800,000 lbf per post for a load applied 30 inches above the deck. This value is four times the value specified in AAR S-580. Recalling that such a strength is currently achieved through utilization of high strength material with conventional geometries, substantially higher collision post strengths are likely achievable via alternate designs.

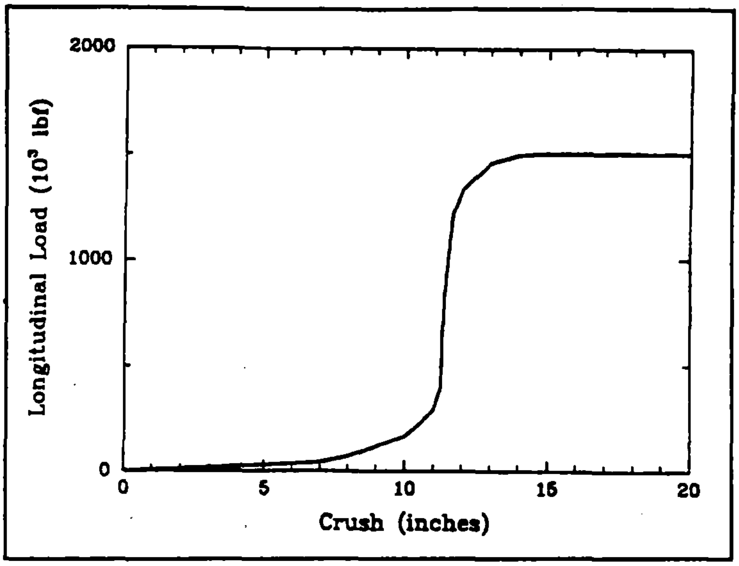

Figure 3.5 Calculated Load-Crush Curve for the Concept Short Hood/Collision Posts

The collision dynamics model results indicate that cab crush is substantially reduced when the concept collision post replaces the post that just satisfies AAR S-580 in the baseline scenario. The predicted short hood/collision post crush for this concept is **only 1 foot compared to the baseline value of 8 feet.** Peak acceleration in the simulated collision with the stronger collision posts is the same as for the case that just satisfies AAR S-580. However, the pulse shown in Figure 3.6 differs from the baseline crash pulse at later times in the collision.

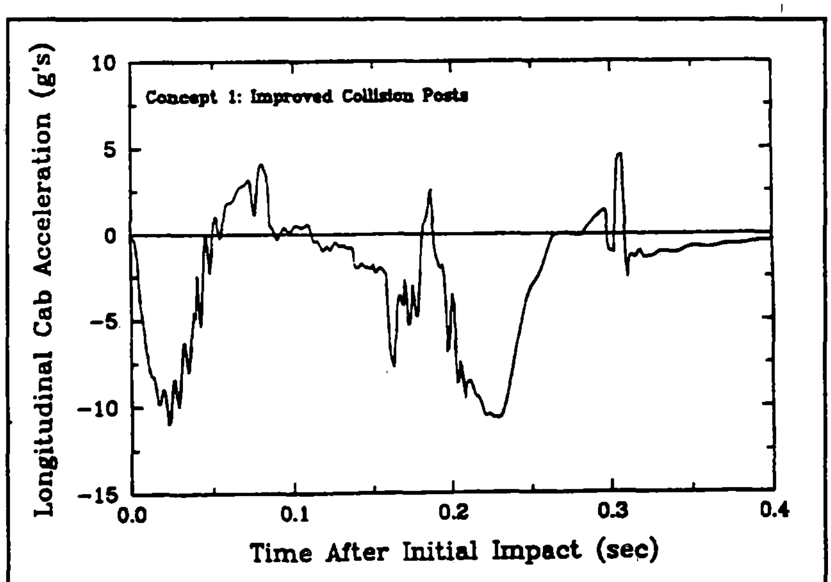

Figure 3.6 Cab Crash Pulse for the Concept Collision Post Locomotive

Four ATB simulations were conducted using occupant positions in the cab identical to those employed with the baseline crash scenario, with the results shown in Table 3-4. The HIC exhibited a wide range of values from a low of 55 to a high of 725; the average magnitude was 332 compared to 160 in the baseline scenario. The injury risk function indicates that approximately 12 percent of the simulated occupants would be likely to suffer a minimum level AIS ≥ 2 head trauma for this average exposure. The C_R values displayed a relatively narrow variance—from a low of 27 to a high of 44 g's. The average C_R value was 37 g's, as compared to 20 g's in the baseline scenario. This magnitude of acceleration would subject about 43 percent of the simulated occupants to the chance of sustaining a minimum level AIS ≥ 3 general thoracic trauma.

Table 3-4. Locomotive Cab Occupant Response for the Braced/Higher Strength Collision Post Concept

Occupant Position in Cab	Head Response - HIC	Torso Response - C_R (g's)
Behind engineer's seat, against rear wall	725	36
Behind engineer's seat, forward of rear wall	55	27
Center of cab, against rear wall	157	39
Center of cab, forward of rear wall	390	44

As was the case with simulations conducted with the baseline locomotive crash pulse, the above two injury parameters were highly dependent on secondary impact considerations. Key head impacts occurred with the floor, support, underside, and exterior (unpadded) back surface of the engineer's seat and front wall. The severity of some of these contacts were mitigated by the cushioning presence of an arm between the head and a cab interior surface. The torso contacted the floor and front wall of the cab.

The results presented above are based on the baseline crash scenario, utilizing a 30 mph closing speed to determine measures of crush and occupant survivability. Further calculations were conducted at higher closing speeds for the baseline scenario (a two locomotive consist colliding with a five locomotive consist) in which the lead locomotives were equipped with the concept improved collision posts having a strength of 800,000 lbf each at 30 inches above the deck. Computations at higher closing speeds show that the survivable cab volume is consumed at a closing speed of about 40 mph for this configuration. This represents an increase in closing speed at which survivable volume remains of about 10 mph over that predicted to be provided by a locomotive whose collision posts just satisfy AAR S-580.

Rollover Protection Devices

Rollover protection devices are structural reinforcement of the sides and/or roof of the locomotive. These devices are intended to make the cab volume less vulnerable to crushing or penetration in the event the locomotive rolls during a collision, and to a lesser extent in the event the locomotive is struck from the side.

Current Practice There are no current industry or Federal specifications for rollover protection in freight locomotives. While it is commonly accepted that existing hardware such as engine components and the electrical cabinet located at the rear of the cab could provide some protection in the event of rollover, such protection has not been verified through testing and/or actual accident evaluation.

Concept Description Figure 3.7 illustrates the roll bar concept generated and analyzed through the modeling effort. It is essentially a structural frame located near the front of the cab attached to the underframe at each side of its base. The estimated structural member sizes required to support rollover loads are large enough to require some redesign of the front cab—otherwise, there would be some obstruction of vision. An additional frame located at the rear of the cab was contemplated, but was not included due to the added weight and the likelihood that the equipment in the long hood would provide some support during a rollover.

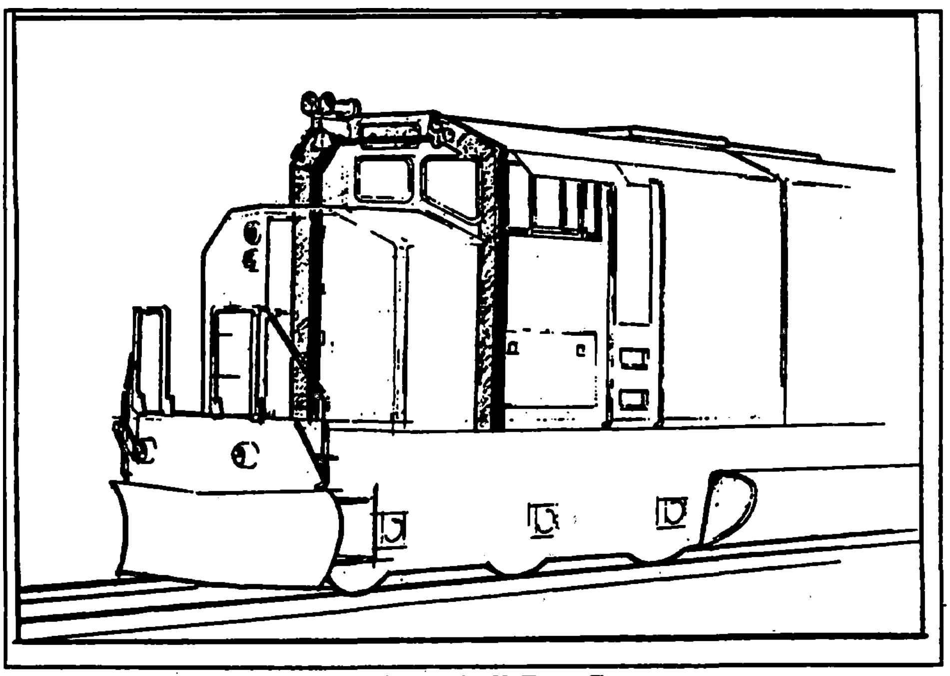

Figure 3.7 Illustration of the Roll Bar Concept

The estimated cost and weight associated with the front cab roll bar are $10,000 and 3,000 pounds respectively.

Evaluation The formulation of the selected roll bar concept was guided primarily through selection of a loading designed to provide some equivalence to that which would occur in a rollover situation. This loading is shown in Figure 3.8. Top loading is similar to the Federal standard for school buses which requires that the roof not compress by more than 5 inches when subjected to a vertical load equal to 1.5 times the bus' empty weight applied over a prescribed area of the roof. The load used for the locomotive roll bar strength analysis was taken to be equal to one-half times the locomotive weight. This represents the belief that one-half of the locomotive weight will be supported by some other part of the body. Side loading was also investigated in selecting roll bar section size, and ultimately was the determining load. In this case, the roll bar was required to also sustain one-half the locomotive weight at the roof line. This is the static load that would have to be supported if one-half the load was supported by the underframe and the other half was totally supported by the roll bar. Figure 3.8 shows that a design crash load of 200,000 pounds is necessary to provide this level of protection at the roof line. By comparison, analysis of a structure that approximately represents that found in currently manufactured locomotive cabs indicates that the ultimate side load, at the roof line, is less than 20,000 lbf.

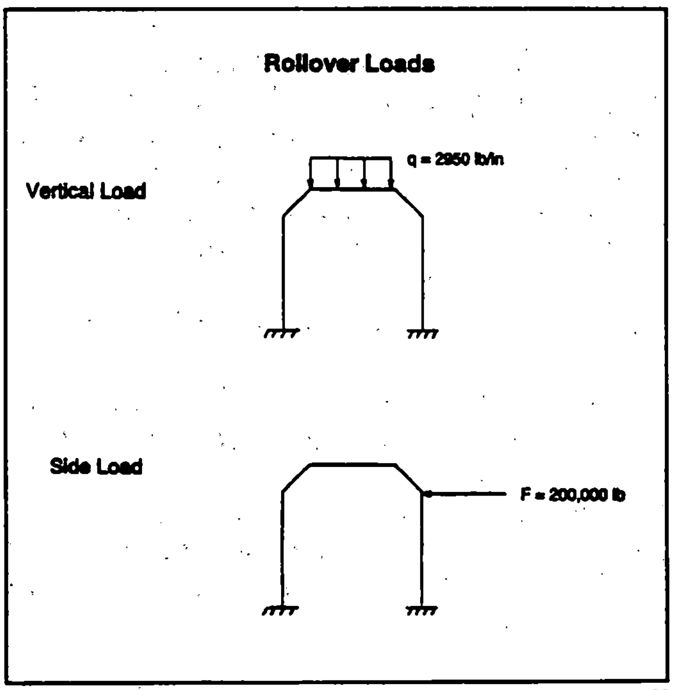

Figure 3.8 Design Crash Loads for the Roll Bar Concept

A 14x14x1/2-inch square tube section which weighs 90 lb/ft will provide sufficient support for the side loads illustrated in Figure 3.8.

It should be noted that extensive review of accident reports and accompanying photographs of the respective collision sites revealed no cases in which a locomotive rolled past one of its immediate sides (i.e., had done a complete, 360-degree roll). This accident history tends to support the loading scenario presented above for the roll bar concept selected.

Deflection Plates

The purpose of deflection plates is to deflect another train or road vehicle laterally from the path of the lead locomotive to reduce the energy which must be dissipated by the collision and minimize damage to the cab.

Current Practice There are no current industry or Federal requirements related to deflection plates. While a deflection plate may seem like a beneficial concept, the potential exists for deflection plates to cause more harm than good. If trailing cars do not follow the locomotive off the track, trailing cars could be subject to a more severe collision. Obvious examples of such incidents include the hazard of collisions on bridges, danger to structures next to the track or potential casualties in populated areas, and the possibility of deflected locomotives falling great distances in elevated terrains. These scenarios may likely increase casualties or cause more severe hazardous material spills.

Concept Description The deflection plate concept analyzed is very similar to the interlocking anticlimber discussed in a following section. It is intended to act as an anticlimber, to include the interlocking lips and to form a point in plan view as shown in Figure 3.9. The surfaces forming the point were selected to have a 12.5 degree angle with respect to the usual front plate, because this was felt to be the largest possible angle without substantially extending the length of the locomotive underframe.

The estimated cost and weight for this concept is $5,000 and 2,000 pounds, respectively.

Evaluation The collision dynamics model was first modified to treat lateral motion of the vehicles in the consist. A lateral ramp, rather than a vertical one, was placed on the lead locomotive of the 21 mph consist in the baseline crash scenario. In addition, coupler interaction between the lead locomotives was not included and motion was only permitted in a plane parallel to the ground—in other words, there was no pitch. The load-crush response of the deflection plate/underframe was taken the same as the underframe as was done with the interlocking anticlimber crashworthiness concept.

Calculations were first conducted to determine whether the 12.5 degree deflection plates would cause lateral deflection. Only the two lead locomotives of the baseline consists were modeled and no resistance to lateral motion was included. The results showed that the collision was nearly identical to that of the interlocking anticlimber—no significant lateral

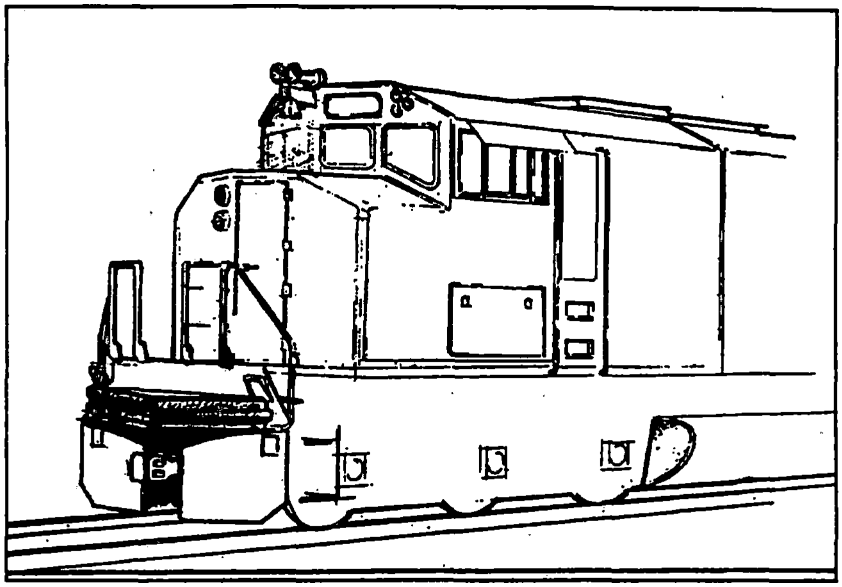

Figure 3.9 Illustration of the Deflection Plate Concept

deflection occurred prior to arrest. In fact, the deflection angle had to be increased to nearly 45 degrees before substantial lateral deflection of the type envisioned occurred. Figure 3.10 is a plot of longitudinal load vs. lateral deflection for the 45 degree case, showing that a collision force of nearly 6×10^6 lbf resulted prior to substantial lateral deflection. These calculations strongly suggest that very large deflection plate angles, and consequently, a large increase in underframe length, would be required to overcome the lateral resistance that exists in track and to significantly deflect the train before inducing excessive crush of the lead locomotives. For this reason, no further calculations were conducted.

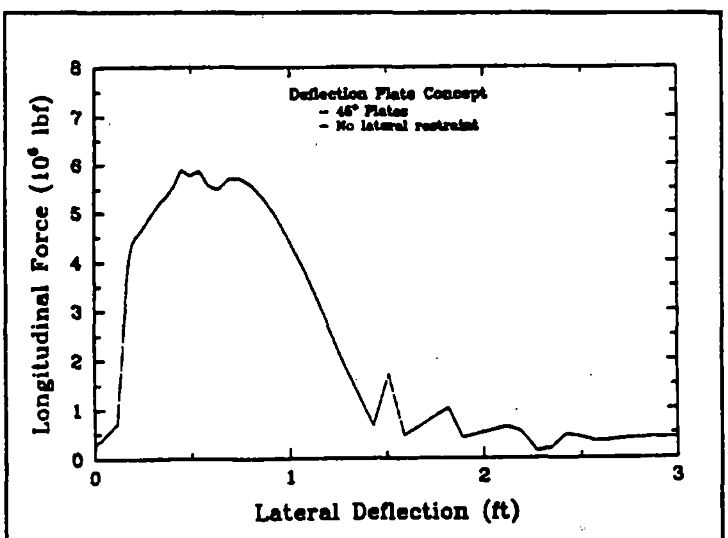

Figure 3.10 Load-Lateral Deflection Curve for the 45 Degree Deflection Plate Concept

Shatterproof Windows

Shatterproof windows are intended to make a locomotive less vulnerable to penetration by foreign objects striking the windows. While no glazing can be completely shatterproof, increased levels of shatter resistance can be achieved through alternate designs. Front end glazing for locomotives must provide high impact resistance to provide adequate occupant safety from numerous threats including, but not limited to, the following:

- low mass objects, such as ballast, thrown up from the tracks by passing trains;
- vandalism, including thrown objects and items suspended or dropped from overpasses; and
- guns fired at passing trains or oncoming locomotives.

Accident statistics in this area are somewhat ambiguous. While it is certain that objects such as ballast, cinder blocks, and bullets have impacted, and will continue to impact locomotive glazing, there have been very few reportable injuries requiring treatment resulting from failure of the glazing from these incidents. This low rate of reported injuries seems to indicate that current glazing designs, manufactured in accordance with applicable FRA regulations, have provided reasonable protection to locomotive cab occupants. However, many of these incidents could be classified as "near misses" in which impact and even penetration could have occurred, but no injury was reported. As train speeds continue to increase, and as vandals become increasingly creative in their efforts, the risk associated with one of these incidents causing permanent blindness or a fatality becomes of greater concern.

Laminated glazing, as used in numerous transportation applications such as military vehicles, aircraft, and naval vessels, is typically two or more sheets of glass bonded together under pressure at an elevated temperature with a sheet of plastic, typically polyvinyl butyral (PVB), between them. When this laminated glazing is broken, the pieces tend to remain attached to the plastic, reducing the risk of flying glass. The laminated structure also tends to remain intact, thus providing some limited protection from further impact and protection from the elements. However, penetration of the impacting object does not pose the only concern with respect to the design of glazing systems for locomotives. If the inner surface of the glazing is glass, impact of an object at sufficient velocity, while not penetrating the glazing, may still cause a chipping, or spallation, of the inner glass surface and shower cab occupants with small glass fragments which have the potential to cause lacerations and eye injuries. This has prompted some railroads to require that locomotive crews wear safety glasses when operating the locomotive.

Current Practice The current Code of Federal Regulations (49 CFR 223) states the following requirements imposed by the FRA for window glazing in locomotive cabs:

- All locomotives built after June 30, 1980 must be equipped and all locomotives built before this date must be retrofitted with certified glazing in all cab windows.

- Glazed windows must be able to deflect with no penetration a 24 lb cinder block (8 inch x 8 inch x 16 inch) at 44 ft/sec (30 mph).

- Glazed windows must be able to sustain with no penetration a 0.22 caliber bullet at 960 ft/sec.

- Additionally, a witness plate constructed of 0.006 inch thick aluminum mounted parallel to, and 6 inches behind, the test item must resist penetration from spalling effects for each of the tests described above.

It is not clear with what margin these requirements are being met by the locomotive manufacturers.

During the informal meetings held by FRA with industry representatives, several segments of the industry expressed concern over the adequacy of current glazing requirements. The adequacy, accuracy, and repeatability of the cinder block test has been questioned for a number of reasons. Current CFR requirements call for the corner of the cinder block to impact the center of the glazing sample, but due to the frangible nature of the block, it shatters upon impact. In spite of the American Society for Testing and Materials (ASTM) standard cinder block specification, these blocks shatter in different ways during different iterations of the same test scenario. The way in which the cinder block fractures upon impact is directly dependent on the precise orientation of the block as it hits. Additionally, as the cinder block breaks upon impact, it produces a lower effective mass than a non-shattering object. The corner impact called for in the current regulation also insures that the block will shatter before its full force is delivered to the glazing, and thus reduces the penetrability in comparison to a contact of a flat side of the block.

Current European standards do not incorporate a large object (such as the 24 pound cinder block) impact test for their glazing systems. Instead, a steel, geometric (cube, cylinder, etc) test object weighing approximately 2 pounds is impacted into a glazing sample at speeds far exceeding the 30 mph required for the cinder block—and usually closer to the maximum speed of the train. Studies have approximated that the penetration resistance of glazing for a small object at high speed, or a large object at low speed but the same kinetic energy is approximately equivalent. Additionally, as the cinder block shatters upon impact, it may have a lesser penetration than the small steel test device utilized by the Europeans.

Specific concerns identified following the informal industry meetings also included a perceived need to improve the anti-spalling characteristics of glazing. The current witness plate of 0.006 inch thick aluminum mounted 6 inches behind the glazing sample does not detect spallation of small glass particles that can still cause significant injury and lacerations, particularly to the eyes. Numerous glazing specifications exist that employ much more stringent requirements with respect to spallation, including the following:

- o British Railways Board, BR 566: High Impact Resistant Windows. A 0.0005 inch thick aluminum foil witness plate is used, 15.7 inches behind the sample, which receives an impact of a 2 pound steel cube moving at 137 mph. No marks are allowed on the witness plate after the test.

- o ASTM F 1233-89, Standard Test for Security Glazing: A 0.0009 inch aluminum foil witness plate is used to test spallation from bullet impacts on "bullet proof" glazing. After 5 shots, there can be no penetration of the witness plate.

- o UNI (Italian) Standard for bullet proof glazing: A 0.0008 inch aluminum witness plate is used, with no penetration following 3 shots.

- o H.P. White Laboratories, Standard Test for Ballistic Threat: A 0.001 inch aluminum witness plate is used, 6 inches from the sample, with no penetration allowed of the witness plate after 3 shots.

The industry also questioned the wisdom of the current glazing standards, which allow glazing manufacturers to perform a one-time test of their own products to ensure compliance with FRA rules. Several organizations recommended that all glazing manufacturers be required to periodically have an independent testing organization recertify their products.

Concept Description

There are a number of commercially available glazing systems that can meet and/or exceed the current Code of Federal Regulations requirements listed above. As discussed above, laminated glazings are able to resist higher levels of impact than pure glass, while at the same time reducing the risk of flying glass through the incorporation of a polyvinyl butyral interlayer. However, even laminated glass has limited impact resistance, which necessitates the use of thicker, heavier cross sections to achieve higher levels of protection. Additionally, laminates with an interior layer of glass toward the operator present the possibility of spallation problems at high impact levels for the cab occupants. There are several alternative methods of achieving greater levels of protection that can be used without sacrificing weight and size considerations.

Many high-level security institutions, military vehicles, and marine craft incorporate a glazing design that utilizes a layer of polycarbonate sandwiched between two layers of glass. Polycarbonate has an impact resistance that is 250 times greater than that of glass, has good light transmission, is much lighter than glass, and is economically feasible. However, polycarbonate scratches easily and is attacked by a range of chemicals and cleaning fluids.

Thus, the glass-clad polycarbonate system combines the increased strength properties of polycarbonate with the scratch and chemical resistance of glass.

The glass-clad polycarbonate laminate described above still presents a spallation hazard to cab occupants at higher impact levels, as it incorporates a glass inner layer. This hazard can be significantly reduced through the addition of a plastic layer to the inside surface of the glazing. This almost totally stops spallation from entering the occupant compartment if the laminated glazing is thick enough to prevent penetration of a rock or bullet. In many cases, this additional plastic layer will also contribute to the penetration resistance of the glazing. Alternatively, a polycarbonate layer may be used as the spall ply, although other limitations are introduced due to an unsymmetrical cross-section.

Table 3-5 lists four glazing options with increasing resistance to shatter and penetration as demonstrated by impact of a 2-inch diameter, steel, hemispherical dart at 30 mph[13]. The options are listed in order of increasing effectiveness and cost. The first glazing type, which apparently just meets current FRA requirements, consists of layers of tempered glass between which is laminated a relatively thick layer of polyvinyl butyral (PVB). The second system is identical to the first, but includes a spall resistant layer applied on the interior surface which raises the level of protection modestly. On the other hand, the third system is a glass-clad polycarbonate glazing that utilizes a polycarbonate inner core, and demonstrates substantial improvements over the first system with about a 50 percent increase in cost. Greater improvements can be realized through the incorporation of a spall resistant layer on the interior of the glass-clad polycarbonate laminate as shown for the fourth system at an additional cost as shown in the table.

It is important to note that while glazing systems are being developed that have the ability to withstand very high impact forces, the associated frame and mounting techniques used to secure the glazing in place may become the "weak link" in protecting cab occupants when subjected to these increased forces. If the glazing support or bonding methods used to secure the glazing in place are inadequate, penetration may occur through failure of the attachment structure and not through failure of the glazing itself. Consequently, as the threats associated with locomotive glazing continue to become more severe, increased attention regarding framing and mounting design is necessary.

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[13] Advanced Windshield Design for Rail Transportation, Kane, D. and Hayward, D., ASME Paper, 1994, 6 pages

Table 3-5 **Representative Glazing Options**

Impact Properties of Various Windshield Designs 2.0 Inch Diameter Hemispherical Tipped Steel Dart, Impact Velocity = 30 mph				
Physical Make-Up	**Price for a Representative Locomotive Window**	**Glazing Penetration (ft-lbs.)**	**Witness Plate Damage (ft-lbs.)**	**Approximate Relative Resistance to Penetration**
Semi-Tempered Glass/PVB Laminate	$200	381.3	< 777.8	1 X FRA Standard
As above, with interior spall resistant layer	$280	457.5	> 777.8	15 percent over FRA Standard
Semi-Tempered Glass/Polycarbonate Inner Core	$300	No penetration up to 1,500	> 1,500	3-4 X FRA Standard
As above, with interior spall resistant layer	$325	No penetration up to 1,622	> 1,622	5 X FRA Standard

Evaluation Table 3-5 clearly shows that improved glazing designs are available that significantly increase the level of protection afforded the locomotive cab occupants in the event of an impact, especially with respect to protection from the hazards of spallation. These improved designs provide this increased protection with no significant increase in overall weight, and at moderate costs that are not prohibitive. Comparison of occupant survivability measures, as compared to the baseline scenario, were not performed due to the lack of definitive accident statistics relating to injuries sustained as a result of glazing penetration.

The glazing requirements specified in the performance specification for Amtrak's High Speed Trainset directly support concerns that current glazing standards provide inadequate protection given the increasing speeds of trains. This performance specification includes increased awareness with respect to framing requirements, more stringent witness plate requirements, and more severe ballistic and large object impact resistance requirements. The incorporation of these more demanding glazing requirements, due largely to increased train speeds, directly parallels the recommendations provided during the informal industry meetings.

Readily Accessible Crash Refuges

The crash refuge feature refers to a safe and sturdy area or volume into which crew members can position themselves to be protected from secondary impact, crush, or both.

Current Practice Currently there are no U.S. standards requiring a crash refuge for a rail vehicle. This topic was the subject of some prior work on freight locomotive crashworthiness which recommended that the cab consist of a strong structural "cage" that could also act as a ramp to vertically deflect an overriding locomotive or other vehicle. The vertical strength of the cab in this cage-type structure is necessary to protect cab occupants in the event of a rear-end collision in which cars are pushed to the top of the cab, thus crushing the cab.

Some high speed rail vehicles are now designed with what one could consider a crash refuge. In this case, a length of the car is reinforced to have greater longitudinal crush strength than the parts of the vehicle on either side of it. In the event of a collision with substantial crush, the zones on each side of this protected length would crush sacrificially. In conducting interviews with railroad personnel, it became very evident that there would be great resistance to a refuge that would be totally enclosed. This perception affected the choice of concepts.

Concept Description Three crash refuge concepts were considered for analysis in this study. The first two are related and utilize the crew member's seat as shown in Figure 3.11. In both cases, protection against secondary impact is provided by rotating the seat so that the occupant can ride down the collision with his or her back to the oncoming vehicle or obstruction. Connecting the occupant to the vehicle in some manner as quickly as possible is one of the primary crashworthiness goals for passenger restraint systems in motor vehicles and aircraft. In one of the seat crash refuge concepts studied here, the seat simply rotates and locks to face aft; in the other, the seat rotates, locks and drops in order to place the occupant closer to the floor, at which the chances of survivable volume are greater. The need for somewhat more robust seats and a stronger seat support to absorb the shock of the collision is anticipated. Seat belts are not necessary to provide the basic protection against secondary impact with the rotating seat concept, even though there is likely to be some recoil action of the impact as the locomotive comes to rest. However, a seat belt would minimize the risk of injury from this event.

The third crash refuge resembles a trench. It is located at the rear of the cab and is formed when a lever is pulled and a floor panel drops down toward the rear to expose a padded space between the cab floor level and the sill of the underframe as shown in Figure 3.12. Current locomotives include some crawl space in this area for access to various mechanical and electrical components. However, some modification to increase this space as well as to provide a shock absorbent wall facing frontwards would be required. Placement of the trench crash refuge concept provides somewhat of an advantage over alternative concepts presented in that it is located lower with respect to the locomotive structure. This lower location translates into an increased probability of maintaining a survivable volume in the event that the locomotive cab is crushed due to any number of collision scenarios.

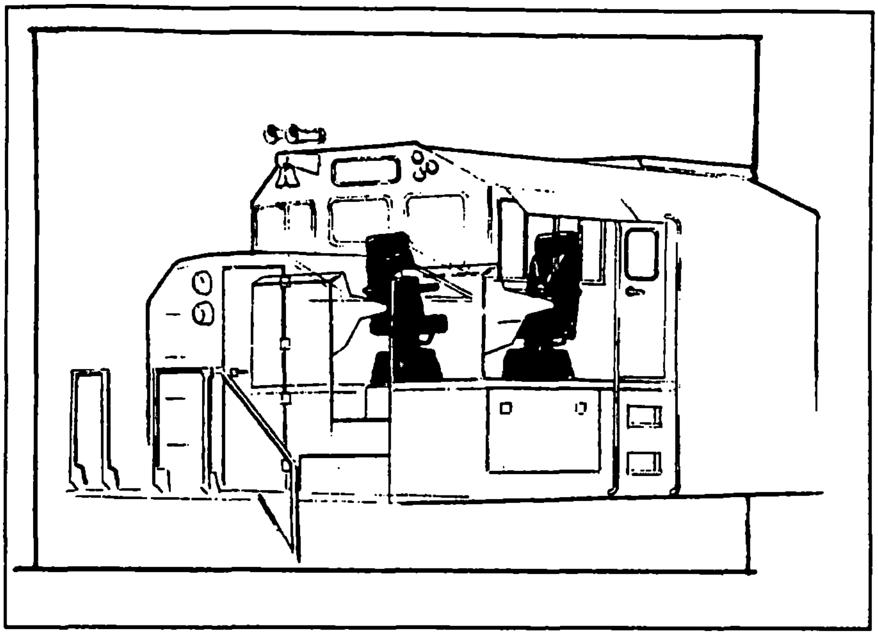

Figure 3.11 Illustration of the Rotating Seat Crash Refuge Concept

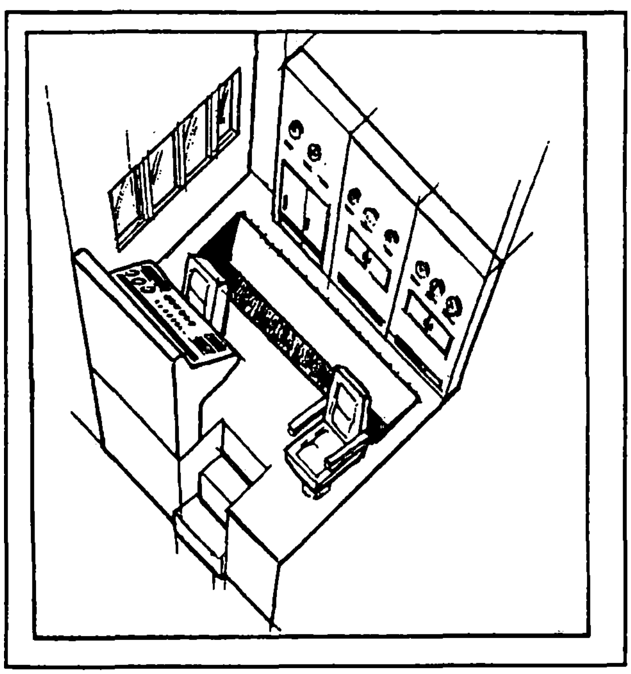

Figure 3.12 Illustration of the Trench Crash Refuge Concept

All three of these crash refuge concepts protect the occupant against secondary impact, but provide limited or no protection against crush. Thus, some other feature would be required to protect the crew in the baseline scenario, for which a crush of 8 feet is predicted.

Estimates of weight and cost increases associated with these three concepts are listed in Table 3-6. Pictorial views of each of the three concepts evaluated are provided in Figures 3.13 through 3.15.

Table 3-6. Estimates of Weight and Cost Increase Over the Baseline Locomotive for the Three Crash Refuge Concepts Analyzed

	Crash Refuge Concept		
	Rotate Seat Only	**Rotate & Drop Seat**	**Trench**
Weight	300	600	400
Cost Increase	$15,000	$20,000	$2,000

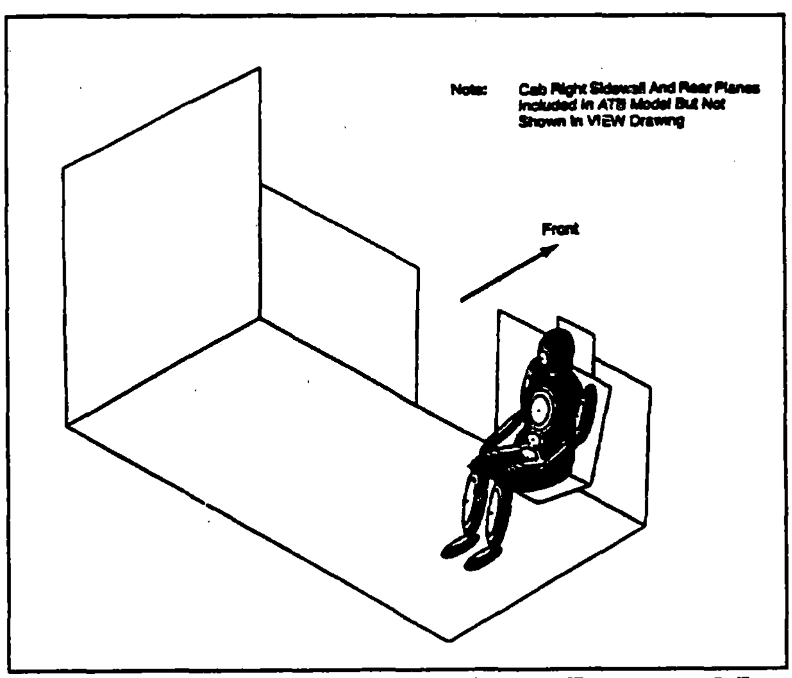

Figure 3.13 Occupant Position in the Rotate and Loc k Seat Crash Refuge Concept

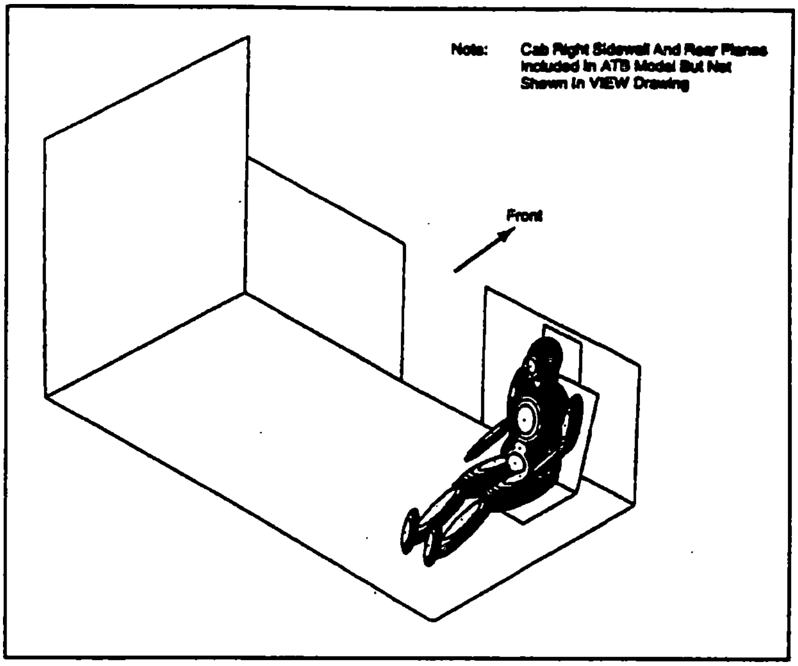

Figure 3.14 Occupant Position in the Rotate, Lock, and Drop Crash Refuge Concept

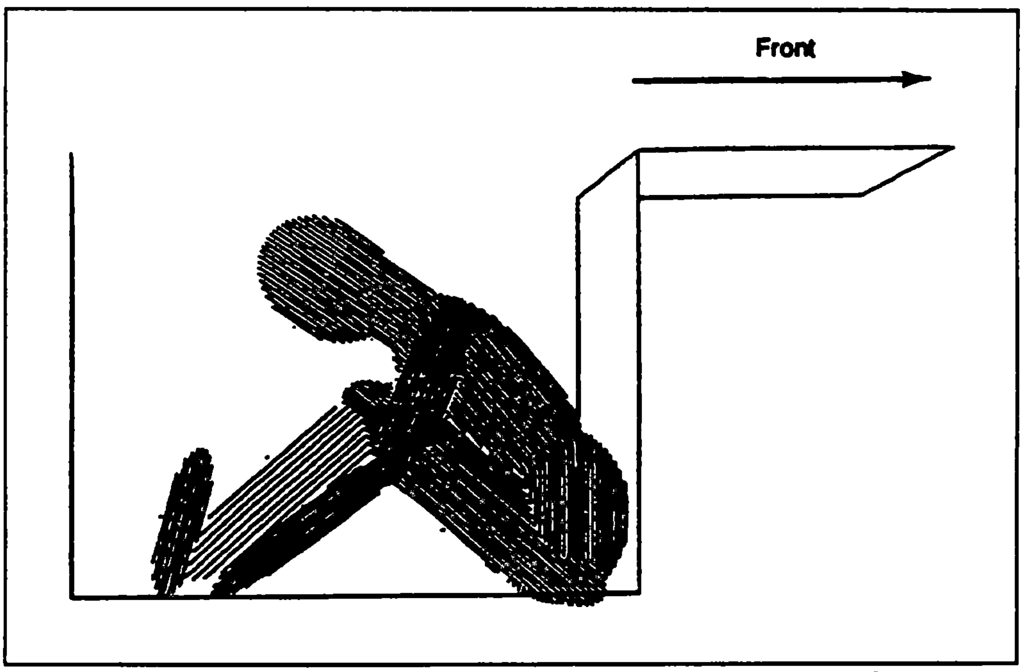

Figure 3.15 Occupant Position in the Trench Crash Refuge Concept

Evaluation In making evaluations of the crash refuge concepts, recall that any of these refuges alone would not protect the occupant against the crush of the baseline crash scenario, since they add no strength or crush resistance to the front end components. Therefore, the evaluation is made to determine what, if any, reduction in secondary impact measures is provided by the crash refuge concept. If there is a reduction, then the concept could be of practical use when combined with other crashworthiness features that induce more severe crash pulses, such as the interlocking anticlimber or stronger collision posts.

Finite element analyses and collision dynamics calculations were not needed to evaluate these concepts. Instead, approximate hand calculations were made to estimate the strength required for rotating seat support posts, and support channels for the trench concept. The crash pulse generated for the baseline crash scenario was also used for each refuge concept.

The rotating seat models utilized seat geometry and cushioning (i.e., force-deflection and energy absorbing) material properties indicative of seat characteristics found on a late model domestic light truck. Padding characteristics used in the trench refuge model were given a stiffness roughly mid-way between that specified for the seat cushioning material and cab floorpan.

ATB-predicted occupant response for the crash refuge concepts are presented in Table 3-7. Minimum-level HICs were recorded for all three concepts, indicating that most of the general population would not be exposed to even moderate head trauma. Chest accelerations ranged between 15 and 28 g's. These levels correspond to about a 20 to 36 percent chance of incurring severe general thoracic trauma.

It should be noted that while all three crash refuge concepts provide exceptional protection with respect to head injury, the HIC value associated with the trench concept is noticeably higher than that for either of the seat concepts. This is a direct result of the occupant position prior to impact, with the head forward and towards the knees, as shown in Figure 3.15. In this case, the head is not supported at the point of collision, and is free to impact the padded wall of the trench. It may be possible to incorporate some type of head support in conjunction with other forms of occupant restraint within the trench crash refuge concept to further reduce the severity of head impacts.

The seat-type crash refuge simulations shared one extremely important commonality: no body region contacts occurred with cab interior surfaces other than the floor (feet only) and the padded seat cushion and seat back components. In the trench crash refuge simulation, the occupant stayed within the confines of the protective trench during the collision ridedown period. A crash refuge eliminates or greatly mitigates of uncontrolled kinematics resulting in potentially damaging secondary impacts of cab occupants with hard cab interior surfaces.

Table 3-7. Locomotive Cab Occupant Response for the Crash Refuge Concepts (Baseline Crash Pulse)

Occupant Position in Cab	Head Response HIC	Torso Response C_R (g's)	Remarks
Engineer's seat (rotate only)	95	28	Occupant slid on the seat (towards the rear of the cab) during the latter stages of the crash ridedown
Engineer's seat (rotate, drop, and lock)	62	21	Occupant slid on the seat (towards the rear of the cab) during the latter stages of the crash ridedown
In trench located at rear of cab	165	15	

ATB calculations were also conducted to assess the benefit provided by the crash refuges for the more serious crash pulse provided by the interlocking anticlimber. Table 3-8 lists the secondary impact values obtained for two of the crash refuge concepts when modeled using this more severe crash pulse. The HIC values measured are higher than when modeling the baseline crash pulse, but still relatively low. The value of C_R using the interlocking anticlimber crash pulse is low for the seat refuge and relatively high for the trench when compared to that measured using the baseline crash scenario.

Table 3-8. Locomotive Cab Occupant Response for the Crash Refuge Concepts (Interlocking Anticlimber Crash Pulse)

Occupant Position in Cab	Head Response - HIC	Torso Response - C_R (g's)
Engineer's seat (rotate only)	247	30
In trench located at rear of cab	404	55

Anticlimbers/Uniform Sill Heights

Anticlimber devices are intended to counter the tendency for one locomotive to override the underframe of the other during a head-on collision. If override occurs, much of the protection provided by the structural strength of the underframe is bypassed.

NTSB has specifically addressed the issue of override, and the important role that a structurally strong underframe can play in inhibiting such override from occurring during collisions, in Safety Recommendation R-88-20. It is the Safety Board's position that since the sill is the strongest section in the structural design of a locomotive, a standardized compatible main frame sill height would help prevent locomotive override during collisions. NTSB has called for FRA to establish a regulatory standard mandating compatible sill heights in the design of locomotives.

Current Practice Anticlimbers on locomotives that satisfy AAR Specification S-580 are required to sustain a vertical load of 200,000 lbf applied under the anticlimber, uniformly distributed between the center sill webs. The specification also requires that the anticlimber shall be attached to the underframe end plate in line with the center sill webs. No indication is given for the longitudinal location under the anticlimber at which the load is to be applied, although manufacturers use the very front as the conservative position. There is also no requirement on the longitudinal strength of the anticlimber. The technical basis for the anticlimber vertical strength required by AAR S-580 is not certain. Discussions with locomotive and railroad personnel suggest that the anticlimber was originally conceived to protect against debris rising toward the cab from grade crossing collisions.

The 200,000 lbf strength is achieved using several plates angled down from the horizontal surface, or top plate, of the anticlimber to the underframe front plate. Figure 3.16 shows the geometry analyzed for the baseline case. Analysis suggests that anticlimbers on locomotives built after AAR S-580 was implemented achieve a vertical strength more than 50 percent greater than that required.

Uniform sill heights are not currently specified by AAR S-580 or any other U.S standard. The main frame platform height on railway equipment has traditionally been determined by the design and placement of such elements as the truck and suspension system, traction motors, electrical apparatus, and the configuration of the cooling air ducts. There is approximately a 6-inch difference in the height of the platform between locomotives built by the two major U.S. manufacturers, GE and EMD, as well as a difference in platform heights on six-axle and four-axle locomotives of the same manufacturer. Review of head-on collision accident reports, including one in which the sill heights differed by less than 1 inch, indicates that uniform sill height with current front-end arrangements will not necessarily prevent override. This is due to the fact that asymmetric shear deformations between interacting anticlimbers during a collision can permit one anticlimber to ramp over another.

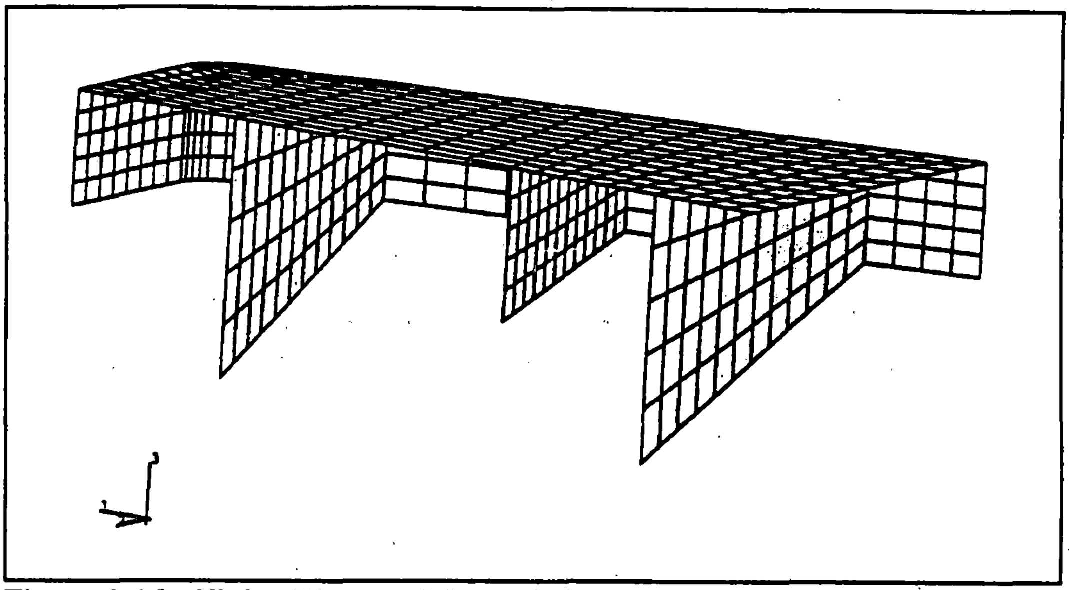

Figure 3.16 Finite Element Mesh of the Anticlimber Modeled to Satisfy AAR S-580 Requirements (looking forward from sill end; only left half of anticlimber structure is shown)

In a study assessing improvement in crashworthiness of locomotive cabs attributable to the implementation of AAR S-580 performed for AAR[14], a study of 10 head-on collisions showed that override occurred in six cases, did not occur in one case, and could not be determined in three cases. In the six cases of override, there were four in which the underframe heights were similar, and two in which they were dissimilar. In the one case where no override was observed between lead units, the underframe heights were dissimilar. This study also notes that in one of the cases examined, the rear end of an EMD unit overrode a trailing GE unit which would have a higher underframe than the EMD unit. From this, it was concluded that a difference in height of the underframes of colliding locomotives is not of itself a sufficient condition for override to take place.

An important result of the modeling effort and validation performed is that the anticlimber will, in general, not experience a significant vertical load in a head-on collision and, consequently, provides little or no protection against override. Photographs of actual head-on collisions as well as model results indicate that deformation of the anticlimber and the draft gear support structure occurs primarily in shear. In addition, the time required to have the coupler of one locomotive vertically challenge the anticlimber of the other locomotive in a head-on collision appears too long to be physically possible in all but the slowest collisions. Even if the coupler, or another component, did exert a vertical force on

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[14] *Assessment of Improvement in Crashworthiness of Locomotive Cabs Attributable to the Implementation of AAR Specification S-580*, Radford, R.W., March 8, 1994

the anticlimber during a collision, the force required to lift the end of a locomotive would be much larger than one-half the locomotive body weight because of inertial effects. For these reasons, anticlimber concepts that provided a more positive interlocking engagement in a head-on collision than afforded by current designs were sought.

As the current anticlimber design provides limited resistance to vertical loads except at very low closing speeds, its primary benefits lie in (1) restricting debris from rising toward the cab in a grade crossing type accident, and (2) acting as a form of "crash energy management" whereby the anticlimber structure absorbs a portion of the collision energy which will typically reduce the severity of secondary impact injuries. The current anticlimber was not designed to function as a structure to absorb energy. If this is to be the function of an anticlimber, a complete redesign will be necessary to maximize the effectiveness of this feature.

Concept Description The alternative anticlimber analyzed here has the geometry depicted in Figure 3.17. It is a cast steel or fabricated piece welded to the underframe front plate that consists of integral, protruding shelves such that two opposing interlocking anticlimbers would fit together and provide substantial resistance to relative vertical motion. The concept interlocking anticlimber is intended to project out beyond the front plate enough to provide protection against rising debris from grade crossing collisions and to have a positive engagement when two opposing locomotives are in a full buff position. This engagement in the buff position may not result in longitudinal load between anticlimbers.

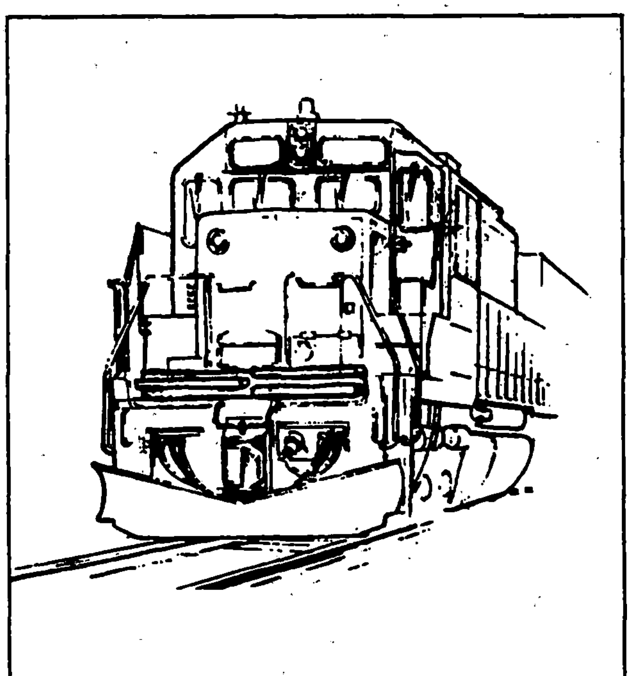

Figure 3.17 Illustration of the Interlocking Anticlimber Concept

This alternative anticlimber, ***by the nature of its design described above***, would require nominally equal sill heights for its implementation to ensure a positive engagement of the protruding shelves when two locomotives are in a full buff position. It is important to note that compatible sill heights—in and of themselves—have not demonstrated the ability to provide additional crashworthiness protection in the event of a collision, but ensuring that the protruding shelves on opposing anticlimbers fully engage to provide resistance to relative vertical motion would require compatible sill heights.

There will always be some difference in vertical height between locomotives—even with uniform sill heights—as a result of manufacturing tolerances, wheel wear, the effects of vertical height differences and coupling in curves, the amount of fuel remaining in the fuel tanks, and dynamic motion prior to a collision. If sill heights were uniform, this difference could amount to between 2 and 4 inches and a comparable vertical tolerance in the shelves of the interlocking anticlimber would be required. In the absence of uniform sill heights, a tolerance of between 6 and 9 inches would most likely be required. Additionally, in order to prevent contact between anticlimbers for coupled locomotives in curves, the anticlimber width would have to be narrower than the full locomotive width.

In order for this concept interlocking anticlimber to be effective, comparable anticlimbers would need to be installed on all locomotives. This poses a commonality problem in the short term with respect to retrofitting the current fleet of locomotives. Obvious time and monetary constraints would limit the full implementation of the interlocking anticlimber described above, which, in turn, limits the effectiveness of the feature. Additionally, all future locomotive procurements would need to specify inclusion of the selected anticlimber arrangement to ensure effectiveness of the feature in the event of a collision.

Tough, castable or high strength steel materials are available with the strength and toughness needed for this design to resist over 1,000,000 lbf vertically without fracturing on impact. The increase in weight resulting from use of this interlocking anticlimber over current designs is about 2000 pounds. Quotes from vendors for a cast piece with the approximate geometry shown in Figure 3.17 total $5,000. Interlocking anticlimbers fabricated from high strength steel may be less costly and weigh less than the above estimates.

Evaluation Structural deformation analyses were not conducted for the interlocking anticlimber. Rather, the structure was assumed to have compressive strength sufficient to transfer all of the longitudinal collision load to the underframe.

The collision dynamics model was run by assuming that once the two colliding locomotives interlock, there would be no relative vertical displacement between them at the anticlimbers. Relative rotation was allowed. As a result, there was no loading of the short hood/collision posts structure and, therefore, no crush. On the other hand, there was a significant increase in the peak acceleration as expected as shown in the crash pulse of Figure 3.18. A maximum acceleration of about 12 g's acting over about 150-msec period is predicted for this collision as compared to the 11 g value over a 60-msec period for the locomotive that just satisfies AAR S-580, both in the baseline crash scenario.

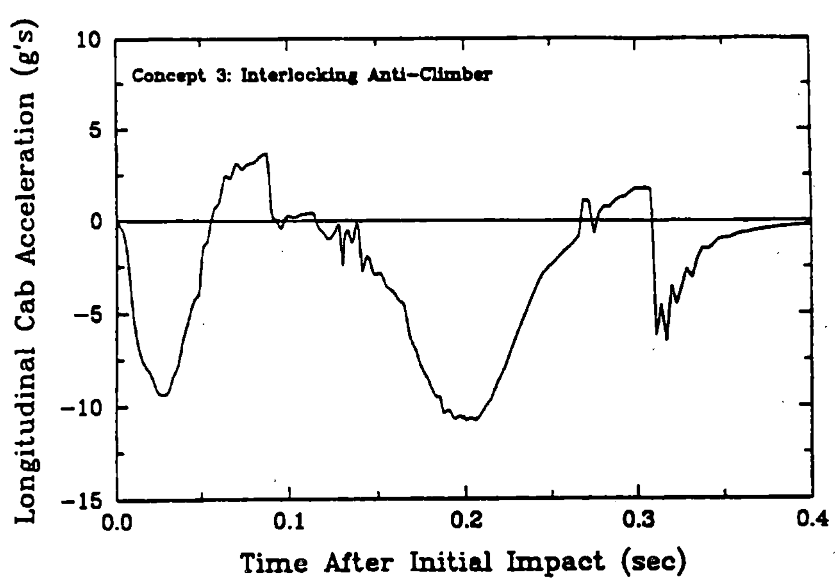

Figure 3.18 Cab Crash Pulse for the Interlocking Anticlimber Concept

The occupant survivability model was again exercised with occupant positions identical to those used for the baseline crash scenario. Table 3-9 presents the occupant performance predictions generated by ATB. The HIC parameter displayed disparate values between 56 and 1830, with an average of 925. This magnitude would be likely to cause about 43 percent of the populace to incur moderate head trauma.

Occupant chest response also varied significantly, ranging from 17 to 73 g's. Average C_R was 50 g's, indicating that about 53 percent of the public would be exposed to severe thoracic trauma.

The varied nature of the secondary impacts in the cab again played a major role in generating the injury-indicating parameters listed in Table 3-9. Both direct and indirect head contacts occurred with the front wall as well as with the support, underside and exterior back surface of the engineer's seat. The torso impacted the floor, front wall and the seat support (indirect via arm).

Table 3-9. Locomotive Cab Occupant Response for the Interlocking Anticlimber

Occupant Position in Cab	Head Response - HIC	Torso Response - C_R (g's)
Behind engineer's seat, against rear wall	809	45
Behind engineer's seat, forward of rear wall	56	17
Center of Cab, against rear wall	1830	73
Center of cab, forward of rear wall	1005	66

Calculations were performed for higher closing speed collisions using the Accident Scenario "C" (43 mph closing speed) locomotive consist configuration as a baseline, while maintaining the ratio of the two consist speeds constant. The resulting comparison of short hood structure/collision post crush and closing speed showed that a peak in cab crush is attained. This peak, which is less than the 6 feet of crush corresponding to the elimination of survivable space, is due to the effects of locomotive body rotational inertia. This inertia, which becomes dominant as closing speed increases, prevents significant pitching motion and, hence, override from occurring before there is substantial crush of the underframe, whose energy-absorbing capability is simulated to be far greater than that of the short hood/collision post structure. The important implication of this predicted behavior is that greater deformation of the underframes is likely at higher closing speeds even in the absence of an interlocking anticlimber, provided the colliding underframes are approximately at the same height.

Effects of Underframe Bending The results provided above for the concept interlocking anticlimber were obtained from modeling that simulated the two underframes locking together with no deformation other than axial crush. In actual crash scenarios, however, it is extremely unlikely that two underframes will load each other perfectly symmetrically through their neutral axes during a collision. Such asymmetries arise from manufacturing differences, wheel wear, and dynamic vertical motions just prior to the collision. As a result, there will be some bending component of the load into the underframes.

To examine these effects, the collision dynamics model was modified to allow underframe bending about a point on the underframe located a specified distance from the tip of the anticlimber. In the revised model, only the underframe of one of the lead locomotives was permitted to bend—an assumption was made that there would be enough difference between impacting underframes to preferentially induce bending in one of the underframes over the other. An initial vertical offset between the neutral axes of the underframes was simulated, and was selected to induce downward rotation of the bending underframe. In this simulation, there is a limit of downward rotation at which the underframe or its attached components will contact the track, and thus limit the energy absorbing capability of the structure.

Calculations were performed using the baseline locomotive consist configuration (two locomotives colliding with five locomotives), keeping the ratio of the speeds the same for each closing speed evaluated and using an initial vertical offset of 4 inches. The results of this simulation indicate that substantial rotation of the bending underframe is predicted at a closing speed at about 43 mph. This demonstrates that the effects of underframe bending are likely to limit the closing speed at which interacting underframes can dissipate energy in a collision. Additionally, increased vertical offset between the two underframes will cause this limiting rotation to occur at a lower closing speed.

Equipment to Deter Entry of Flammable Liquids

Current Practice Current Federal standards do not provide explicit requirements for equipment to deter post-collision entry of flammable liquids. However, the AAR Specification S-580 requirement for a 0.5-inch wall thickness, 25 ksi yield strength material for the short hood end-facing skin provides a degree of protection. The penetration resistance of the glazing can also be considered to provide protection against the ingress of materials in a collision, provided that they remain intact and in their frames.

Concept Description FRA did not perform detailed assessments of any alternative concepts with respect to deterring post-collision entry of flammable liquids into the locomotive cab. Accident reports indicate that current design features are sufficient, and have not identified weaknesses in this area. Implementation of improved glazing designs and strengthened frame requirements for the glazing will also inherently improve the ability of the cab to resist penetration following a collision.

Other Findings

Corner Posts

Evaluation of the current locomotive cab roof has shown that it is structurally inadequate to protect occupants in many collision scenarios. While the Act mandates evaluation of braced collision posts and rollover protection, accident experience has suggested that attention should also be given to cab corner post and roof strength. From the point of view of efficiency and weight, a unitized, or monocoque end structure design that is tied together and acts as a single structure during a collision may be preferable to a design incorporating collision posts, corner posts, and/or rollover protection that is not unitized. The Amtrak High Speed Trainset specification identifies specific loading requirements for an end structure that acts as one unit to protect the crew members. A similar approach is worthy of consideration for conventional locomotives.

On January 18, 1993, Northern Indiana Commuter Transportation District (NICTD) eastbound commuter train 7 and NICTD westbound commuter train 12 collided in a corner-to-corner impact in Gary, Indiana, resulting in seven passenger fatalities and 95 injuries. The damage that both trains sustained after the initial impact resulted from the action of dynamic forces that caused the left front corner and sidewall of the passenger compartment of each car to experience a complete structural failure and intrude inward. Because no structure was available in the corner post areas to successfully absorb the crash forces of the collision, the substantial car body intrusion into each car left no survivable space in the left front areas of either car. NTSB concluded that the use of collision energy absorption structures in the corner post assemblies of these rail cars would have decreased the impact intrusion in this collision and may have prevented or substantially reduced the number of fatalities and serious injuries. Consequently, NTSB issued Safety Recommendation R-93-24, which recommends that FRA:

> In cooperation with the Federal Transit Administration and the American Public Transit Association, study the feasibility of providing car body corner post structures on all self-propelled passenger cars and control cab locomotives to afford occupant protection during corner collisions.

While the above recommendation specifically addresses self-propelled passenger cars and control cab locomotives—and not freight locomotives—FRA believes that current freight locomotive cab structures are similarly vulnerable to corner impacts. Given the continuing occurrence of accidents involving shifted lading, equipment fouling the track, and side incursion accidents, consideration should be given to costs and benefits of improved corner post arrangements on freight locomotives.

Fuel Tanks

Background Due to the location of locomotive diesel fuel tanks—beneath the underframe and between the trucks—they are exposed and vulnerable to damage due to collisions, derailments and debris on the roadbed. Damage to the tank frequently results in spilled fuel, creating the safety problem of increased risk of fire and the environmental problem of clean-up and restoration of the spill site.

NTSB has identified and published concerns regarding the safety problems caused by diesel fuel spilled from ruptured or punctured locomotive fuel tanks in their report NTSB/SS-92-04, PB92-917009, entitled *Locomotive Fuel Tank Integrity Safety Study*. As the basis for this report, NTSB reviewed 29 accidents that they had investigated during 1991 that resulted in one or more derailed locomotives. These 29 accidents resulted in a total of 83 derailed locomotives. Fifty-five of the derailed locomotives experienced definitive fuel tank damage, and 43 lost fuel as a result. Twenty-five of these locomotives that lost fuel also experienced fires resulting from diesel fuel ignition.

As a result of this study, NTSB recommended that the railroad industry undertake a cooperative research effort to improve the ability of fuel tanks to resist puncture and rupture due to collisions or derailments. Further, NTSB recommended that FRA establish, if warranted, minimum performance standards for locomotive fuel tank design based on the results of this research.

In response to the NTSB recommendation regarding fuel tank integrity, AAR published Report WP-161, *Locomotive Fuel Tank Integrity Study*, in February 1994. This report is based on a fuel spill survey conducted by AAR for the 3-year period from 1991 through 1993. This survey reported 221 instances of diesel fuel spilled from locomotives during this time period. From the survey, AAR estimates 100,000 gallons of diesel fuel per year leaks from damaged locomotive fuel tanks. Figure 3.19 graphically presents the distribution of the sizes of fuel spills reported to AAR during the survey. The total number of instances depicted is less than 221 because the size of the spill could not always be quantified.

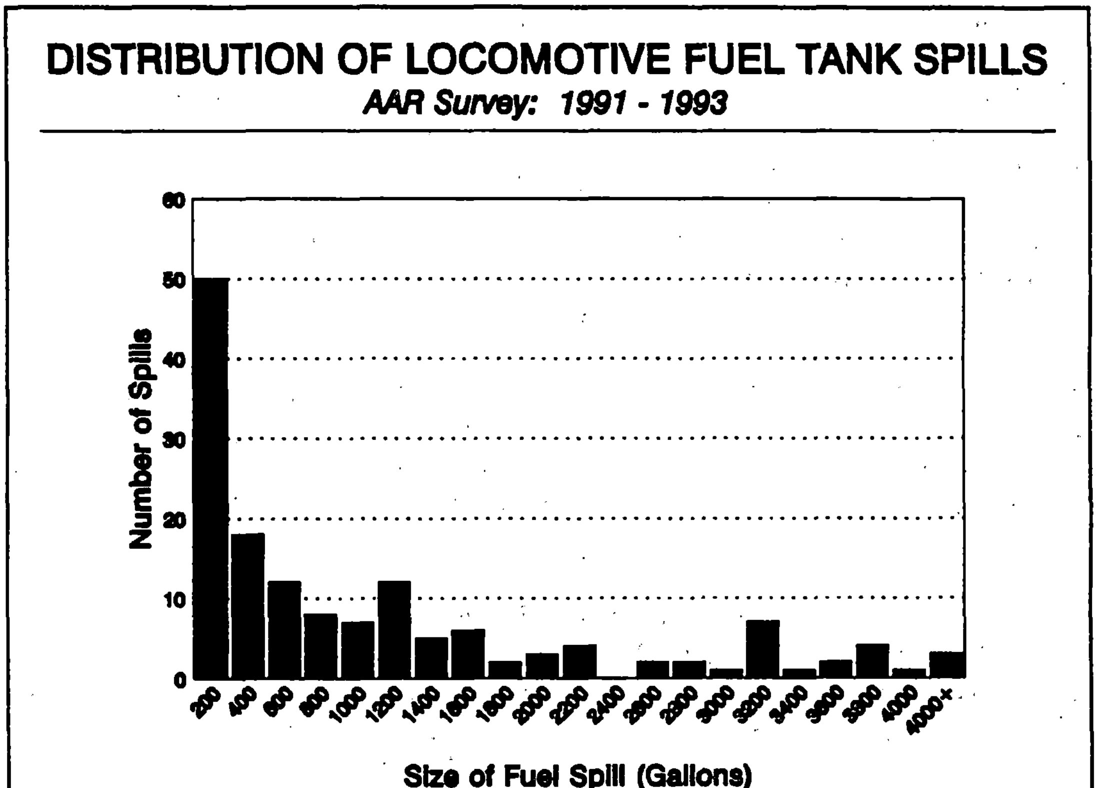

Figure 3.19 AAR Fuel Tank Spill Survey

From this survey, AAR drew the following conclusions:

- o Locomotive fuel spills are not a widespread problem.
- o Fires resulting from locomotive fuel spills are rare.
- o The need for additional fuel tank research is questionable.

However, on November 30, 1994, AAR issued Circular Letter C-8292 proposing performance requirements for diesel electric locomotive fuel tanks. Table 3-10 summarizes the standards proposed by AAR for recommended practices to its membership.

FRA searched its accident/incident data base for instances of locomotive fuel leaks or spills reported by railroads to FRA for the same 3-year period from 1991 through 1993. Table 3-11 summarizes these incidents. Several reasons exist for the discrepancy between AAR and FRA data on the number of locomotive fuel spills during this 3-year period. FRA has only required that fuel spill information be included as a part of the accident reporting system since January 1, 1993. Data provided in Table 3-11 prior to this date was gathered from various sources, primarily from narrative provided with accident reports. Additionally, railroads are not required to report incidents to FRA unless the damage to on-track equipment, track, track structures, and/or roadbed exceeds $6300. The cost of diesel fuel clean-up is not considered by railroads to be damage to their property.

FRA also requested that inspectors investigating locomotive accidents carefully document any fuel tank damage. Figures 3.20 through 3.22 illustrate typical fuel tank damage resulting from locomotive accidents found by FRA inspectors.

Current Practice Current FRA regulations do not address the design, size, locations, or performance of locomotive fuel tanks, nor do they require a regularly scheduled or periodic inspection of fuel tanks to ensure no safety hazards are present. 49 CFR 229.71 does require a minimum clearance of 2.5 inches between the top of the rail and the lowest point on a fuel tank.

Until very recently, industry practice has dictated that fuel tank designs be a lightweight structure adequate to support the weight of the fuel and to accommodate sloshing. Fuel tank design factors have not been based on safety. As a result, current fuel tanks are typically constructed with end plates of 3/8-inch steel with 25,000 psi yield strength and bottom and side walls of 3/16-inch with 25,000 psi yield strength. The tank often extends out to the side past the carbody in an effort to maximize the tank capacity. Current practice shows most freight locomotive fuel tanks are suspended approximately 6 inches above the top of the rail.

SUMMARY OF AAR FUEL TANK PERFORMANCE REQUIREMENT RP-506

Design Parameter	AAR Recommended Practices RP-506
Ability to Support a vertical load	Load Case 1 - minor derailment: Support on the end plate of the fuel tank one half the weight of the car body at a vertical acceleration of 2g without exceeding the ultimate strength of the material. Load Case 2 - Jackknifed Locomotive: Support on the fuel tank transversely at the center a sudden loading equivalent to a vertical acceleration of 2g without exceeding the ultimate strength of the material
Ability to Resist a Horizontal Side load	The fuel tank shall withstand, without exceeding the ultimate strength, a 200,000 pound side load distributed over an area of 6" inches by 48 inches at a height of 30 inches above the rail.
Tank Location	Consideration should be given in the design of the fuel tank to maximize the vertical clearance between the top of the rail and the bottom of the fuel tank.
Sliding Contact Protection	No requirement.
Interior Compartment alization	Internal structures of the tank must not impede flow of fuel through the tank while fueling at a rate of 300 gpm.
Spill Resistance	Vents and fills shall be designed to avert spillage of fuel even in the event of a roll over.
Resistance to Trapping Foreign Objects	To minimize fuel tank damage from side swipes, no tank component shall extend beyond flush with the side of the tank or shall be adequately protected from catching foreign objects or breakage. All seams must be protected or flush to avoid catching foreign objects.
Material Properties	The minimum thickness of sides bottom sheet end plates shall be equivalent to 5/16-inch steel with 25,000 PSI yield strength. The lower 1/3 of the end plates shall have the equivalent penetration resistance of 3/4-inch steel with 25,000 PSI yield strength. This may be accomplished by any combination of materials or mechanical protection.
Tank Securement to Carbody	No Requirement.

Table 3.10

Fuel Spills Reported To FRA By Railroads 1991-1993

DATE OF ACCIDENT	TIME	RAILROAD	TEMP	MPH	CAUSE	#OF GAL.	FIRE Y-N
2/13/91	9:00AM	UP	30F	23	DERAILMENT	8000	NO
4/10/91	6:28AM	BN	30F	35	DERAILMENT	100	NO
1/13/92	9:40AM	BN	28F	28	GRADE CROSSING	UNKNOWN	NO
9/11/92	5:30PM	UP	84F	50	GRADE CROSSING	UNKNOWN	NO
9/17/92	3:20PM	SOO	70F	35	GRADE CROSSING	2500	NO
2/5/93	2:40AM	ARR	10F	28	DERAILMENT	3766	NO
11/13/93	12:25AM	IC	66F	43	VANDALISM	2500	NO
12/28/93	12:50AM	SOO		8	COLLISION	15	NO
1/15/92		BA			DERAILMENT	4000	NO
1/25/92		BA			DERAILMENT	UNKNOWN	NO
7/11/91		AMTRAK			DEBRIS	UNKNOWN	NO
7/18/91		AMTRAK			DEBRIS	UNKNOWN	NO
7/24/91		AMTRAK			DEBRIS	UNKNOWN	NO
8/13/91		AMTRAK			DEBRIS	UNKNOWN	NO
10/19/91		AMTRAK			DEBRIS	UNKNOWN	NO
12/11/91		AMTRAK			DEBRIS	UNKNOWN	NO
2/14/92		AMTRAK			DEBRIS	UNKNOWN	NO
5/3/92		AMTRAK			COLLISION	UNKNOWN	NO
5/7/92		AMTRAK			DEBRIS	UNKNOWN	NO
6/27/92		AMTRAK			UNKNOWN	UNKNOWN	NO
7/3/92		AMTRAK			UNKNOWN	UNKNOWN	NO
10/24/91		LI			TURNTABLE	UNKNOWN	NO
8/12/92		LI			3rd.RAIL ARC	UNKNOWN	NO
10/6/92		LI			UNKNOWN	UNKNOWN	NO
10/20/92		LI			UNKNOWN	UNKNOWN	NO
4/2/91		MNCW			DERAILMENT	400	NO
10/10/91		MNCW			DEBRIS	UNKNOWN	NO
6/6/92		MNCW			DEBRIS	UNKNOWN	NO
9/19/92		MNCW			DEBRIS	UNKNOWN	NO

Table 3.11

Fuel Spills Reported To FRA By Railroads 1991-1993

DATE OF ACCIDENT	TIME	RAILROAD	TEMP	MPH	CAUSE	#OF GAL.	FIRE Y-N
5/15/91		NJTR			DEBRIS	UNKNOWN	NO
6/4/91		NJTR			DEBRIS	UNKNOWN	NO
7/7/92		NJTR			DEBRIS	UNKNOWN	NO
1/30/92		PW			DEBRIS	UNKNOWN	NO
5/7/91		ST			BROKEN RAIL	UNKNOWN	NO
5/15/91		ST			BROKEN RAIL	UNKNOWN	NO
9/21/92		ST			BROKEN RAIL	UNKNOWN	NO
5/12/93	1:57AM	ARR		39	MUD SLIDE	2000	NO
4/12/93		WP			DERAILMENT	UNKNOWN	NO
3/23/93		UP			BROKEN RAIL	1400	NO
9/8/92		UP			GRADE CROSSING	600	NO
11/20/92	1:53AM	UP			DERAILMENT	1300	NO
8/30/91		BN			COLLISION	30000	NO
6/19/91		BN			COLLISION	200	YES
12/8/93	3.10AM	UP		12	ROCK SLIDE	5000	NO
1/26/93	10:30PM	CSX			DERAILMENT	3000	NO
9/10/91		BN			UNKNOWN	2000	NO
6/4/92		SP			GRADE CROSSING	1200	NO
11/22/91		SP			ROLLOVER	2100	NO
11/19/91		SP			SIDESWIPE	400	NO
7/14/91		SP			DRAFT FORCES	1100	NO
11/25/92		ATK			GRADE CROSSING	UNKNOWN	NO
11/5/92		ATSF			SIDE COLLISION	UNKNOWN	NO
12/5/93	9:38AM	SP		9	DERAILMENT	200	NO
12/5/93	9:38AM	SP		9	DERAILMENT	2500	NO
12/5/93	9:38AM	SP		9	DERAILMENT	2500	NO
12/5/93	9:38AM	SP		9	DERAILMENT	200	NO
4/19/93	10:00AM	SP		20	DERAILMENT	1800	NO
11/22/91		SP			COLLISION	8000	NO
6/20/91		SP			GRADE CROSSING	2500	YES

Table 3.11 (continued)

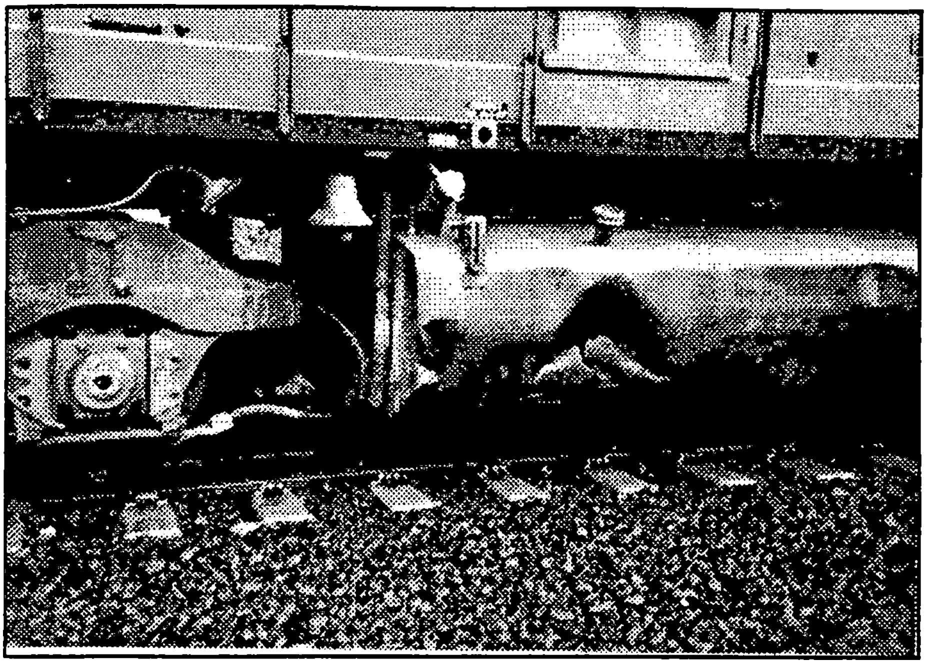

Figure 3.20 Fuel Tank Damage Due to Rock Slide

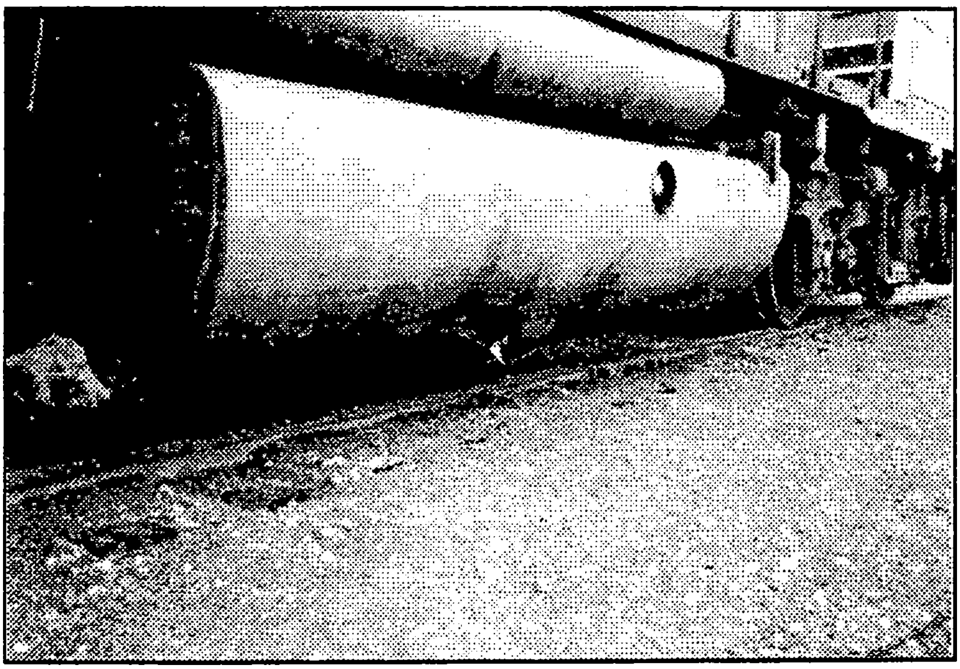

Figure 3.21 Fuel Tank Penetrated by Broken Rail

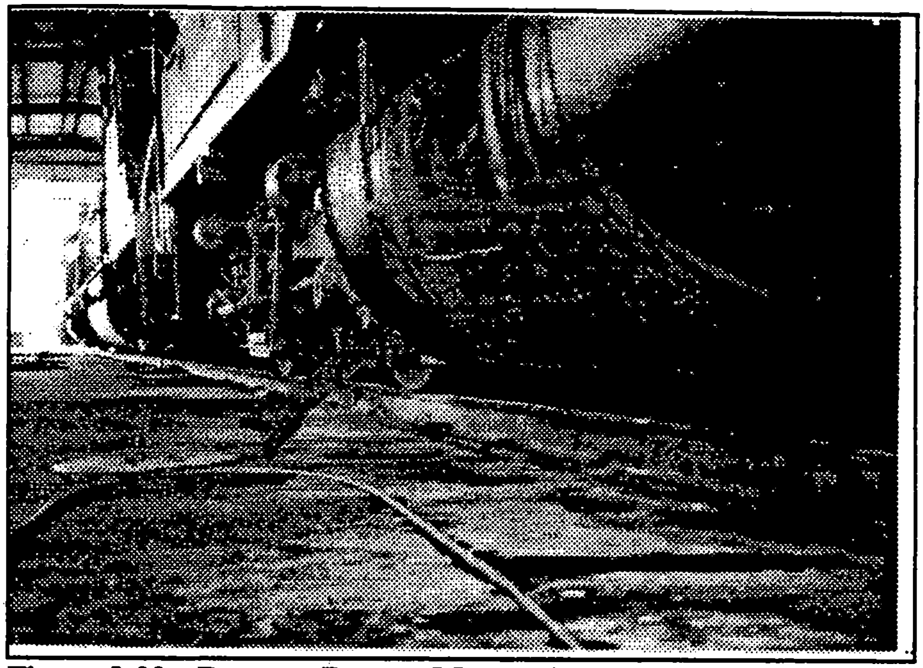

Figure 3.22 Damage Due to Motor Vehicle Collision with Fuel Tank

Some significant, but not widespread, improvements to current practice have recently taken place. Conrail ordered locomotives from GE with 1-inch thick steel end plates and 3/4-inch thick bottom and side walls. The new Amtrak AMD 103 locomotives have what is essentially an internal, compartmentalized fuel tank that is much higher off the rail and part of the carbody structure. However, such a change may not be practical for the higher capacity fuel tanks required for freight locomotives. The Long Island Rail Road is conducting experiments with three 1,200-gallon capacity tanks with a stronger steel shell that is lined with a carbon composite (kevlar) fiber bladder inside the tank. This tank is designed to support the weight of the locomotive sliding on the rails, and to withstand a 250,000 lb horizontal load without failure. Application of this technology may require some research and development for implementation to a 4,000-5,000 gallon tank typical of a modern freight locomotive.

Evaluation Past locomotive fuel tanks have not been designed to be structurally strong, using safety and environmental concerns as design drivers. Data collected by NTSB, AAR, and FRA show fuel leaks or spills to be frequent when damage to a locomotive occurs. The possibility of fire resulting from the ignition of spilled fuel is increased in these instances, and frequently increases the number and severity of casualties resulting from accidents involving locomotives. Both AAR and some individual railroads have responded to environmental and safety pressures and costs created by diesel fuel spills by taking steps to improve current locomotive fuel tank design practice. FRA believes that an industry standard for fuel tanks can be practically implemented and will result in safer and more environmentally sound railroad operations. Based on accident/incident experience with respect to the nature, location, and cause of fuel tank ruptures, and the recent advances in fuel tank design being undertaken by industry as discussed above, FRA believes that the following objectives need to be addressed and standardized to reduce the probability of future fuel spills from locomotives:

- o By virtue of their location beneath the underframe and between the trucks, locomotive fuel tanks are vulnerable to damage from impact during a derailment or collision, or by debris and loose equipment on the roadbed. As such, fuel tanks need to be structurally designed to withstand the probable loads and forces that result from these occurrences. Examples of improved structural design include:

  - The material used for construction of tank exterior surfaces other than end bulkheads should as a minimum provide penetration resistance equivalent to that of 0.25-inch thick 50,000 psi yield strength steel.

  - The material used for end bulkhead construction should as a minimum provide penetration resistance equivalent to that of 0.5-inch thick, 50,000 psi yield strength steel.

  - The tank should be securely attached to the body of the locomotive in a manner that prevents tank sag over time.

  - The material used for construction of fuel tank exterior surfaces should not exhibit a decrease in yield strength or penetration resistance in the temperature range of 0 to 160 degrees Fahrenheit.

  - The bottom surface of the fuel tank should be equipped with wear skid surfaces to prevent sliding contact with the rail or ground to easily wear through the tank.

  - The end bulkhead surfaces should be arranged to deflect downward any projectile and be designed to be a uniform surface in a single plane with no projections, protrusions, wells, lips or joints to catch and hold a broken rail or other object that may strike that surface of the tank.

- o Following a derailment or collision, a locomotive often comes to rest outside of the track structure causing the weight of the locomotive to be supported—at least in part—by the structure of the fuel tank. To prevent subsequent rupture and spillage, the structural strength of the tank should be adequate to support 1.5 times the dead weight of the locomotive without deformation of the tank.

- o Current fuel tank designs provide a very limited distance between the bottom of the fuel tank and the top of the rail. Collision and derailment experience has clearly shown that fuel tanks contact the rail structure in these scenarios, causing rupture and spillage. An effort to vertically raise the position of the locomotive fuel tank would reduce the probability of such impacts. With all locomotive wheels resting on the ties beside the rail, the lowest point of the fuel tank should clear an 8.5 inch combined tie plate/rail height by a minimum of 1.5 inches. This requirement results in a minimum 10 inch vertical distance from the lowest point on wheel flanges to the lowest point on the fuel tank.

- o In the event of a fuel tank rupture, measures need to be taken to minimize the quantity of fuel that spills. Such measures can be accomplished through design efforts as follows:

    - The interior of fuel tanks should be divided into a minimum of four separate compartments designed so that a penetration in the exterior skin of any one compartment shall result in loss of fuel only from that compartment.

    - Fuel tank vent systems should be designed to prevent them from becoming a path of fuel loss in the event the tank is placed in any orientation due to a locomotive over turning.

FRA believes strongly that fuel tank design has a direct impact on safety. Minimum performance standards for locomotive fuel tanks should be incorporated into Federal safety regulations. Although differences exist between the AAR proposed recommended practices and the above recommendations, FRA is committed to working closely with AAR to resolve the differences between the two sets of standards.

Emergency Lighting

Current locomotive cabs are not equipped with emergency lighting to aid in egress in the event of a collision. NTSB has addressed the need for Amtrak passenger cars to be equipped with portable emergency lighting for passenger safety when exiting the train as a result of its investigation report of the Amtrak accident near Mobile, Alabama. As a result of that accident, the Safety Board recommended on September 30, 1994, that Amtrak equip cars with portable lighting for use by passengers in an emergency (Safety Recommendation R-94-8). Amtrak has included requirements for such lighting in their High Speed Train Set performance specification, and FRA recommends that similar requirements be considered on freight locomotives. Such a system would:

- o be energized upon power loss;

- o clearly illuminate and mark all exits and the location of emergency equipment;

- o provide adequate illumination that operates in all possible orientations of the unit for a period of at least two hours; and
- o provide a minimum illumination level of 5 ft-candles at floor level for all potential locomotive evacuation routes.

Attachment of Interior Equipment

The computer modeling performed for the improved collision posts and crash refuge concepts identified a maximum acceleration of approximately 11 g's given the baseline crash scenario. Given this threshold, it is recommended that all ancillary equipment within the interior of the cab be designed to withstand 12g longitudinal acceleration (along the train principal axis), 4g vertical acceleration, and 4g lateral acceleration without structural failure that will free any item restrained or secured in the cab. This will further limit the possibility of flying debris within the cab in the event of a collision. The maximum acceleration associated with the interlocking anticlimber concept as modeled is 15g, but may be reduced to a level closer to the other concepts through additional design efforts to maximize the effectiveness of the anticlimber arrangement.

Optional Egress

Current wide cab freight locomotives do not incorporate an optional opening in the roof structure to be used for egress following a collision, especially in the event of rollover whereby access to the cab doors is often blocked and/or crushed as a result of the collision. Implementation of a crash survivability strategy should include consideration of an optional egress path in the roof of the cab to be used as an emergency exit. In order to be useful, such an opening would need to be a minimum size of 30 inches in diameter or 30 inches long by 30 inches wide, clearly marked and posted with clear, simple instructions for use from both inside and outside of the cab.

Crash Energy Management

FRA recently worked with Amtrak in the development of their design specification for the High Speed Trainset, specifically in the areas of safety and crashworthiness design. During this effort, FRA and Amtrak jointly developed minimum design specifications for the High Speed Trainset relating to locomotive cab crashworthiness and cab survivability that addressed features not specified for evaluation in the Congressional mandate.

To make a collision of a locomotive survivable, two design features are required: (1) the spaces occupied by people must be strong enough not to collapse, crushing the people, and (2) the initial deceleration of the people must be limited so they are not thrown against the interior of the train with great force. The first of these objectives is addressed by requirements currently contained in 49 CFR 229.141 and the locomotive crashworthiness rulemaking proposed in this report. Achieving the second of these general objectives is the more challenging and requires technology that is just starting to be developed for locomotives.

This technology to limit secondary impacts during collisions is called crash energy management. Crash energy management is a design technique whereby unoccupied spaces are intentionally designed to be slightly weaker than occupied spaces. This is done so that during a collision, the unoccupied spaces will deform before the occupied spaces, absorbing energy and allowing the occupied spaces to be decelerated more slowly.

The value of crash energy management design is not in the energy absorbed—only a few percent of the kinetic energy of a collision can be absorbed in a reasonable crush distance. The real safety benefit comes from allowing the occupied spaces to decelerate more slowly. If the occupied spaces are decelerated more slowly, people will be thrown about the interior of the cab with less force resulting in fewer and less severe injuries.

Primarily from experience gained in work related to the High Speed Trainset, FRA recommends that consideration of crash energy management design parameters similar to the following be included in future locomotive design:

> Locomotives shall be designed to crush and absorb energy in a controlled manner by "zones" when subjected to end loads in collisions which exceed the static load of the structure. The zones shall be as follows, from highest to lowest priority:
>
> > Zone A: High density crew space
> >
> > Zone B: Low density crew space, such as toilets and entryways
> >
> > Zone C: Unoccupied space
> >
> > Zone D: space occupied by large, solid-mass, relatively uncrushable equipment

A more detailed description of recommended crash energy management guidelines is provided in Appendix D.

Representation of AC Locomotive Effect

It is expected that locomotive units equipped with AC traction motors will come into widespread use in the freight motive power fleet by the end of the 1990's. This may have an indirect beneficial effect on crashworthiness because fewer such units are needed to move a train than the present units equipped with DC traction motors, and the results already shown in this report indicate that crashworthiness is most directly affected by the number of locomotives involved in a head-on collision.

One ADAMS analysis was conducted to examine the effect of fewer locomotives involved in a collision scenario using the baseline scenario based on FRA Report B-02-93. This ADAMS analysis retained the same parameters that were used to validate the simulation model with respect to this scenario, except that the number of locomotives in the eastbound consist was reduced from five to two, and the number of locomotives in the westbound consist was reduced from two to one. Evaluation of the effect of the reduced numbers of locomotives was accomplished by comparing the crush and crash pulse for the overridden locomotive, as calculated form the revised analysis, with the corresponding results already obtained from the validation analysis.

The amount of predicted cab crush for this revised scenario is just 1.2 feet, compared to the value of 8 feet for the baseline scenario. This value of 1.2 feet is comparable to the predicted cab crush for the baseline crash configuration—seven locomotives total—in which the lead locomotives were simulated to have the concept collision posts, whose strength is four times that currently required by AAR S-580. The cab crush for this case was predicted to be 1.3 feet. Thus, the model predicts that reducing the number of locomotives in a consist can have dramatic effects in reducing the severity of head-on collisions, comparable to the effect of implementing other crashworthiness features such as the strong collision posts evaluated earlier in this report.

Control Cab Cars (Cab Cars)

Background While the modeling described to this point focuses primarily on the development of methods to improve the crashworthiness of conventional locomotives in response to the requirements of the Act, FRA proceeded with a logical extension of this work to examine the crashworthiness of commuter train cab cars. With increasing frequency, commuter railroads are operating trains in a push-pull configuration, with a control car at one end of a train of several passenger cars that has a locomotive at the other end. This push-pull configuration requires a single locomotive that generally pulls during outbound trips and pushes during inbound trips so that the exhaust and noise of the locomotive does not enter the terminal building of the primary metropolitan station. Additionally, the time and scheduling impacts associated with switching the locomotive such that it is at the lead end of the train for each trip are viewed by the commuter railroads as operationally unacceptable and unnecessary given the accident history. However, an obvious concern with this type of train configuration is that the occupants of the relatively exposed cab car—including the engineer—are vulnerable to serious injury or fatality in the event of a collision with either a vehicle at a grade crossing or with another train.

On January 18, 1993, Northern Indiana Commuter Transportation District (NICTD) eastbound commuter train 7 and NICTD westbound commuter train 12 collided in a corner-to-corner impact in Gary, Indiana, resulting in seven passenger fatalities and 95 injuries. The damage that both trains sustained after the initial impact resulted from the action of dynamic forces that caused the left front corner and sidewall of the passenger compartment of each car to experience a complete structural failure and intrude inward. Because no structure was available in the corner post areas to successfully absorb the crash forces of the collision, the substantial car body intrusion into each car left no survivable space in the left front areas of either car. Consequently, NTSB issued Safety Recommendation R-93-24, which recommends that FRA:

> In cooperation with the Federal Transit Administration and the American Public Transit Association, study the feasibility of providing car body corner post structures on all self-propelled passenger cars and control cab locomotives to afford occupant protection during corner collisions.

Following the general approach that was used to evaluate locomotive crashworthiness, an evaluation of the crashworthiness of cab cars was performed to assess the level of protection provided for the engineer in a typical existing cab car, and the potential for improvements.

Current Practice Cab cars are built to the same standards applicable to electric multiple-unit (MU) as provided in 49 CFR 229.141 as follows:

> *(a) MU locomotives built new after April 1, 1956 that are operated in trains having a total empty weight of 600,000 pounds or more shall have a body structure designed of meet or exceed the following minimum specifications:*
>
> > *(1) The body structure shall resist a minimum static end load of 800,000 pounds at the rear stops ahead of the bolster on the center line of draft, without developing any permanent deformation in any member of the body structure.*
> >
> > *(2) An anti-climbing arrangement shall be applied at each end that is designed so that coupled MU locomotives under full compression shall mate in a manner that will resist one locomotive from climbing the other. This arrangement shall resist a vertical load of 100,000 pounds without exceeding the yield point of its various parts or its attachments to the body structure.*
> >
> > *(3) The coupler carrier and its connections to the body structure shall be designed to resist a vertical downward thrust from the coupler shank of 100,000 pounds for any horizontal position of the coupler, without exceeding the yield points of the materials used. When yielding type of coupler carrier is used, an auxiliary arrangement shall be provided that complies with these requirements.*
> >
> > *(4) The outside end of each locomotive shall be provided with two main vertical members, one at each side of the diaphragm opening; each main member shall have an ultimate shear value of not less than 300,000 pounds at a point even with the top of the underframe member to which it is attached. The attachment of these members at bottom shall be sufficient to develop their*

full shear value. If reinforcement is used of provide the shear value, the reinforcement shall have full value for a distance of 18 inches up from the underframe connection and then taper to a point approximately 30 inches above the underframe connection.

Though not required by 49 CFR 229.141, it is not uncommon for cab car specifications to include a corner post structure with an ultimate strength requirement of 150,000 lbf at the underframe level.

Evaluation Two specific accident scenarios were developed for the evaluation of cab car crashworthiness based on review of accident reports and consideration of the manner in which typical commuter trains operate.

The first is based on the August 11, 1981 head-on collision between the Boston and Maine Corporation's Extra 1731 East and the Massachusetts Bay Transportation Authority's Train No. 570, in Beverly, Massachusetts, which caused several serious injuries. This accident, in which a freight locomotive collided head-on with a control car, occurred at a closing speed of approximately 31 mph. The result was the severe deformation and fracture of the cab car underframe followed by override of the cab car onto the locomotive.

In the case of a collision between a locomotive and a cab car whose longitudinal centerlines are collinear as above, it appears that the crush load in the cab car will be transferred to the overall structure primarily through the underframe. Because the underframe in cab cars is generally lower than that for locomotives, it is likely that—subsequent to coupler impact and deformation—the cab car underframe will be trapped between the protruding draft gear support structure and the underframe or anticlimber of the locomotive. The draft gear support structure in locomotives has an ultimate strength of 2 to 3×10^6 lbf, and the locomotive underframe strength exceeds this range considerably. On the other hand, the cab car underframe, whose yield-based design strength is 0.8×10^6 lbf, has an ultimate strength of less than 2×10^6 lbf. The consequence of the trapping phenomenon and the locomotive/cab car structural strength difference is that the cab car underframe will be the primary component crushed. Such a loading situation appears to have occurred in the accident described above.

The second is based on the Gary, Indiana accident described earlier in which two commuter trains collided, resulting in a direct impact between the corners of the two lead cab cars that resulted in destruction of the corner posts, crush of approximately 25 feet on each vehicle side, and seven passenger fatalities.

In the case of a collision between a locomotive and a cab car whose longitudinal centerlines are parallel but offset laterally causing the corner post to be directly loaded, similar to above, the locomotive draft gear support structure can be completely to the side of the cab car underframe. As a result, there is little opportunity for trapping and the locomotive underframe is likely to challenge the corner post directly, just at or above the cab car underframe. A similar situation occurred between the two cab cars in the accident in Gary, Indiana.

The two baseline crash scenarios used for evaluation of cab car crashworthiness are based on the first accident described above, utilizing the same train configuration and initial speeds. The second baseline crash scenario is different in that it incorporates a lateral offset at the point of impact.

Finite element models for the major structural elements of a typical cab car were developed and utilized to compute the load versus deformation characteristic curves for each element. These characteristics were used as input to the train collision dynamics model developed previously for locomotives. The collision dynamics model was modified to represent a typical passenger train with a cab car at the head end, instead of a freight train with locomotives at the head end. The occupant survivability model was also modified to represent the control cab interior in place of the road freight locomotive interior. These new and modified models were then validated by comparison of predicted results with the actual damage and injuries documented in the actual collisions in Beverly, Massachusetts, and Gary, Indiana.

In the centered collision crash scenario, modeling predicts 1 foot of cab car underframe crush at a closing speed of about 25 mph (for a velocity ratio as given in the baseline scenario). However, the cab car underframe crush becomes very large—greater than 6 feet—at closing speeds above approximately 35 mph. This behavior is a result of the assumed underframe load-crush curve, which decreases monotonically after the peak strength is achieved. The closing speed at which substantial crush occurs would be increased if the cab car structure was somehow designed and built to maintain the peak load for substantial crush. The predicted response for underframe crush is in reasonable agreement with the outcome of the accident on which the simulation was based. In the actual accident, which is reported to have occurred at a closing speed of about 31 mph, there was also substantial underframe crush, including fracture between the underframe and superstructure.

In the offset collision crash scenario, the closing speed at which substantial crush of the corner post occurs is much lower than that corresponding to underframe crush. Modeling shows that substantial corner post crush occurs when the closing speed is above 15 mph. Although an actual accident involving a locomotive and a cab car in a corner post accident could not be found for comparison, the Gary, Indiana accident in which destruction of the corner posts followed by 25 feet of crush along the sides of each cab car can be used. Although the predicted results of this evaluation do not extend to 25 feet of crush, substantial crush would certainly be predicted at a closing speed of 32 mph.

In an effort to determine whether significant structural modifications made to the cab car body would preserve a survivable volume in the above collision scenarios, the model was modified to assess the effects of increasing component strength on the degree of crush. These were:

- an increase in underframe strength of 50 percent, applied over the entire range of crush. This corresponds to a peak underframe strength of 2.6×10^6 lbf, and

- an increase in the corner post strength by a factor of four, to 60,000 lbf, thus matching the combined, currently required strength of two collision posts.

For the centered collision, the closing speed at which very large vehicle crush will occur is in the range of 40 to 45 mph, only about 10 mph greater than that for the baseline component strengths. Similar increases in the closing speed needed to induce substantial crush were obtained for the offset collision scenario, for which the range is increased to 20 to 25 mph, again only 10 mph greater than that of the baseline evaluation. These results suggest that only a small improvement in protection is possible through structural changes for the case of a cab car-leading train-to-train collision. However, these structural changes may provide a much more significant increase in protection for the less severe scenarios of a grade crossing collision, a collision with debris (including lading that falls from freight trains), or a collision with an object overhanging the track.

Conclusions

Table 3-12 provides a comparative summary of the crashworthiness concept evaluation results with respect to weight increase, cost increase, and occupant survivability measures. Each of these various concepts was evaluated in terms of the likelihood to provide practical, cost-effective benefit to the crew in the event of a collision. The results illustrated in Table 3-12 clearly indicate that implementation of some of the crashworthiness concepts specified in the Act will provide added protection to locomotive crew members involved in a collision.

From the modeling and evaluation performed, incorporation of stronger collision posts appears to be the method that is most effective for maintaining a survivable space inside the locomotive while minimizing associated weight and cost penalties. Most significantly, the model results for the simulated crash scenario show a decrease in cab crush from 8 feet to 1 foot. Remembering that cab crush in excess of 6 feet beyond the tip of the short hood is assumed to begin the elimination of survivable space in the cab, incorporation of stronger collision posts as modeled renders such a collision survivable as opposed to the baseline crash scenario in which approximately 2 feet of survivable space would be expected to be crushed. The occupant survivability measures calculated as a result of the modeling effort are moderately higher than those calculated for the baseline scenario using a locomotive that just met the strength requirements of AAR S-580 with respect to collision posts. However, these occupant survivability figures are well within the accepted range in which crew members would be expected to escape serious injury as a result of secondary impacts.

Current collision post designs are often stronger than those required by AAR S-580, and some also extend above the required total height of 30 inches. The modeling effort provides only one variation of geometry that significantly increases the strength, providing increased

TABLE 3-12. **Summary of Crashworthiness Concept Evaluation Results**

Concept	Description	Weight Increase (lbs)	Cost Increase	Occupant Survivability Measures
Baseline (S-580)	Collision post strength = 200,000 lbf (each) at 30 inches Anticlimber vertical strength = 200,000 lbf Short Hood: 0.5 inch x 25,000 psi yield	N/A	N/A	Crush: 8 feet Max acc: 11 g's HIC (avg): 160 C_R (avg): 20
Strong Collision Posts	Increase strength from 200,000 lbf/post at 30 inches to 750,000 lbf/post total height = 71 inches	0-400	$1,000	Crush: 1 foot Max acc: 11 g's HIC (avg): 330 C_R (avg): 36
Roll Bar	Structural frame near front of cab	3,000	$10,000	not calculated
Deflection Plates	Angled plates on front of locomotive intended to derail one or both lead locomotives	2,000	$5,000	analysis suggests that this feature is not effective
Shatterproof Windows	Semitempered glass/polycarbonate	Minimal	$1,000	provides 4-5 times the impact resistance over current designs

Notes: Maximum cab crush allowable before elimination of survivable space = 6 feet
50% probability of serious injury values: HIC = 1090 and C_R = 46

TABLE 3-12. **Summary of Crashworthiness Concept Evaluation Results (continued)**

Concept	Description	Weight Increase (lbs)	Cost Increase	Occupant Survivability Measures
Rotating Seat Crash Refuge	Requires locking mechanism and some other protection measure identified in this study	300	$10,000 to $15,000	Crush: varies with associated design feature Max acc: 11 g's HIC (avg): 95 C_R (avg): 28
Rotate & Drop Seat Crash Refuge	Requires locking <u>and</u> drop mechanism as well as some other protection measure	600	$15,000 to $20,000	Crush: varies with associated design feature Max acc: 11 g's HIC (avg): 62 C_R (avg): 21
Trench Crash Refuge	Lever-action drop down floor panel in rear of cab exposes trench	400	$2,000	Crush: varies with associated design feature Max acc: 11 g's HIC (avg): 165 C_R (avg): 15

Notes: Maximum cab crush allowable before elimination of survivable space = 6 feet
50% probability of serious injury values: HIC = 1090 and C_R = 46

TABLE 3-12. Summary of Crashworthiness Concept Evaluation Results (continued)

Concept	Description	Weight Increase (lbs)	Cost Increase	Occupant Survivability Measures
Interlocking Anticlimber	Casting or fabricated piece welded to front of locomotive	2,000	$5,000	Crush: 0 Max acc: 15 g's HIC (avg): 925 C_R (avg): 50
Equipment to Deter Post-Collision Entry of Flammable Liquids	Covers for openings in short hood, doors that open out, shatterproof windows	minimal	$1,000 same as for windows	Provides 4-5 times the impact resistance over current designs

Notes: Maximum cab crush allowable before elimination of survivable space = 6 feet
50% probability of serious injury values: HIC = 1090 and C_R = 46

protection to the crew. The tapered, wide flange geometry collision post modeled has a total height of 71 inches, more than double the current AAR S-580 requirement. It is certain that other design concepts can be generated that similarly minimize space and weight impacts while still improving structural strength over current designs. The added protection afforded to locomotive crew members, with minimal weight penalties and little additional cost as identified, clearly demonstrates that a reevaluation of appropriate dimensional and structural requirements for collision posts should be pursued.

The modeling performed for this report identifies a weakness regarding current anticlimber design. AAR S-580 currently requires that locomotives be equipped with anticlimbers designed to withstand a minimum of 200,000 pounds when applied vertically and uniformly between the center sill webs under the anticlimber of the locomotive. The intent of this requirement is not completely clear. It has been assumed that the requirement is an attempt to limit or prevent override during collisions, which in most scenarios results in significant cab crush and the elimination of survivable space. The model shows that the anticlimber of an overridden locomotive is not heavily loaded vertically during head-on collisions, except at very low closing speeds. Instead, the model predicts complete failure of the draft gear support structure of the overriding locomotive together with ramping between coupler or anticlimber components in colliding locomotives permits a path for override to occur. This has been confirmed through examination of several collisions in which override occurred at moderate closing speeds.

It has been suggested that the intent of the AAR S-580 requirement for anticlimber vertical strength is to prevent the rise of debris from grade crossing type accidents. As substantial cab crush is typically associated with override of one locomotive onto another, the arrest of override by whatever means possible is an important design goal. It has been shown that current anticlimber designs are inadequate to resist override even at medium closing speeds, and as such, a new approach needs to be taken to limit the relative vertical motion of locomotives during collisions.

The interlocking anticlimber concept modeled yielded significant results in that cab crush was eliminated under the crash scenario evaluated. The occupant survivability measures significantly increased over those calculated for the baseline crash scenario, but still remained in the acceptable range with respect to the expected resultant injuries as defined earlier. Successful operation of the interlocking anticlimber concept modeled for this report is dependent on other factors, including the need to equip all locomotives with this feature.

Modeling results for the improved collision posts and for the interlocking anticlimber yield one very important, common result—either of these crashworthiness concepts nearly eliminates cab crush at moderate closing speeds. The preservation of a survivable volume for the locomotive crew is obviously a desirable design goal, as crew members would not be crushed and design of the locomotive cab interior to be more "user-friendly" with respect tosecondary impacts could be emphasized. In this respect, incorporation of **both** stronger collision posts and an interlocking anticlimber in future locomotive designs may be somewhat redundant.

While few reportable injuries have been directly attributable to inadequate glazing designs, the possibility exists to significantly increase the level of protection afforded to the locomotive cab occupants in the event of an impact, especially with respect to protection from the hazards of spallation. These alternative designs provide improved protection with no significant increase in overall weight and at moderate costs that do not appear to be prohibitive.

Evaluation of the current locomotive cab roof has shown that it is structurally inadequate to protect occupants in many collision scenarios. While the Act mandates evaluation of braced collision posts and rollover protection, accident experience has suggested that attention should also be given to cab corner post and roof strength. From the point of view of efficiency and weight, a unitized, or monocoque end structure design that is tied together and acts as a single structure during a collision may be a preferable to a design incorporating collision posts, corner posts, and/or rollover protection that is not unitized. The Amtrak High Speed Trainset specification requires an end structure which incorporates corner posts in addition to the collision posts mandated by AAR S-580. Amtrak has identified specific loading requirements for these corner posts and collision posts, both at the underframe and at the roofline, in an effort to provide maximum protection to the cab occupant. A similar approach, or incorporation of a monocoque end structure design as described above, is worthy of consideration for conventional locomotives. Appendix E provides conceptual end structure strength and roofline loading strength requirements for consideration.

NTSB, AAR, and FRA have all identified deficiencies with respect to the current design of locomotive fuel tanks. While AAR Recommended Practice RP-506 represents a definite advance in specifying design requirements for locomotive fuel tanks, FRA believes that an industry standard for fuel tanks—developed jointly by FRA, AAR, and the railroad industry— can be practically implemented and will result in safer and more environmentally sound railroad operations.

The incorporation of emergency lighting provisions and an optional emergency egress opening in the roof structure of a locomotive cab could provide additional safety measures beyond the structural improvements discussed above. These would be consistent with an overall crash survivability strategy that encourages the crew to ride out the event, rather than choosing the demonstrably unsafe option of jumping from the train. The implementation of these features is both technically and economically feasible and practical, and would provide cab occupants with additional resources in the event of a collision.

Other crashworthiness concepts identified in the Act similarly demonstrate safety benefits to the locomotive crew, but may not be as defined due to a lack of information regarding specific crash scenarios or the lack of mature technology to practically implement the feature.

Occupant survivability analyses were not conducted for the roll bar concept, as definition of a specific crash scenario from which to evaluate its benefits against the baseline crash scenario was not possible. Of all the crashworthiness features evaluated in response to the Act, the roll bar concept evaluated as part of this study was by far the heaviest and in the upper ranges for cost of implementation. Additionally, the estimated structural member sizes required to support the rollover loads are large enough to require some redesign of the front cab. Based on known accident experience, a roll bar requirement would not be justified.

None of the three crash refuge concepts evaluated provide improved protection to locomotive cab occupants with respect to cab crush. Accordingly, evaluation was made to determine what, if any, reduction in secondary impact measures is provided by each concept. Evaluation results showed that each of the concepts evaluated provided sufficient levels of protection against serious injury, either comparable to, or better than measures developed for the baseline crash scenario. These results show that any of the crash refuge concepts presented in this study can be beneficial when implemented in conjunction with another feature that provides protection against cab crush.

Implementation of the trench crash refuge appears to provide the most beneficial approach to providing a survivable volume inside the locomotive cab. While all three crash refuge concepts provide exceptional protection with respect to secondary impacts, the trench is located below the floor level of the locomotive cab, and thus, less likely than either of the seat concepts to be crushed in the event the locomotive cab is crushed as a result of override or another failure mode. Again, it is important to note that implementation of such a trench would require use of another feature (i.e. improved collision posts) that limits the amount of cab crush.

The effectiveness of a crash refuge concept can be greatly aided through implementation of crash energy management techniques. By designing the unoccupied spaces to be slightly weaker than occupied spaces, the unoccupied spaces will deform before the occupied spaces absorbing more energy and allowing the occupied spaces to be decelerated more slowly. If these occupied spaces are decelerated more slowly, crew members will be thrown about the interior of the cab with less force, resulting in fewer and less severe injuries. Thus, implementation of crash energy management techniques in conjunction with a well designed and properly placed crash refuge may greatly increase the probability of survival following a collision. More detailed information regarding crash refuges, and concepts for consideration are provided in Appendix F.

During the informal industry meetings held at the inception of this locomotive crashworthiness research project, industry representatives recommended that the current glazing standards be revised to protect crew members from increasingly hazardous impacts attributable to increasing train speeds and the increasing creativity of vandals. The current glazing standards listed in 49 CFR 223 were developed for locomotives traveling at 79 mph or less, and may not afford the locomotive crew members adequate protection from today's hazards. Numerous industry groups have recommended that FRA adopt a multi-level glazing standard that ensures increased levels of protection as speeds increase. This "tiered" approach appears to be logical, and previous sections have identified that improved glazing options are available that provide much higher levels of protection with respect to impact and spallation at minimal weight and cost penalties. Based on this information, Appendix G provides detailed information regarding more stringent glazing requirements for consideration by the industry.

The modeling also identified features listed in the Act that do not demonstrate a direct safety benefit to the locomotive crew, and/or are not economically or technically feasible to implement. While a deflection plate may seem like a beneficial concept, the potential exists for deflection plates to cause more harm than good. If trailing cars do not follow the locomotive off the track, trailing cars could be subject to a more severe collision. Obvious examples of such incidents include the hazard of collisions on bridges, danger to structures next to the track or potential casualties in populated areas, and the possibility of deflected locomotives falling great distances in elevated terrains. These scenarios will likely increase casualties or cause more severe hazardous material spills. Because of the above concerns, FRA does not recommend further development of similar concepts.

Neither accident investigation data nor computer modeling shows conclusively that uniform sill heights will help prevent override. However, correctly designed and installed anticlimbers can be effective in preventing override up to a limiting maximum collision closing speed. Further development in the area of anticlimbers should address the need for compatible anticlimber engagement heights.

Summary and Recommendations

This portion of the report has evaluated the specific suggestions for improvement of locomotive crashworthiness set forth in the Act and offered commentary on them individually. As a result of this evaluation, FRA recommends no action on rollover protection, deflection plates and uniform sill heights.

The accident data does not support a material need for rollover protection, and the costs of providing for this contingency would be substantial. Deflection plates cannot be designed to function practically within the design limitations of multi-use freight locomotives, and a successful deflection device would induce collateral safety problems involving trailing equipment. Uniform sill heights, without other measures, would not significantly reduce life-threatening crash damage. The costs of making a conversion to a standard sill height would be significant, and any benefits would accrue only after an extended period during which older non-standard locomotives would be gradually retired. As noted below, compatible anticlimbing arrangements may be achievable that accomplish the purposes sought by advocates of uniform sill height.

Recent voluntary industry action has improved crash survivability by specifying minimum crashworthiness standards that help to protect space needed for survival and resist intrusion of flammable liquids. Research in support of this study suggests that strengthening of collision posts beyond the minimum levels specified by the current industry standard could produce a meaningful reduction in loss of cab volume in collisions at moderate speeds, without incurring significant weight or cost penalties. Coupling this improvement with innovative crash refuge concepts and improved fuel tank survivability might encourage crew members to rely upon a more secure cab environment, in lieu of jumping from the train under circumstances where fatal injury is a likelihood. Depending upon the results of further research, more effective anticlimber mechanisms could further improve crash survivability. Innovative crash energy management concepts could offer alternatives to exclusive focus on structural strength, if notable practical issues can be successfully addressed.

Improved corner post arrangements could reduce the risk of fatal injury to crew members where objects (such as intermodal trailers and other shifted lading from passing trains) foul the clearance envelope. Additional concepts that appear to warrant further exploration include cab emergency lighting and more reliable means of rapid egress when locomotives roll to their sides in derailments and collisions. Existing safety glazing standards appear to warrant strengthening in light of evolving service environments, international standards, and availability of improved materials.

Implementation of even the most attractive "crashworthiness" options should not be attempted in isolation. A sustainable strategy for crew survival in collisions and other life-threatening incidents must consider trends in pertinent risk factors, crew acceptance, compatibility of new and existing equipment, operational practicability, initial and continuing costs, and other factors.

FRA recommends that the promising safety measures identified by this report be further developed in active consultation with those who would be benefitted or burdened by implementation of such measures, including employee representatives, railroads, and equipment manufacturers. The objective of these consultations will be to identify a cost effective array of further safety measures for implementation through appropriate means. Such means would likely include Federal rulemaking where clearly justified, development of private voluntary standards, and further research and development. Inclusion of industry parties in program development will ensure that issues of cost, effectiveness, and practicability are adequately explored and that, where feasible, resulting standards are stated as flexible performance objectives.

CHAPTER 4

Locomotive Cab Working Conditions

FRA conducted a nationwide investigation into the working conditions of locomotive crews aboard trains. This investigation encompassed a 2-year period and over 200 locomotives—belonging to 13 Class 1 Freight Railroads and Amtrak—selected as representative of both cold and hot weather operations. Key areas addressed were temperature, noise, air quality, sanitary facilities, ergonomics, vibration and asbestos.

Each key area is provided as a separate chapter and includes current FRA regulations, applicable industrial and governmental guidelines, effects of exposure on human performance, injuries/illnesses reported to FRA, measurements, and observations. For each key area, FRA provides conclusions concerning the impact of the working condition on crew performance, health, and safety.

Background

To ensure that railroads provide a safe and healthy working environment for train crews, Congress enacted the Rail Safety Enforcement and Review Act (RSERA) of 1992. The Act became effective in September 1992, and requires FRA to initiate rulemaking and/or report to Congress on several aspects of locomotive cab working conditions. Specifically, Section 10 of the Act requires the Secretary to address, at a minimum:

- o the extent to which environmental, sanitary, and other working conditions in locomotive cabs affect the crew's health, productivity, and the safe operation of locomotives;
- o the costs and benefits associated with equipping locomotives with functioning and regularly maintained sanitary facilities, and
- o the effects on train crews of the presence of asbestos in locomotive components.

In addition, the Act invites the Secretary to consider other factors that affect the working environment of locomotive cabs.

This chapter introduces the subject of locomotive working conditions and describes the procedures used by FRA to conduct a large-scale locomotive cab working condition evaluation program. The purpose of this chapter is to present the broad survey results that are difficult to separate by individual working condition effect in a single location in the report. Subsequent chapters, addressing each of the individual factors affecting locomotive working conditions in greater detail, will make reference to the procedures and results described in this chapter. These subsequent chapters include:

- o Locomotive Cab Temperature - Chapter 5;
- o Locomotive Cab Noise Level - Chapter 6;
- o Locomotive Cab Air Quality - Chapter 7;
- o Locomotive Cab Sanitary Facilities - Chapter 8;
- o Locomotive Cab Layout (Ergonomics) - Chapter 9;
- o Other Factors Affecting Locomotive Cab Working Conditions - Chapter 10; and
- o Effects of Cab Working Conditions on Locomotive Productivity - Chapter 11.

Each of these chapters provides a discussion of the following areas with respect to the particular working condition being addressed:

- o current FRA regulations, if any, covering the working condition;
- o standards, guidelines, and practices from other industries or government agencies that may be applicable or similarly applied to locomotive cabs;
- o effects of exposures that exceed established limits on human performance;
- o complaints alleging problems directly attributable to the specific working condition;
- o incidents of injuries or illnesses reported to FRA by railroads due to each working condition;
- o FRA measurements and observations made during an extensive locomotive cab working condition survey;
- o meaning of FRA measurements and observations from this survey; and
- o conclusions drawn by FRA concerning the impact of the working condition on crew performance, health and safety.

During informal industry meetings held by FRA, railroad labor organizations strongly emphasized the potential for adverse cab working conditions to cause medical damage to crew members. In their view, improvements in cab working conditions should be an immediate and high priority effort. Labor organizations identified specific examples of current conditions that they believe degrade the health of crew members, including illness caused by excessive temperatures, hearing loss caused by long duration exposure to high noise levels, and illness linked to inhalation of diesel exhaust fumes.

Over recent years, there have been numerous instances of rail labor—either directly or via a member of Congress—stating concern with respect to existing in-cab working conditions. Examples of letters addressing such concerns include the following:

- United Transportation Union letter, dated March 12, 1988, addressed to Mr. John Riley, FRA Administrator. In this letter, Mr. James M. Brunkenhoefer urged FRA to initiate a locomotive environmental study that would review certain problems, such as the long-term health effects of crew member's exposure to diesel exhaust;

- Senator J. James Exon letter, dated 1993, wrote on behalf James M. Brunkenhoefer regarding the effects of locomotive cab air quality on crew members;

- United Transportation Union letter, dated August 1993, addressed to Ms. Jolene M. Molitoris, Administrator, FRA. In this letter, William R. Ralls, Esq., requested information regarding the status of FRA mandating locomotive sanitation and toilets, and who had jurisdiction (either FRA or the State of Michigan) over this matter in the State of Michigan;

- United Transportation Union letter, dated August 30, 1993, addressed to Ms. Jolene M. Molitoris, Administrator, FRA. In this letter, Mr. James M. Brunkenhoefer asked FRA to examine crews working in excessive cab temperatures (130°F) in the Texas summer heat, and consider mandating air conditioning units on trains, especially where needed on a daily basis;

- U.S. Representative Al Swift letter, dated November 17, 1993. In this letter, Congressman Swift wrote on behalf of Norfolk and Western Railroad locomotive crews regarding the need for safe and sanitary toilets;

- Maine Attorney General Linda Conti letter, dated December 21, 1993. In this letter, issues were outlined regarding regulations covering locomotive toilet sanitary conditions (OSHA, FRA and the State of Maine); and

- U.S. Representative Sanford D. Bishop, Jr. letter, dated November 6, 1994. In this letter, Congressman Bishop wrote on behalf of a crew member from Georgia regarding cab temperatures and crew safety.

Some of the data developed in response to these and other individual inquiries is included in this report. Where information from complaint-based investigations is included in our findings, the data are so identified.

Approach

To investigate these and other concerns, and to provide Congress a detailed report covering the working conditions aboard locomotives, FRA conducted the following research and analysis on cab working conditions and their effects on crew productivity, health, and safe operation of locomotives as mandated in the Act:

- review of complaints and reported incidents of injury or illness;
- survey of cab working conditions;
- cab air quality tests under conditions of restricted outside air exchange;
- investigation of cab sanitary facilities and toilet chemicals;
- human factors evaluation of locomotive cabs; and
- study of the effects of working conditions on productivity.

The locomotive cab working condition survey forms the basis for the majority of FRA's findings. This survey, which was conducted by FRA inspectors, covers 17 separate sets of measurements or visual observations made on locomotives. The cab air quality tests and cab sanitary facility and toilet chemical investigation are expansions of the general survey to focus on a specific problem. The human factors evaluation of locomotive cabs is a separate research effort performed by the Volpe Center for FRA. In response to the Act, FRA's Office of Policy conducted a separate study on cab working conditions effects and their impacts on productivity. Each of these efforts will be introduced in this chapter.

Review of Complaints and Accidents/Incidents

Complaints submitted to FRA alleging violations of safety standards pertaining to locomotive cab working conditions, and reports of injuries or illnesses directly attributed to cab working conditions are both indications of the extent of the problem caused by poor cab working conditions. FRA compiled complaints due to working conditions from 1989 to 1993, and injury/illness reports attributable to cab working conditions for the time period between 1990 and 1994.

FRA investigated over 100 complaints of alleged violations regarding cab working conditions. These complaints are itemized and discussed by working condition in the respective chapters covering each individual working condition.

Figure 4.1 provides a graphic depiction of the number of incidents of injuries or illnesses reported to FRA by railroads between January 1990 and November 1994. It should be noted that temperature and noise criteria do not include the mental effects to report when judgment, and attention might be affected. The physical effects will appear long after these mental processes are influenced.

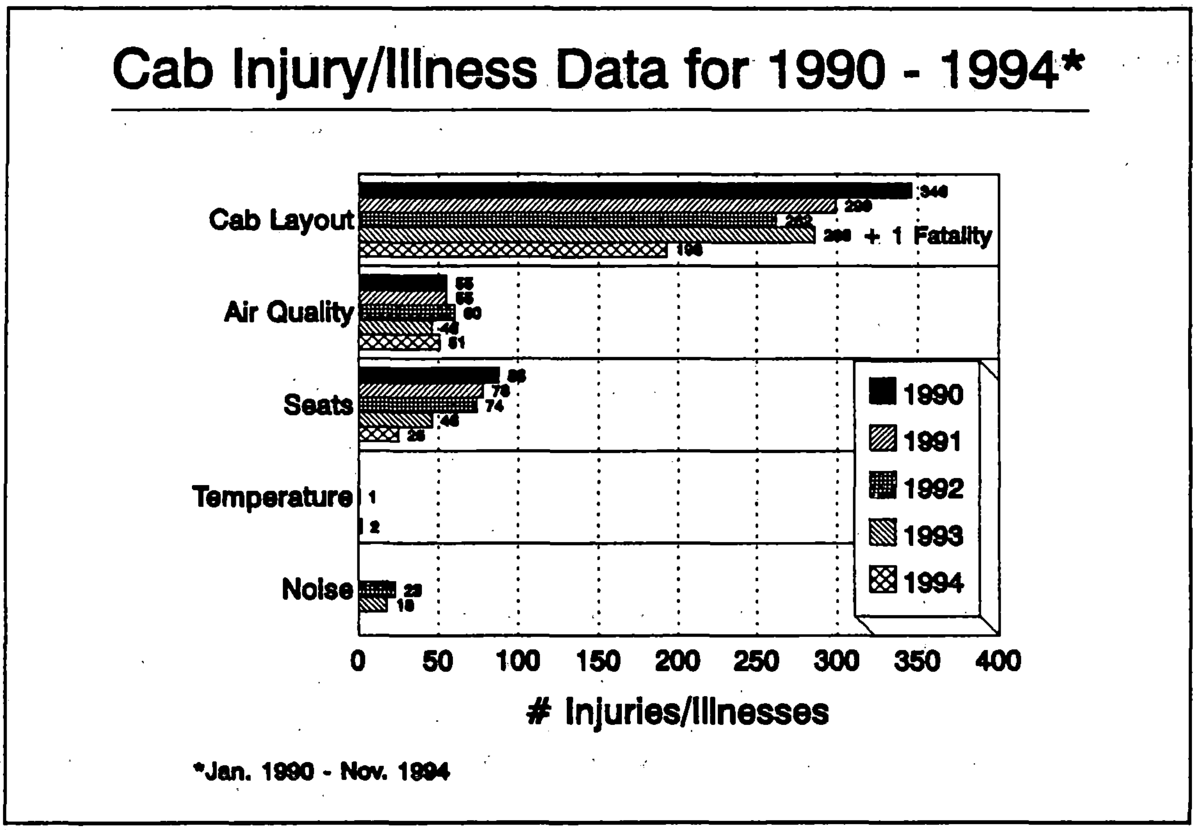

Figure 4.1 Cab Injury/Illness Data for 1990 - 1994

FRA compiled the information contained in Figure 4.1 in the following manner:

o all events connected with the operation of a railroad reported to FRA that resulted in one or more of the following consequences (and reported on form FRA F 6180-55a):

- death of a person within 365 calendar days of the accident/incident;
- injury to a person, other than a railroad employee, that requires medical treatment;
- injury to a railroad employee that requires medical treatment, results in restriction of work or motion for one or more work days, the loss of

one or more work days, termination of employment, transfer to another job, or loss of consciousness; and

- any occupational illness of a railroad employee which is reportable when it is diagnosed as being work-related by a physician or other qualified health care professional.

o The following FRA illness/injury codes were used to develop the charts:

<u>**Temperature (Disorders due to physical agents):**</u>

- 1141: Heat stroke/sun stroke (a serious heat-related condition in which the patient often stops sweating and experiences a marked rise in core temperature).

- 1142: Effects of ionizing radiation (refers to the various effects of ionizing radiation, e.g., gamma rays or x-rays).

- 1143: Effects of non-ionizing radiation (refers to effects of electro-magnetic radiation, e.g., radio waves, microwaves, welding flash, ultraviolet rays of the sun, etc.).

- 1144: Heat exhaustion (a heat-related condition of moderate degree which, if not treated, may lead to heat stroke).

- 1145: Freezing/frostbite (freezing of tissue with disruption of the blood supply).

- 1146: Other disorders due to physical agents other than toxic materials.

- 1149: Death resulting from physical agents (other than toxic materials).

<u>**Cab Noise (Disorders due to repeated trauma):**</u>

- 1151: Noise induced hearing loss (A Standard Threshold Shift (STS) is a change in hearing threshold relative to a baseline audiogram that averages 10 decibels or more at 2000, 3000, and 4000 hertz in either ear. Documentation of a 10 dB shift is not, of and by itself, reportable. There must be a determination by a physician (or a railroad may choose to delegate decision authority to another qualified health care professional) that environmental factors at work were a significant cause of the STS.)

However, if an employee has an overall shift of 25 dB or more above the original baseline audiogram, then an evaluation must be made to determine to what extent it resulted from exposure to work. Any conclusion that the shift was not significantly caused by factors at work must be supported by an evaluation/diagnosis of either a QHCP or a physician.

Note: The change in hearing may be adjusted for aging. A case does not need to be reported if a retest conducted within 30 days does not confirm the original STS. Once a reportable STS has occurred, the current baseline should be adjusted to reflect the test result. A subsequent test revealing an additional STS from this baseline value is a new case. Additional information concerning occupational noise exposure, monitoring, age corrections, etc., can be found in 29 CFR 1910: Occupational Noise Exposure; Hearing Conservation Amendment; Final Rule, as published in the Federal Register, Vol. 48, No. 46, on March 8, 1983.

Air Quality (Respiratory conditions due to toxic agents):

- 1121: Pneumonitis (inflammation of the lungs).
- 1122: Pharyngitis (inflammation of the throat).
- 1123: Rhinitis (inflammation of the nose).
- 1124: Acute congestion due to chemicals, dust, gases, or fumes.
- 1129: Death resulting from respiratory conditions due to toxic agents.
- 1132: Poisoning by carbon monoxide, hydrogen sulfide or other gases.
- 1139: Death resulting from poisoning.

Cab Layout (While operating or on locomotive):

- 101: Burn or electrical shock (equipment standing).

- 101T: Burn or electrical shock (equipment moving).
- 102: Striking parts of body against equipment while moving about locomotive (equipment standing).
- 102T: Striking parts of body against equipment while moving about the locomotive (equipment moving).
- 103: Struck by tools or other falling objects (equipment standing).
- 103T: Struck by tools or other falling objects (equipment moving).
- 104: Stumbled, slipped, fell or stepped on foreign object or irregular surface (equipment standing).
- 104T: Stumbled, slipped, fell or stepped on foreign object or irregular surface (equipment moving).
- 119: Other accidents/incidents while operating locomotive (equipment standing).
- 119T: Other accidents/incidents while operating locomotive (equipment moving).
- 914: Opening or closing locomotive doors (equipment standing).
- 914T: Opening or closing locomotive doors (equipment moving).
- 915: Opening or closing locomotive windows (equipment standing).
- 915T: Opening or closing locomotive windows (equipment moving).

Seats (While operating or on locomotive):

- 110: Defective locomotive seat (equipment standing).
- 110T: Defective locomotive seat (equipment moving).

- 111: Adjusting locomotive seat (equipment standing).
- 111T: Adjusting locomotive seat (equipment moving).

These reported injuries/illnesses are discussed in the individual chapters devoted to each working condition.

Survey of Cab Working Conditions

To comply with the Act, FRA collected data aboard locomotives in a variety of operating situations, and under a broad range of ambient conditions. FRA inspectors made specific measurements and observations on how each of the following cab working environment factors affects the performance of the crew:

- o cab temperature;
- o cab noise levels;
- o cab air quality;
- o cab sanitary facilities;
- o cab layout; and
- o general work environment.

Appendix H contains the guidance given to inspectors on how to conduct this survey. FRA conducted a broad, formal survey of the cab working conditions during 1993 and 1994 by having inspectors travel aboard locomotives—during environmental extremes and various working conditions—to determine whether existing in-cab working conditions impair the crew's health or ability to operate the locomotive safely.

The survey consisted of the following phases:

- o fall/winter season measurements and observations;
- o summer season measurements and observations;
- o Cascade Tunnel tests; and
- o toilet chemical evaluation.

The survey included a broad spectrum of locomotives in operational service. FRA designed the survey with care to include locomotives representing different:

- o makes and models;
- o years in service (from 1950's to 1990's);
- o types (road or switch);
- o location in train (lead or trail);
- o owners and operators (both major and smaller carriers); and
- o operation locations across the United States.

The survey included locomotives operated by the following railroads:

- o Atchison, Topeka and Santa Fe Railway Company;
- o Burlington Northern Railroad Company;
- o Chicago and North Western Transportation Company;
- o Consolidated Rail Corporation;
- o CSX Transportation;
- o Florida East Coast Railway Company;
- o Grand Trunk Western Railroad Company;
- o Illinois Central Railroad Company;
- o Kansas City Southern Railway Company;
- o National Railroad Passenger Corporation (AMTRAK);
- o Norfolk Southern Corporation;
- o Soo Line Railroad Company;
- o Southern Pacific/DRGW Companies;
- o Union Pacific Railroad Company.

FRA Motive Power and Equipment (MP&E) inspectors took actual measurements and made the field observations under the guidance, and with the assistance, of MP&E Specialists and headquarters technical personnel. Measurements were taken at environmental extremes when the ambient outside temperature was below freezing in the northeastern United States to over 100°F in southern Texas.

Figure 4.2 illustrates the form used by FRA inspectors to collect and record the data and observations for each cab working condition evaluated. The inspectors recorded data and observations regarding each of the following areas affecting cab working conditions:

- heater condition
- air conditioner condition (if equipped)
- toilet condition (if equipped)
- water cooler condition
- food storage condition
- seat(s) condition
- visor(s) condition (if equipped)
- glazing condition
- Noise level (in-cab, decibel level)
- temperature level (in-cab)
- diesel fumes and/or odors (if present)
- toilet ventilation (if equipped)
- floor condition
- passageway condition
- overall cab maintenance
- cab cleanliness
- air valve exhaust (vented to inside or outside of cab; or in control stand).

Fall/Winter Measurements and Observations

FRA conducted a portion of the survey during the months of October 1993 through January 1994 to obtain data under cold weather working conditions. Each of the eight FRA regions conducted a locomotive cab environmental survey that included cab noise measurements (via calibrated, electronic recording-equipment) and thermometer readings. Due to cold weather, the cab windows were usually closed to keep the heat in the cab, and noise measurements during open cab window conditions were not obtained. During the winter phase of the survey, 204 locomotives were evaluated. Appendix I gives a summary of the evaluations of the locomotives surveyed during this time period. Additionally, Appendix I describes and explains a five-point scale used to quantify the observations made by inspectors. Table I-1 gives the ratings on this scale for each locomotive for the winter survey.

Department of Transportation
Federal Railroad Administration

LOCOMOTIVE CAB ENVIRONMENTAL SURVEY

Motive Power & Equipment
Public Law 102-365 Sect. 10

1. Inspector's Name:	2. Inspector's I.D. No.	3. Region:	4. Date of Inspection:	5. Locomotive Owner's Full Corporate Name:	6. Location or Trip of Inspection:

7. Locomotive Manufacturer:	8. Model Number & Built Date:	9. Locomotive Number:	10. Locomotive Service: (Circle) Road Switching Yard Out of Service	11. Locomotive Power: Diesel LNG Electric Other	12 Locomotive Position: Lead Trailing

Cab Equipment

Equipment	Type/Manufacturer	Capacity/Size	Condition	Maintenance Program	Cleanliness/Odors
Heater:	13.	14.	15.	16.	17.
Air Conditioner:	18.	19.	20.	21.	22.
Toilet:	23.	24.	25.	26.	27.
Water Cooler:	28.	29.	30.	31.	32.
Food Storage:	33.	34.	35.	36.	37.
Seats:	38.	39.	40.	41.	42.
Sun Visors:	43.	44.	45.	46.	47.

Glazing Condition

Glazing Location	Type?	Clean?	Cracked?	Spalled?	Describe Other Damage or Condition:
Side Glazing	48.	49.	50.	51.	52.
Front/Rear Glazing	53.	54.	55.	56.	57.

Noise Measurements

Operating Mode: (Circle) Powered: Throttle Position ____ Braking Idling At Rest

Time	Location of Measurement	Train Speed	Measured Value	Source of Noise?	Annoyance Level?
58.	59.	60.	61.	62.	63.
64.	65.	66.	67.	68.	69.
70	71.	72.	73.	74.	75.
76.	77.	78.	79.	80.	81.
82.	83.	84.	85.	86.	87.
88.	89.	90.	91.	92.	93.

Temperature Measurements

Operating Mode: (Circle) Powered: Throttle Position ____ Braking Idling At Rest

Time	Location of Measurement	Measured Value	Outside Temperature	Comfort Level
94.	95.	96.	97.	98.
99.	100.	101.	102.	103
104.	105.	106.	107.	108
109.	110.	111.	112.	113
114.	115.	116.	117.	118
119.	120.	121.	122	123.

Fumes/Odors

Location of Fume/Odor	Locomotive Operating Conditions	Describe Fume/Odor	Effect of Fume/Odor on Crew
124.	125.	126.	127.
128.	129.	130.	131.
132.	133.	134.	135.
136.	137.	138.	139.

Other Cab Interior Features

~~140. Type Ventilation of Toilet~~ Area:	141. General Cab Interior Cleanliness:
142. Condition of Cab Floor:	143. General Impression of Quality of Cab Interior Maintenance:
144. Condition of Passageways:	145. Location of Brake Valve Exhaust

146. How Do Cab Environmental Factors Appear to Affect the Ability of the Crew to Safely Operate the Train?: Locomotive?

Figure 4.2

Summer Measurements and Observations

The three southernmost FRA regions—regions 3, 5, and 7—conducted noise and temperature measurements and observations on a total of 30 locomotives to obtain data under hot weather working conditions. FRA attempted to select days and locations where the ambient outside temperature could be expected to reach 95°F or more. The survey recorded the noisemeasurements for both open and closed window conditions, and aboard locomotives equipped with and without air conditioning to whether background noise levels are reduced (by the windows being closed).

The same survey instructions and form were used for recording the observations and measurements. Cab noise measurements were made via calibrated electronic recording equipment. During the summer portion of the survey, some FRA inspectors who had been trained in the use of Wet Bulb Globe Temperature (WBGT) meters were able to measure cab temperature using a WBGT meter. This device measures temperature, humidity, and air movement in combination to determine a heat stress value that more thoroughly addresses the effects of temperature on the locomotive crew.

As part of the summer survey, 30 locomotives were evaluated in the same categories used to evaluate the 204 locomotives during the winter survey. Table I-2 of Appendix I gives the full results for locomotives evaluated under summer operating conditions.

CHAPTER 5

Locomotive Cab Temperature

FRA found greatly varying temperatures—from 30°F to 121°F—aboard locomotives, depending on the age and condition of the locomotive, air-conditioning availability (equipped and functional), season, and region of the country.

During the winter, crew members are protected from excessively low temperatures as mandated by the FRA in-cab requirement to maintain a minimum temperature of 50°F. The current FRA lower temperature limit does not provide sufficient protection when compared with US Military guidelines or with widely-prescribed (and ideal) minimum and maximum human performance extremes.

During the summer, in-cab temperatures were found to be greater than the outside temperature—due to heat from the engine. Opening the cab windows permits a greater air flow, but negates the glazing requirements—permitting projectiles, such as rocks, bottles, and the like to enter the cabs—and permits diesel exhaust to enter the cab. In addition, this practice does little to change the temperature. FRA found that crews can experience heat stress, and may be subject to risk of heat exhaustion in extreme cases.

Additional effort should be made to ensure that crews are not subject to temperature extremes.

Current FRA regulations regarding temperature levels in the locomotive cab address only a lower limit, and provide no guidance regarding an upper limit or controlling the temperature in the toilet compartment. Studies have shown that exposure to excessive temperature levels in a working environment can directly accelerate the onset of fatigue, which causes a deterioration in performance. During the informal industry meetings held by FRA, rail labor organizations specifically identified the lack of, or improperly functioning, air conditioning systems in locomotive cabs as a primary concern with respect to the safety and health of locomotive crews. Many older locomotives are not equipped with air conditioning, and those that are have typically experienced significant problems associated with the maintenance of these units, often rendering the units partially or totally inoperable. An inability to adequately control temperature within the locomotive cab, coupled with extreme environmental conditions encountered by train crews, is a cause of concern with respect to health and safety considerations. In an effort to assess the adequacy of current regulations, FRA conducted a study that (1) examined the effects of temperature levels on human performance, (2) reviewed past complaints and accidents/incidents attributable to temperature extremes in the locomotive cab, and (3) measured actual temperature levels of 234 locomotive cabs in varying environmental and operating conditions.

Review of Existing Regulations

The current FRA regulation regarding cab temperature is provided in 29 CFR 229.119(d) as follows:

> *Cabs, floors, and passageways*
>
> *The cab shall be provided with proper ventilation and with a heating arrangement that maintains a temperature of at least 50°F 6 inches above the center of each seat in the cab.*

FRA also reviewed guidelines published by other government agencies and professional society sources, such as the U.S. Military and the American Conference of Governmental Industrial Hygienists (ACGIH), regarding acceptable limits for exposure to temperature extremes. ACGIH provides recommendations regarding temperature extremes, and guidelines that identify heat stress conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects.[1] A more detailed description of these standards, including specified limits, is included in the discussion of the effects of temperature levels on human performance.

Effects of Temperature Levels on Human Performance

Individuals differ greatly on what is perceived to be hot or cold[2], and as a result, a determination of one's comfort level tends to be very subjective. However, effects of temperature on human performance are well documented. Table 5-1 describes how humans respond to various temperatures ranging from 50°F (the current FRA standard for the lower limit of cab temperature), to 90°F (considered the upper limit for performing continuous light work). At the lower limit of 50°F currently established by FRA, Table 5-1 shows the locomotive crew can expect extreme stiffness and pain with strength applications after exposure to this effective temperature for only a few minutes.

The U.S. Military has established the upper limit for continued occupancy over any reasonable period of time to be 90°F in MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. The optimal temperatures for winter and summer comfort are identified as 68°F and 70°F, respectively. MIL-STD-1472 also

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[1] 1994-1995 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, page 85.

[2] "Number of Opinions verses Effective Temperature" in Advances in Human Factors/Ergonomics, Book 4, Engineering Physiology: Physiologic Bases of Human Factors/Ergonomics,1986, by K.H.E. Kroemer, H.J. Kroemer, and K.E. Kroemer-Elbert of the Ergonomics Research Institute, Inc. in Blacksburg, VA

Table 5-1 *HUMAN PERFORMANCE EFFECTS AT VARIOUS EFFECTIVE TEMPERATURES (PERCEIVED BY HUMAN BODY)[3]

EFF. °F	HUMAN PERFORMANCE EFFECTS
90	Upper limit for continued occupancy over any reasonable period of time
80-90	Expect universal complaints, serious mental and psychomotor performance decrement, and physical fatigue
80	Maximum for acceptable performance even of limited work; work output reduced as much as 40 to 50 percent; most people experience nasal dryness
78	Regular decrement in psychomotor performance expected; individuals experience difficulty falling asleep and remaining asleep; optimum for bathing or showering
75	Clothed subjects experience physical fatigue, become lethargic and sleepy, and feel warm; unclothed subjects consider this temperature optimum without some type of protective cover.
72	Preferred for year-round sedentary activity while wearing light clothing
70	Mid-point for summer comfort; optimum for demanding visual-motor tasks
68	Midpoint for winter comfort (heavier clothing) and moderate activity, but slight deterioration in kinesthetic response; people begin to feel cool indoors while performing sedentary activities
66	Midpoint for winter comfort (very heavy clothing), while performing heavy work or vigorous physical exercise.
64	Lower limit for acceptable motor coordination; shivering occurs if individual is not extremely active.
60	Hand/finger dexterity deteriorates, limb stiffness begins to occur, & shivering is positive.
55	Hand dexterity is reduced by 50 percent, strength is materially less, and there is considerable (probably uncontrolled) shivering.
50	Extreme stiffness; strength applications accompanied by some pain; lower limit for unprotected exposure for more than a few minutes.

**Note—Table 5.1: These temperature effects are based on relatively still air and normal humidity (40 to 60 percent). Higher temperatures are acceptable if airflow is increased and humidity is lowered (a shift of from 1°F to 4°F)]; lower temperatures are less acceptable if airflow increases (a shift upward of 1 to 2°F). Effective temperature means the temperature perceived by the human body.*

provides detailed design guidelines for heating, ventilation, and air conditioning (HVAC), stating "the crew compartment shall be provided with a heating system capable of maintaining temperatures above 68°F during occupancy when personnel are not wearing

[3] "Human Factors Design Handbook - Information and Guidelines for the Design of Systems, Facilities, Equipment and Products for Human Use" by Wesley E. Woodson, 1986. Woodson is one of the leading human factors engineering authorities in the world. He has participated in two significant publications which are referenced throughout this report, (1) Human Factors Design Handbook, and (2) Military Standard 1472 (MIL-STD-1472), titled "Human Engineering Design Criteria for Military Systems, Equipment, and Facilities."

arctic clothing and exposure is for an extended duration (i.e., more than 3 hours). The temperature is measured 24 inches above the seated crew position."

ACGIH uses a measure called the Wet Bulb Globe Temperature[4] (WBGT) to provide guidance on acceptable workplace heat/cold stress levels. A WBGT meter measures temperature, humidity, and air movement in combination to determine the permissible heat exposure threshold for physical labor. The acceptable heat level on the Wet-Bulb Globe Temperature (WBGT) Index is 86 for a light, continuous workload by an acclimatized worker wearing light-weight pants and shirt.

The WBGT index was originally developed to provide a convenient method to quickly assess, with a minimum of operator skills, the conditions which posed a threat of thermal overstrain among military personnel[5]. Because of its proven usefulness, it has been adopted as the principal index for a threshold limit value (TLV) for heat stress by ACGIH. The index has not been correlated with mental performance.

A well recognized guide for human factors design[6] recommends that the temperature should not be allowed to fall below 65°F, or to exceed 85°F, and relative humidity values should be controlled between 20 percent and 60 percent for maximized human performance.

Figure 5.1 provides a graphical comparison of the current FRA temperature lower limit, minimum and maximum human performance extremes, U.S. Military HVAC design guidelines (upper and lower levels), and ideal summer and winter temperature levels for human performance.

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[4] WBGT is computed by appropriate weighing of Vernon Globe (T_g), dry bulb (T_a), and natural wet bulb (T_{nwb}) temperatures. The natural wet bulb is depressed below air temperature by evaporation resulting only from the natural motion of the ambient air, in contrast to the thermodynamic wet bulb, which is cooled by an artificially produced fast air stream, thus eliminating the air movement as a variable: For outdoor use (in sunshine), the WBGT is computed; $WBGT = 0.7 (T_{nwb}) + 0.2 (T_g) + 0.1 (T_a)$ and for indoor use, the weighing becomes; $WBGT = 0.7 (T_{nwb}) + 0.3 (T_g)$.

[5] "The Industrial Environment -- its Evaluation & Control," U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, 1973

[6] Human Factors Design Handbook, Woodson

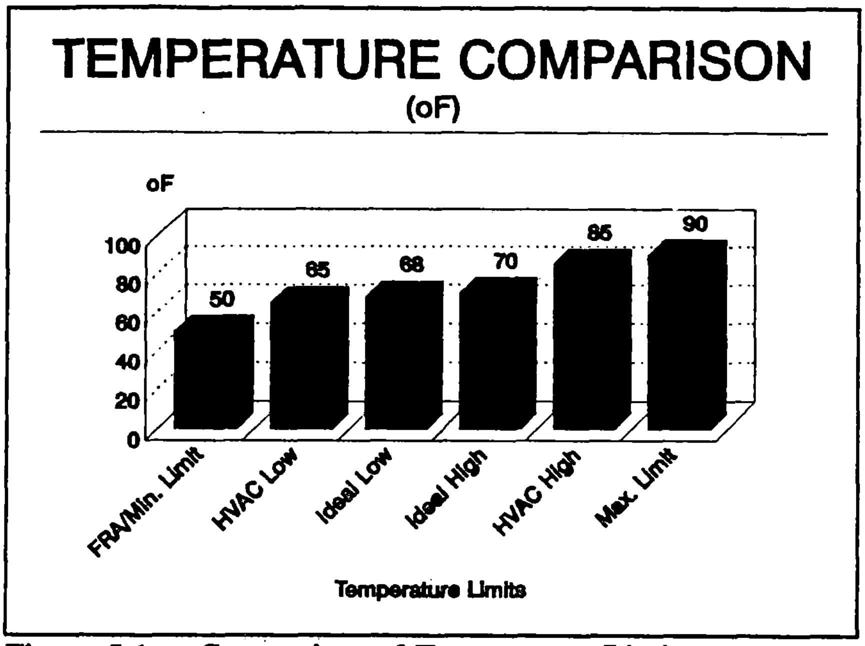

Figure 5.1 Comparison of Temperature Limits

The U.S. Military design handbook provides several engineering guidelines that could be similarly applied to locomotive cab temperature control systems as follows:

- Based upon the locomotive crew's working level and clothing type, the allowable temperature should not exceed 86°F.
- Air conditioning systems should be designed such that cold air discharge is not directed onto personnel.
- A relative humidity of 45 percent should be provided at a temperature of 70°F. This value should decrease with rising temperatures, but should remain above 15 percent to prevent irritation and drying of body tissues such as the eyes, skin, and respiratory tract.
- Temperature levels should be relatively uniform to prevent illness resulting from the body compensating for a dramatic temperature range affecting the body at a particular time. Measurements of air temperature at head level and at floor level should not differ by more than 10°F.
- Adequate ventilation should be assured by introducing fresh air into any personnel enclosure. If the enclosure volume is 150 ft^3 or less per person, a minimum of 30 ft^3 of ventilation air per minute shall be introduced in the enclosure. Approximately two-thirds of this should be outdoor air. Ventilation or other protective measures shall be provided to keep gases,

vapors, dust, and fumes within the Permissible Exposure Limits specified by 29 CFR 1910 and the limits specified in ACGIH TLVs. Intakes for ventilation systems should be located to minimize the introduction of contaminated air from such sources as exhaust pipes.

Heat Exhaustion/Heat Stress

Heat exhaustion is a combined function of dehydration and overloading of the circulatory system which occurs when the human body strains to cool itself. This occurs frequently when an individual is working in a hot environment. Associated effects of heat exhaustion include fatigue, headache, nausea, and dizziness, often accompanied by giddy behavior. Heat syncope indicates a failure of the circulatory system, as demonstrated by fainting. Heat stroke indicates an overloading of both the circulatory and sweating systems, and is associated with hot dry skin, increased core temperature, and confusion of the person.

Table 5-2 outlines the symptoms, causes, and treatment of heat stress disorders. Transient heat fatigue can occur aboard an non-air-conditioned locomotive travelling in a hot climate. The crew can expect to experience a temporary decrease in productivity, alertness, coordination, and vigilance until they become acclimated. An 8- to 12-hour shift under such conditions could cause the onset of heat exhaustion.

Work Regimen

The work regimen, or the percentage of work time verses the percentage of rest time, is also a factor in determining the permissible heat exposure. Temperature exposure limits should be adjusted accordingly depending upon the work regimen. Table 5-3 shows the permissible ACGIH heat exposure limits based upon the work load (work regimen). The locomotive crew operates in a continuous work regimen, which may be classified for use of this table as "light work load." Based upon this calculation, 86°F is the appropriate TLV for the locomotive cab crew.

Impact of Clothing On Temperature Limit

In addition to temperature level and work load, the type of clothing worn (and permitted) in the locomotive cab has an effect on the allowable temperature level. Table 5-4 provides corrections to the WBGT based upon clothing worn by the operators. The insulation value of clothing is measured in units of CLO[7]. Consequently, the TLV (Note: the values in Table 5-3) for cab temperature is adjusted depending upon the clothing type worn.

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[7] One Clo unit = 5.55 kcal/m^2/hour of heat exchange by radiation and convection for each °C of temperature difference between the skin and adjusted dry-bulb temperature

Table 5-2 **HEAT STRESS DISORDERS**[8]

DISORDER	SYMPTOMS	CAUSES	TREATMENTS
Transient Heat Fatigue	Decrease in productivity, alertness, coordination and vigilance	Not acclimated to hot environment	Gradual adjustment to hot environment
Heat Rash ("Prickly Heat")	Rash in area of heavy perspiration; discomfort; or temporary disability	Perspiration not removed from skin; sweat glands plugged; sweat glands inflamed	Periodic rests in a cool area; showering/bathing; drying skin
Fainting	Blackout, collapse	Shortage of oxygen in the brain	Lay down.
Heat Cramps	Painful spasms of used skeletal muscles	Loss of salt; large quantities of water consumed quickly	Adequate salt with meals; salted liquids (unless advised differently by a physician)
Heat Exhaustion	Extreme weakness or fatigue; giddiness; nausea; headache; pale or flushed complexion; body temperature normal or slightly higher; moist skin; in extreme cases vomiting and/or loss of consciousness	Loss of water and/or salt; loss of blood plasma; strain on the circulatory system	Rest in cool area; salted liquids (unless advised differently by a physician)
Heat Stroke	Skin is hot, dry and often red or spotted; core temperature is 105°F or higher and rising; mental confusion; deliriousness; convulsions; possible unconsciousness.	Thermo-regulatory system breaks down under stress and sweating stops. The body's ability to remove excess heat is almost eliminated.	Remove to cool area; soak clothing with cold water; fan body; call ambulance immediately.

[8] Advances in Human Factors/Ergonomics, Book 4, Engineering Physiology: Physiologic Bases of Human Factors/Ergonomics by K.H.E. Kroemer, H.J. Kroemer, and K.E. Kroemer-Elbert of the Ergonomics Research Institute, Incorporated in Blacksburg, VA 24060 (adapted from Spain, Ewing and Clay, 1985)

Table 5-3 PERMISSIBLE HEAT EXPOSURE THRESHOLD LIMIT VALUES[9] [VALUES ARE GIVEN IN °F AND °C]

Work - Rest Regimen	Work Regimen - Light	Work Regimen - Moderate	Work Regimen - Heavy
Continuous Work	86°F (30.0°C)	80°F (26.7°C)	77°F (25.0°C)
75 percent Work, each hour 25 percent Rest	87°F (30.6°C)	82°F (28.0°C)	78°F (25.9°C)
50 percent Work, each hour 25 percent Rest	89°F (31.4°C)	85°F (29.4°C)	82°F (27.9°C)
25 percent Work, each hour 75 percent Rest	90°F (32.2°C)	88°F (31.1°C)	86°F (30.0°C)

Table 5-4 TLV WBGT CORRECTION FACTORS IN °F (°C) FOR CLOTHING[10]

CLOTHING TYPE	CLO VALUE	WBGT CORRECTION
Summer Work Uniform	0.6	0°F (0°C)
Cotton Overalls	1.0	-3.6°F (-2.0°C)
Winter Work Uniform	1.4	-7.2°F (-4.0°C)
Water barrier, permeable	1.2	-10.8°F (-6.0°C)

A complete discussion of the thermal environment and its effect on the crew is provided in Appendix J.

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[9] 1994-1995 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices by American Conference of Governmental Industrial Hygienists (ACGIH), ISBN: 1-882417-06-2

[10] Human Factors Design Handbook, Woodson

Review of Complaints and Accidents/Incidents

Complaints received by FRA from railroad employees or their representatives regarding temperature extremes provide one indication of the extent of the problem that exists in locomotive cabs. Table 5-5 summarizes the cab temperature complaints by locomotive personnel that were investigated by FRA inspectors from 1989 to 1993. Upon receipt of a complaint, FRA inspected the locomotive to determine whether the cause of the complaint was still present. If the FRA found an unsafe or unhealthful condition, it was promptly reported. However, because of the time that elapsed between the reported condition and the time required for FRA to inspect the subject locomotive, the lack of electronic monitoring equipment onboard the locomotive to provide real-time recording, and/or the lack of appropriate equipment such as electronic analysis tools to evaluate the reported condition, the cause could not be determined in many cases. Consequently, the complaint often could not be verified.

Table 5-5 CAB TEMPERATURE COMPLAINTS: 1989 to 1993

REGION	DATE	RR	ST	TYPE	SERVICE	L/T	A/C	ILLNESS
5	Aug 93	SP	TX	Heat	Freight	Lead	Yes	No
7	Jan 90	ATSF	CA	Cab Heaters	Freight	Lead	Ukn	No
8	Nov 89	SP	OR	Cab Heaters	Freight	Lead	Ukn	No
1	Dec 88	ST	VT	Cab Heaters	Freight	Lead	Ukn	No

Three of the four cab temperature complaints received by FRA involved improperly functioning heating units. Since FRA has an established standard for the lower limit allowable of cab temperature, FRA was able to require the railroads involved to repair the heaters. The fourth complaint alleged that the cab temperature reached 130°F in a locomotive with an improperly functioning air conditioning unit during a hot summer day in southern Texas. If accurate, this is an obvious unhealthy and unsafe working environment.

FRA Accident/Incident Data Base

FRA searched its accident/incident data base (1990 to 1994) for instances of railroads reporting crew injuries or lost time due to the following:

- heat stroke/sun stroke (a serious heat-related condition in which the patient often stops sweating and experiences a marked rise in core temperature);
- effects of ionizing radiation (referring to the various effects of ionizing radiation such as gamma rays or x-rays);

o effects of non-ionizing radiation (referring to the effects of electro-magnetic radiation such as radio waves, microwaves, welding flash, ultraviolet rays of the sun, etc.);

o heat exhaustion (a heat-related condition of moderate degree which, if not treated, may lead to heat stroke);

o freezing/frostbite (freezing of tissue with disruption of the blood supply);

o other disorders due to physical agents other than toxic materials; and

o death resulting from physical agents other than toxic materials.

Figure 5.2 summarizes the results of this data base search. The search revealed lost time due to exposure to temperature extremes.

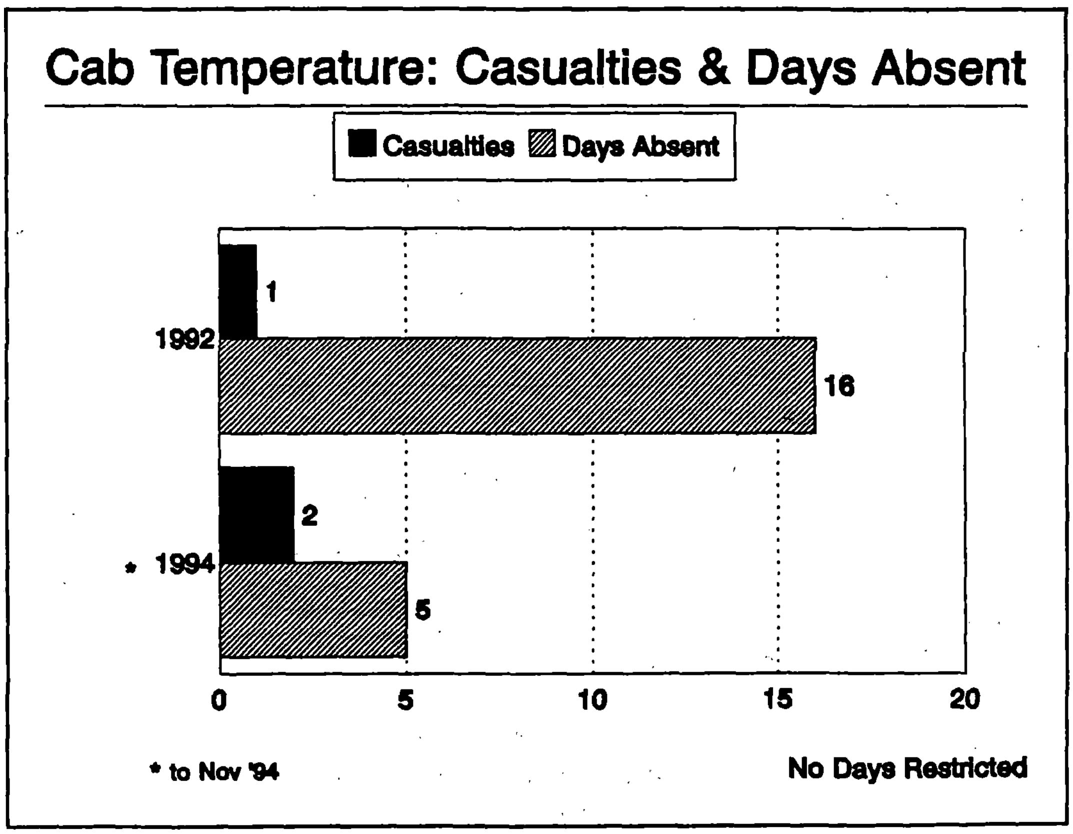

Figure 5.2 Cab Temperature - Casualties and Days Absent

New Locomotives

Locomotive manufacturers currently offer higher quality, more reliable air conditioning systems as options on new locomotives. As a matter of policy, several Class 1 railroads are procuring new locomotives with these systems. Manufacturers estimate that more than 50 percent of new locomotives are being ordered with air conditioning, at a cost of approximately $12,000 to $15,000 per locomotive. While maintenance of air conditioning systems has been a significant issue in the past, the reliability of these new systems has not been established to date.

Cab Heaters

Railroads typically equip locomotives with one of three types of cab heaters, ranging in power from 650 to 3750 Watts:

- wall-mounted type strip heater (74V DC);
- heated coil with a blower fan (74V DC); and
- water-heated radiator with a blower fan (occasionally found in older switch locomotives).

Most of the locomotives inspected were equipped with electric strip heaters located near the engineer and fireman. In many locomotives, additional heaters with three-speed fans are placed in front of the conductor and engineer.

FRA Survey of In-Cab Temperature Conditions

During 1994, FRA implemented a test plan (See Appendix H - Guidance to Inspectors for Conducting Locomotive Cab Surveys) which required FRA field inspectors to conduct a formal survey of the cab working conditions by travelling aboard randomly-selected locomotives—during various working conditions—to determine the effect of existing in-cab temperature conditions on the safe operation of the locomotive or train. FRA inspectors measured the actual in-cab temperature level in a significant number of locomotive cabs under a variety of typical working conditions, in both summer and winter months.

FRA inspectors asked the crew to operate the locomotive in a "normal" manner, i.e., as though the FRA test personnel were not present. FRA placed the measuring transducers as close as possible to the crew members. Crews controlled the window position, opened or closed, based on their own preferences without FRA direction or interference.

Chapter 4 provides details of the procedures used to conduct this broad survey. FRA inspectors typically measured the cab temperatures with a common thermometer, but also used a Wet Bulb Globe Temperature (WBGT) meter in selected instances. The WBGT was used to measure the temperature, humidity, and air movement to determine the "heat stress" value.

Summary of In-Cab Temperature Measurements Results

A detailed evaluation of the in-cab temperature measurements taken aboard locomotives is provided in Appendix I. During these tests, the temperatures found onboard locomotive cabs ranged from a low of 30°F[11] to a high of 121°F[12], a temperature range of over 90 degrees.

Summer Results

In the summer survey of locomotive cab working conditions, in-cab temperature was rated to be the next to lowest category with respect to acceptability in accordance with the established rating scheme. Figure 5.3 shows the years of service for the locomotives evaluated during the summer test phase. In 80 percent (24 of 30) of the locomotives surveyed, the average in-cab temperature was consistently measured to be above 80°F. Figure 5.4 summarizes the in-cab temperature ratings obtained during the summer field tests. It is important to note that a majority (18 of 30) of the locomotives evaluated were not equipped with air-conditioning.

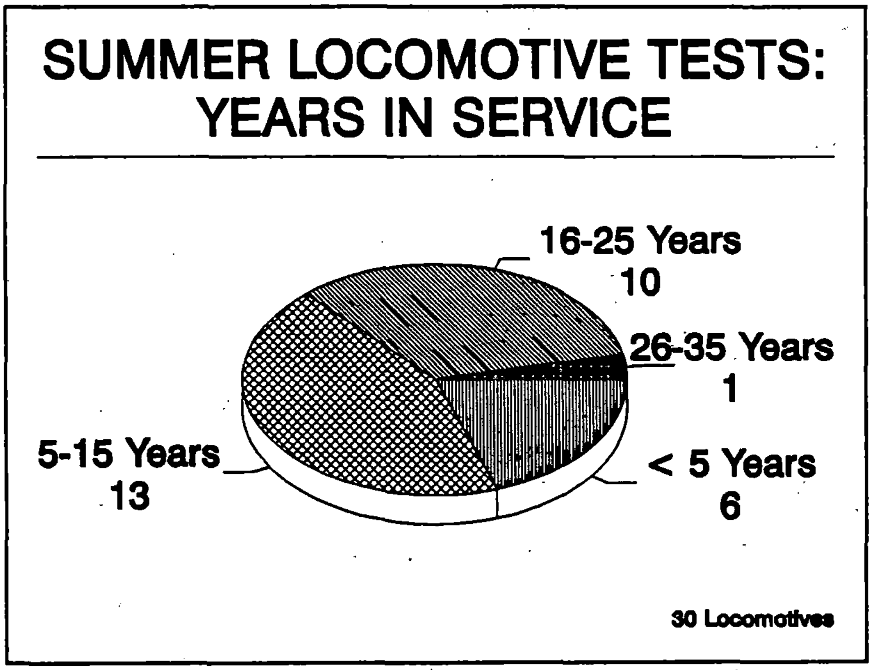

Figure 5.3 Summer Locomotive Tests: Years in Service

[11] Several locomotive cab toilets in January 1994

[12] Locomotive Cabs in Southern Texas in July/Aug 1994

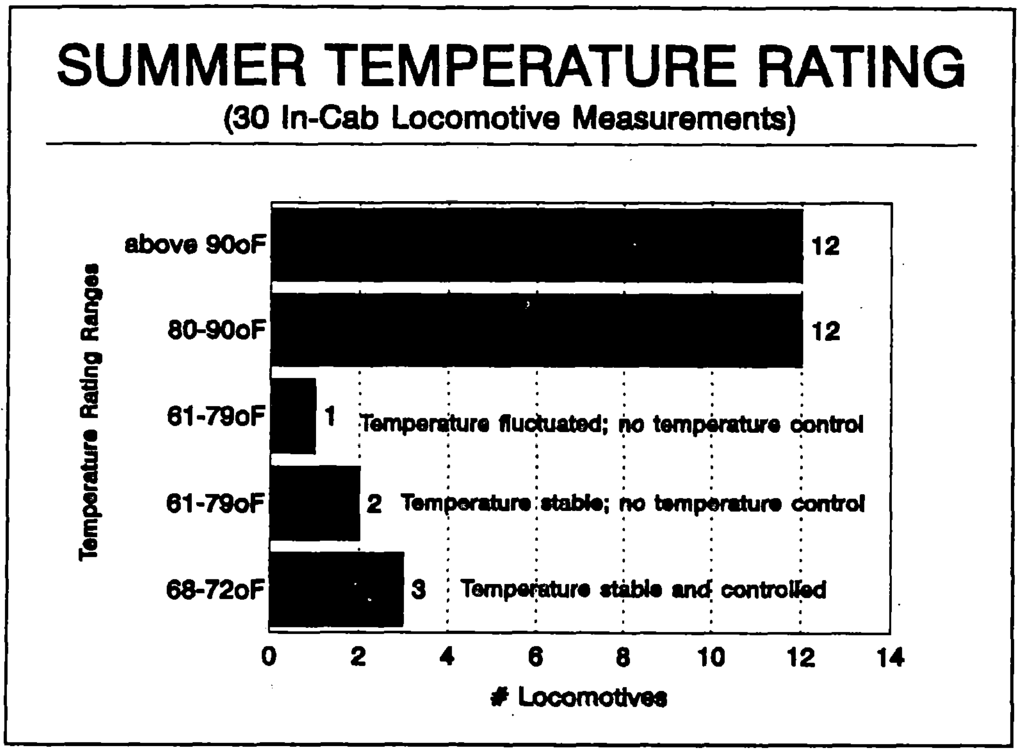

Figure 5.4 Summer Temperature Ratings

While opening the windows increases air flow in the cab, this practice voids the benefits of the glazing and increases the overall noise level in the cab when the locomotive is moving. Numerous temperature readings were taken, both inside and outside of the cab. During the environmental cab surveys conducted between Tucson and Yuma, Arizona, the ambient temperature during these tests ranged between the high 90's to upward of 115°F. The temperature inside the various cabs sometimes reached 121°F with air conditioners that were in poor operating condition, totally inoperable, or non-existent. When the in-cab temperature reached and exceeded 100°F, both the train crews and the inspectors became very uncomfortable and fatigued. Discussions with train crews that had to be on duty for periods of time up to 12 hours in similar conditions indicated that extreme fatigue and weariness are commonplace as a result of the excessive temperature level in the cab. The maximum temperature observed inside a locomotive cab during the study was 121°F, recorded on August 2, 1994.

In an effort to attain a worst-case scenario as closely as possible, WBGT measurements were taken in southern Texas during the months of July and August, 1994, to determine representative heat-stress levels to which locomotive crews are subjected. The WBGT measurements were taken aboard Southern Pacific (SP) locomotives. The following observations were made:

- o Locomotives with fully-operational air conditioning units were below the WBGT 86 limit. The common thermometer inside the cab indicated a range of 6° to 20° lower than the outside heat stress index measured by the WBGT meter.

- o A non-air conditioned locomotive, with the side windows open, had an inside temperature range of 1.5°F lower to 5°F higher than the outside WBGT readings.

- o The highest inside heat stress index measurement of 104 WBGT occurred at 4:15 p.m. on August 2, 1994, in a non-air conditioned cab.

During the course of the study, air conditioners on some locomotives were found to be either non-operational or not fully functional. Air conditioners are typically roof-mounted, and considered by many railroad mechanical officers to be a high-maintenance component. Railroads contend that air conditioning systems are expensive to maintain and present environmental constraints in servicing.

Most locomotives inspected in FRA Region 3, which includes the States of Mississippi, Alabama, Georgia, Florida, North Carolina, North Carolina, Tennessee, and Kentucky, were not equipped with air conditioning, except those locomotives owned by the Florida East Coast (FEC) Railroad. AMTRAK typically has units that are equipped with air conditioning. Heat and humidity are often characterized as being extreme in many areas of Texas, New Mexico, Oklahoma, Arkansas, and Louisiana during the summer months.

FRA inspectors experienced heat-related fatigue and stress due to exposure to excessive temperatures during this survey. Inspectors stated that an undeniable difference existed in the way they felt, both mentally and physically, at the conclusion of each test depending on whether the unit tested was equipped or not equipped with air conditioning.

Winter Results

Figure 5.5 summarizes the in-cab temperature ratings obtained during the winter field tests. The vast majority of locomotives tested (82 percent) were found to have a cab temperature above 60°F. However, freezing temperatures were found in several locomotive toilet compartments. In most cases, toilets were found to be neither heated or air-conditioned. In many cases, temperatures inside the toilet compartments measured below the 50°F temperature requirement established for the cab in 49 CFR 229.119. These low temperatures in the toilet compartment often led to unsanitary conditions and, in some cases, the facilities were unusable. This condition is discussed further in Chapter 8.

Cab temperature levels during the winter months are generally above the FRA requirement. However, moderate to strong drafts occur when locomotives are operated over 30 mph. These drafts are caused by defective door seals, loose side windows, and poorly fitted cab

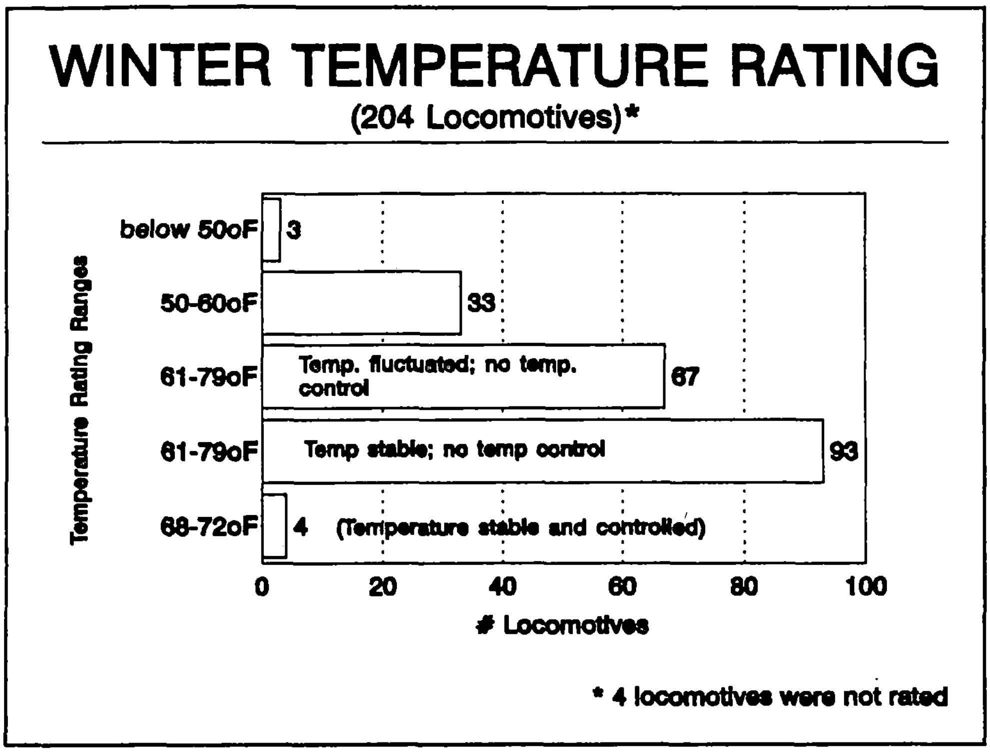

Figure 5.5 Winter Temperature Ratings

doors. When temperatures are below freezing, these air drafts make it very hard to regulate the cab temperature, which can be very uncomfortable and distracting.

Meaning of In-Cab Temperature Survey Results

Observations resulting from the cab temperature study by FRA inspectors are summarized as follows:

- o **winter tests**

  - Nearly all locomotives received either satisfactory or better ratings with respect to in-cab temperature.
  - Crews are not usually subjected to harmfully low in-cab temperatures.
  - Eighty-two percent of the locomotives tested were able to maintain an in-cab temperature above 60°F.
  - Forty-seven percent of the locomotives tested were able to maintain a constant temperature of 61°F to 70°F.

- o **summer tests**

  - Cab temperature levels were ranked either unacceptable or poor for 80 percent of the locomotives tested based on in-cab temperature exceeding 80°F.

  - The majority of train crews are on duty for more than 8 hours, and are physically onboard the locomotives for most of this duty time. The crews experience temperatures exceeding 90°F inside the cab.

Conclusions

This chapter provides information supporting the need for FRA to revise current regulations as they pertain to temperatures within the locomotive cab. Based on measured temperature levels in locomotive cabs, research demonstrating the effect of temperature on human performance, and existing standards and guidelines adopted by other agencies which address acceptable temperature levels in the workplace, FRA will work with the industry parties to review whether and over what period it may be practical to establish both an upper and lower limit for temperatures in the locomotive cab. The upper could be based on the heat stress index that includes the combined effects of high temperature and high humidity on human performance. An upper limit on cab temperature offers several potential health and safety benefits, including:

- o minimizing human errors due to heat stress;
- o reduced cab noise because windows can be closed during warm weather;
- o improved air quality; and
- o reduced risk of flying or thrown objects entering the cab through open windows.

It should be noted that the significance of these findings with respect to human performance must be inferred. FRA does not have available detailed data from which to determine the actual impacts of environmental conditions on locomotive crew performance. In order to be conclusive, any such analysis would need to consider the incidence of extreme environmental conditions, as determined by a very broad and representative sample, and the extent to which crews subjected to those extremes might be over-represented in incidents of unsafe conduct such as rule violations, human factor train accidents, and personal injuries. Care would be required to exclude other variables. The resources required to undertake a study of this kind would be enormous, and the findings would be fully valid only for the study period.

The available data suggests the likelihood that unfavorable impacts on crew health or performance will result from the more extreme conditions documented in the survey. FRA has not been able to gage the extent to which these impacts occur in normal railroad operations.

From the days of steam locomotives to the present, locomotive crew members have shown significant adaptability and tolerance to adverse conditions. Nevertheless, with smaller crews and higher sustained train speeds, significant attention to the work environment of locomotive crews is increasingly warranted. The average age of the relevant workforce is 45 years of age. The following is the average age[13] of members in two representative labor unions:

Labor Union	Average Age (Years) of Membership
Brotherhood of Locomotive Engineers (BLE)	45.85
United Transportation Union (UTU)	45.34

Employee representatives have repeatedly stressed these concerns, and railroads have responded by ordering new locomotives that provide improved environmental conditions. The extent to which favorable trends in locomotive environmental conditions can be accelerated should be a significant emphasis in the consultations that will follow this report.

As part of this effort, FRA will also review the adequacy of the current lower limit of 50°F contained in the FRA regulation, as there is evidence that suggests that this level permits an environment in which it would be difficult to sustain a proficient working level.

FRA, railroads, and locomotive manufacturers need to work together to provide a safe and reliable HVAC system aboard locomotives. Future locomotive designs should incorporate HVAC system designs that consider the following design attributes:

- positive air pressure to prevent the entry of unwanted and detrimental air pollutants, such as diesel fumes and the like, and to exhaust toilet odors and chemical vapors to the outside;
- operator-selectable temperature control with a temperature-staying capability of 65-80°F, regardless of the outside ambient temperature level, allowing a time period for the system to reach operating levels;
- humidity control for both humans and electrical/mechanical systems;
- cold-air discharge away from personnel;

[13] National Railway Labor Conference, C. Kerns (202-862-7217), "Years of Service by Craft," as of 31 Dec 1994

- temperature uniformity of the air at floor level and at head level, not to differ by more than 10°F;

- adequate ventilation—assured by introducing fresh air into any personnel enclosure. If the enclosure volume is 150 ft^3 or less per person, a minimum of 30 ft^3 of ventilation air per minute shall be introduced in the enclosure; approximately two-thirds should be outdoor air. Ventilation or other protective measures shall be provided to keep gases, vapors, dust, and fumes within the Permissible Exposure Limits specified by 29 CFR 1910 and the limits specified in the current ACGIH TLVs. Intakes for ventilation systems shall be located to minimize the introduction of contaminated air from such sources as exhaust stacks; and

- temperature control of the locomotive toilet compartment.

CHAPTER 6

Locomotive Cab Noise

FRA conducted a noise survey, using state-of-the-art electronic measurement equipment, aboard 350 locomotives. FRA found that frequent high in-cab noise levels can make the necessary internal (voice) and external (2-way radio) cab communications extremely difficult, if not impossible

Noise measurements taken as part of complaint investigations, and in support of this report, indicate that train and engine crew members are not subject to excessive noise levels during a majority of their assignments; however, some assignments involve noise exposure above the OSHA threshold for hearing conservation programs and, a smaller percentage, above the absolute FRA and OSHA exposure limits.

Several Class 1 railroads have established mandatory hearing protection programs, and newer locomotives feature quieter cab environments. However, additional effort is needed to provide assurance that the potential safety and health impacts of cab noise are adequately addressed.

Hearing loss due to occupational noise exposure is our most prevalent industrial malady and has been recognized since the Industrial Revolution[1]. In a locomotive cab, a high noise level can make voice and radio communications, which are necessary for safe operation of the train, much more difficult. Sustained high noise may accelerate fatigue, causing the crew's performance to deteriorate with potential impacts on safety and productivity.

This chapter provides an overview of existing standards which address acceptable noise levels for both FRA and other government agencies, a review of noise-related complaints and injuries/illnesses attributable to excessive noise levels during the time period between 1989 and 1993, and an evaluation of the results of an extensive survey of noise levels measured aboard 350 locomotives. As a result, FRA has developed a number of recommendations that, if implemented, will minimize the likelihood of locomotive crew members being subjected to excessive noise levels.

Review of Existing Regulations

The current FRA regulation addressing acceptable levels of noise aboard a locomotive are provided in 49 CFR 229.121 as follows:

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[1] Sataloff, Robert Thayer and Sataloff, Joseph Occupational Hearing Loss, 2nd. ed., Marcel Dekker, Inc., New York, 1993, p. 1.

Locomotive cab noise

(a) After August 31, 1980, the permissible exposure to a continuous noise in a locomotive cab shall not exceed an eight-hour time-weighted average of 90 dB(A), with a doubling rate of 5 dB(A). Continuous noise is 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(A) below the peak.

(b) When the 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 formula shown in the CFR.

(c) Exposure to continuous noise shall not exceed 115 dB(A).

(d) Noise measurements shall be made under typical operating conditions using a sound level meter conforming, at a minimum, to the requirements of ANSI S1.4-1971, Type 2, and set to an A-weighted slow response or with an audiodosimeter of equivalent accuracy and precision.

(e) In conducting sound level measurements with a sound level meter, the microphone shall be oriented vertically and positioned approximately 15 centimeters from an axis with the crew member's ear. Measurements with an audiodosimeter shall be conducted in accordance with manufacturer's procedures as to microphone placement and orientation.

FRA also identified similar regulations employed by government agencies, professional societies, and a foreign government that address acceptable exposure limits to noise. Table 6-1 compares the noise level limits for these organizations.

The original OSHA regulation of 1971[2] addressed exposure to changing sound levels by the use of the *noise dose* concept, through which exposure to any sound level at or above 90 dB(A) resulted in the person incurring a partial dose of noise. The partial dose was calculated for each specified sound pressure level above 90 dB(A) as follows:

$$\frac{\text{Time actually spent at the sound level}}{\text{Maximum duration allowed at that sound level}}$$

The total or daily noise dose was equal to the sum of the partial doses. If the daily noise dose exceeded 1.0, the exposure was in violation of the OSHA regulations. However, this

[2] Department of Labor Occupational Noise Exposure Standard, 36 FR 10466, (1971) (codified at 29 CFR Part 1910)

Table 6-1 COMPARISON OF OCCUPATIONAL NOISE LEVEL LIMITS
[Allowable Exposure Time (hour) vs. Decibel Level (dB(A)]

Allowable Exposure Time (hours)	FRA[1] & OSHA[2] [dB(A)]	DOE[3] & USAF[4] [dB(A)]	UK[5] [dB(A)]	NIOSH[6] [dB(A)]	USN[7] [dB(A)]	ACGIH[8] [dB(A)]
12	87 (FRA)	-	-	-	-	-
8	90	85	90	85	84	85
6	92	-	-	-	-	-
4	95	89	93	90	88	88
3	97	-	-	-	-	-
2	100	93	96	95	92	92
1½	102	-	-	-	-	-
1	105	97	99	100	96	95
½	110	101	102	105	100	98
1/4	115	105	-	110	104	101
1/8	115	109	-	115	108	104

[1]FRA: Federal Railroad Administration (per 49 CFR 229.121)
[2]OSHA: Occupational Safety and Health Administration (per 29 CFR 1910.95)
[3]DOE: Department of Energy (per Order 5480.4) OSHA is a minimum; however, most facilities enforce USAF Standards
[4]USAF: U.S. Air Force (per USAF Regulation 161-35, 1973)
[5]UK: United Kingdom
[6]NIOSH: National Institute of Occupational Safety and Health (per NIOSH Recommended Standard for Occupational Exposure to Noise by the U.S. Department of Health, Education and Welfare, Center for Disease Control)
[7]USN: United States Navy (per MIL-STD-1474)
[8]ACGIH: American Conference of Governmental Industrial Hygienists (per the ACGIH 1994-1995 Threshold Limit Values for Chemical Substances & Physical Agents and Biological Exposure Indices)

method ignored exposures to sound levels below the 8-hour permissible noise exposure limit of 90 dB(A), as it was believed that these exposures would not contribute to hearing damage to individuals. This was amended by OSHA via the Hearing Conservation Amendment of 1983[3], which allows for the consideration of sound levels between 80 and 130 dB(A) in the calculation of noise dose. This amendment also requires a hearing conservation program for workers subjected to a 50 percent dose (calculated according to the guidelines in 29 CFR 1910.95, Appendix A) or a time-weighted average (TWA) of 85 dB(A). The TWA is defined as that sound level, which if constant over an 8-hour exposure, would result in the same noise dose as is measured.

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[3] Department of Labor Occupational Noise Exposure Standard, 48 FR 9776-9785, (1983) (codified at 29 CFR Part 1910)

The existing FRA regulation is patterned after the original OSHA regulation in citing the same noise exposure limits, but some differences between the OSHA and FRA regulations exist. Under the FRA standard, continuous noise shall not exceed 115 dB(A), while OSHA permits measures up to 130 dB(A). As the FRA Locomotive Cab Noise Standard was enacted prior to the adoption of the OSHA Hearing Conservation Amendment of 1983, FRA does not require consideration of exposures to sound levels below the 12-hour permissible noise exposure limit of 87 dB(A)[4] in the calculation of noise dose.

In adopting the Hearing Conservation Amendment of 1983, OSHA recognized the value of monitoring the hearing of employees whose exposure may equal or exceed an 8-hour Time Weighted Average (TWA) of 85 dB. A hearing conservation approach focuses on the hearing of the individual, rather than the condition of one or more workplaces in which the individual may be exposed to varying sound levels. The current FRA regulation does not provide guidance in this regard; however, as noted below, major railroads have implemented hearing conservation programs responsive to this need.

Fundamentals of Noise

It is difficult to accurately define "noise," because so much of its meaning depends on its effect at any specific time and place rather than on its physical characteristics. Sound can in one instance or by one individual be considered as very annoying noise, whereas on another occasion or to another observer the same sound may seem pleasant and undeserving of being designated "noise." Most commonly, the term "noise" is used to describe any unwanted sound.

The detailed physical properties describing sound (noise) is a subject that is quite complicated, and one that has been studied and written about extensively by numerous researchers throughout the past 30 to 40 years. However, a discussion of this subject is not within the scope of this report. Brief discussions of the physical units of sound, the measurement of sound, and the effects of varying sound levels on human performance are provided below in an effort to establish a basic understanding of noise levels and their associated effects on human performance.

Physical Units of Sound

Sound is typically measured in decibels (dB). The decibel is a dimensionless unit based on the logarithm of the ratio of a measured quantity to a reference quantity. In the field of acoustics, the decibel is a unit of comparison between two sound pressure levels—the sound

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[4] While OSHA regulations address acceptable noise exposure limits in terms of an 8-hour time-weighted average, FRA Hours of Service regulations allow for a 12-hour workday. Accordingly, the FRA Locomotive Cab Noise Standard prescribes a 12-hour exposure limit of 87 dB(A), which is equivalent to a 90 dB(A) exposure over an 8-hour time period.

pressure level read on a sound level meter as compared to an established reference sound pressure. The unit of pressure is pascals, Pa, which is the same as newtons per square meter (N/m^2). The reference international unit for sound pressure level is 20 $\mu N/m^2$. This reference sound pressure is arbitrary, and has been established to approximate the normal threshold of human hearing at a specified frequency. Figure 6.1 illustrates the relationship between sound pressure as measured in pascals and the sound pressure level measured in decibels based on the established reference sound pressure level.

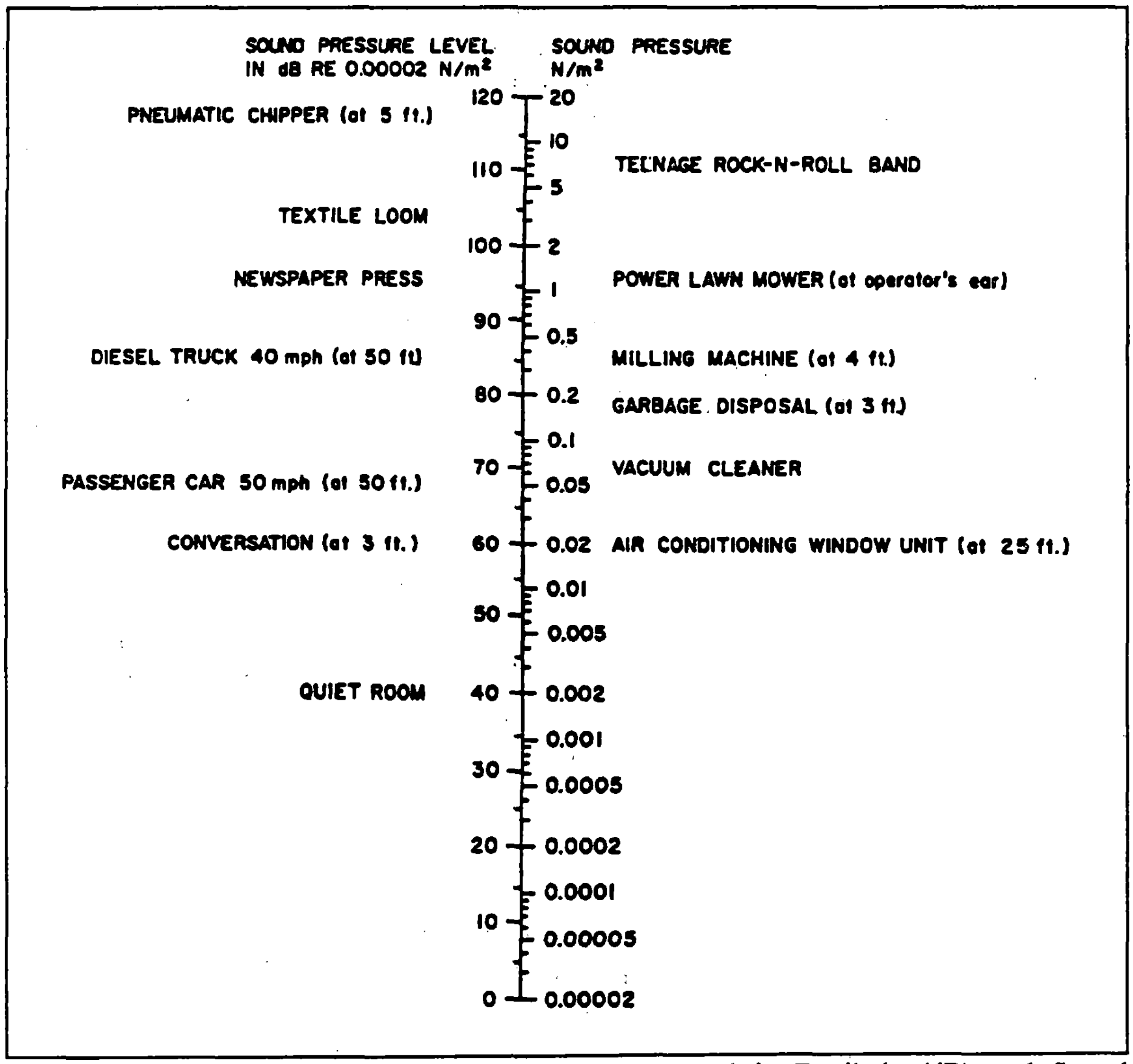

Figure 6.1 Relationship Between Sound Pressure Level in Decibels (dB) and Sound Pressure in Pa (N/m^2)

Measurement of Sound

The decibel level aboard locomotives is measured by a dosimeter, a device which incorporates a sound level meter. The American National Standards Institute (ANSI)[5] has established a standard to which sound level meters should conform. This standard requires that three different weighting networks (designated A, B, and C) be built into such instruments. Each network responds differently to low or high frequencies according to standard frequency response curves. The most commonly used scale (and the scale used throughout this chapter for comparisons) is the A scale. Of the three scales (designated A, B, and C), the A scale comes the closest to approximating the response characteristics of the human ear. Dosimeters can be set at any array or parameters, but for OHSA[6] compliance purposes, the unit should be set for the A-scale (note: The A-filter ignores many low frequency sounds reported in dB, 5-dB exchange rate, 80-dB criterion/threshold, and slow response.

A sound level meter is a device that measures the pressure level of sound at a given moment. Since sound level meters provide a measure of sound pressure level at only one point in time, it is generally necessary to take a number of measurements at different times during the day to estimate noise exposure over a workday. If noise levels fluctuate, the amount of time noise remains at each of the various measured levels must be determined. To estimate employee noise exposures with a sound level meter, it is also generally necessary to take several measurements at different locations within the workplace.

A dosimeter, such as the Metrosonics Db-3100 Metrologger used in noise measurements within locomotive cabs as described later in this chapter, is like a sound level meter except that it stores sound level measurements and integrates these measurements over time, providing an average noise exposure reading for a given period of time. With a dosimeter, a microphone is attached to the employee's clothing and the exposure measurement is read at the end of the desired time period. Since the dosimeter is worn by the employee, it measures noise levels in those locations in which the employee travels.

It is very important to specify some parameters at which the dosimeter was set. For these tests, the dosimeter was set with an exchange rate (doubling rate) of 5 dB which is what is used in the FRA and OSHA standards. This level means for every 5 dB the noise exposure decreases the permissible exposure time is doubled. The dosimeter filter was set to A-weighted which simulates how the human ear perceives noise. It is also the filter used by FRA and OSHA for occupational noise exposure tests.

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[5] Human Factors in Engineering and Design, 5th. ed., 1982, McGraw-Hill, Ernest J. McCormick and Mark S. Sanders

[6] Sataloff, Robert Thayer and Sataloff, Joseph, Occupational Hearing Loss, 2nd. ed., Marcel Dekker, Inc., New York, 1993, p. 1.

Another very important parameter is the cutoff level or threshold level. This is defined as the minimum noise level that the dosimeter will measure and will include in noise exposure analysis. This is an arbitrary procedure used by regulatory agencies.

OSHA requires dual cutoff levels of 80 and 90 dB(A) while FRA has used 87 dB(A) for compliance purposes. Since these tests were designed to investigate the noise environment without any arbitrary cutoffs the data reported was measured without a cutoff level so all noise within the sensitivity of the equipment was measured [40-140 dB(A)].

The significance of this configuration is that if the regulatory cutoff level was used in this survey there would be an overall shift of the noise exposure levels downward. While this would have eliminated all data recording for noise levels less than 87 dBA, making low noise doses (TWAs) in the FRA data base significantly lower or even negligible; it would not significantly change recorded doses where noise levels in the cab were usually equal to or greater than 87 dBA. In short for compliance purposes there might be a decrease as great as 2 dBA for the higher dose category which would lessen the number of data points in the over exposure category used in the report.

Effects of Sound Levels on Human Performance

The effects of noise on job performance have been studied extensively in the laboratory and somewhat less so in the field. Studies have shown that noise can increase, decrease, or have no effect on job performance, depending on the circumstances. A thorough yet succinct analysis of these studies may be found in a discussion by D.E. Broadbent (1979). In general, low to moderate levels of noise may increase job performance in monotonous tasks. Even high noise levels may increase output, but errors are more likely to occur and quality will often be reduced. Tasks involving concentration are more vulnerable to noise disruption than are routine tasks, and intermittent noise tends to be more disruptive than continuous noise (Broadbent, 1979). Studies have shown that people perform more poorly on tasks after being exposed to noise that was unpredictable and uncontrollable. The investigators attributed the poor performance to a sense of apathy or helplessness that resulted from the unpredictability and uncontrollability (Glass and Singer, 1973). Broadbent also cites some research indicating that people exhibit less helpful behavior during and after noise exposure than they do in quiet surroundings.[7]

Table 6-2 outlines the effect of increasing noise levels on human performance. As shown in this table, temporary hearing loss starts to occur when noise levels reach 85 dB(A). With long and repeated exposure to noise at this level, hearing loss can become irreversible. At 100 dB(A), an individual will experience a serious reduction in alertness.

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[7] Noise and Hearing Conservation Manual, edited by E.H. Berger, W.D. Ward, J.C. Morrill and L.H. Royster, 1986, American Industrial Hygiene Association

Table 6-2 EFFECTS OF NOISE ON HUMAN PERFORMANCE[9]

Noise Level dB(A)	Effects on Human Performance
100	Serious reduction in alertness. Attention lapses occur, although attention duration is usually not affected. Temporary hearing loss occurs if no protection is provided in the region 600-1200 Hz. Most people will consider this level unacceptable, and 8 hr duration is the maximum they will accept.
95	Considered to be the upper acceptance level for occupied areas where people expect the environment to be noisy. Temporary hearing loss often occurs in the range of 300-1200 Hz. Speech will be extremely difficult, and people will be required to shout, even though they may be talking directly into a listener's ear.
90	At least half of the people in any given group will judge the environment as being too noisy, even though they expected a noisy environment. Some temporary hearing loss in the range of 300-1200 Hz occurs. Skill errors and mental decrements will be frequent. The annoyance factor is high, and certain physiological changes often occur (e.g., the pupils dilate, the blood pressure increases, and the stroke volume of the heart may decrease). Listening to a radio is impossible without good earphones/headphones. The maximum duration that most people will accept is 8 hr.
85	The upper acceptance level (noise expected) in the range of 150-1200 Hz. Some hearing loss occurs in the range of 300-1200 Hz. This is considered to be the upper comfort level, although some cognitive performance decrement can be expected, especially where decision making is necessary.
80	Conversation is difficult (i.e., people have to converse in a loud voice less than one feet apart). It is difficult to think clearly after about 1 hr. There may be some stomach contraction and an increase in metabolic rate. Strong complaints can be expected from those exposed to this level in confined spaces, and 8 hr is the maximum duration acceptable within the frequency range 1200-4800 Hz.
75	Too noisy for adequate telephone conversation. A raised voice is required for conversation 2 feet apart. Most people will still judge the environment as being too noisy.
70	The upper level for normal conversation, even when conversants are close together (at a distance of 6 feet, people will have to shout). Although persons such as industrial workers and shipboard personnel who are used to working in a noisy environment will accept this noise level, unprotected telephone conversation will be difficult (upper phone level is 68 dB).
65	The acceptance level when people expect a generally noisy environment. Intermittent personal conversation is acceptable. About half of the people in a given population will experience difficulty sleeping.
60	The upper limit for spaces used for dining, social conversation, and sedentary recreational activities. Most people will rate the environment as "good" for general daytime living conditions.
55	The upper acceptance level for spaces where quiet is expected (150-2400 Hz). People will have to raise their voices slightly to converse over distances greater than 8 feet. This level of noise will awaken about half of a given population about half the time. It is still annoying to people who are especially sensitive to noise.
50	Acceptable to most people where quiet is expected. About 25 percent will be awakened or delayed in falling asleep. Normal conversation is possible at distances up to 8 feet.
40	Very acceptable to all. The recommended upper level for quiet living spaces.
30	Necessary for specialized listening tasks (e.g., threshold signal detection).
<30	Introduces additional problems; i.e., low-level intermittent sounds become disturbing. Some people have difficulty getting used to the extreme quiet, and a few may become psychologically disturbed.

Note: The above represents an amalgamation of many studies and contains a general interpretation of a wide variety of subject samples and testing conditions.

[9] Human Factors Design Handbook, Woodson

Figure 6.2 illustrates the maximum noise levels, in decibels, that the human voice can overcome for sustained verbal communication[9]. Above 80 dB(A), conversation becomes difficult, and as can be seen from this research, the maximum noise level that an individual can consistently overcome in verbal communication is 88 dB(A). Above this level, the ability to communicate by voice deteriorates rapidly.

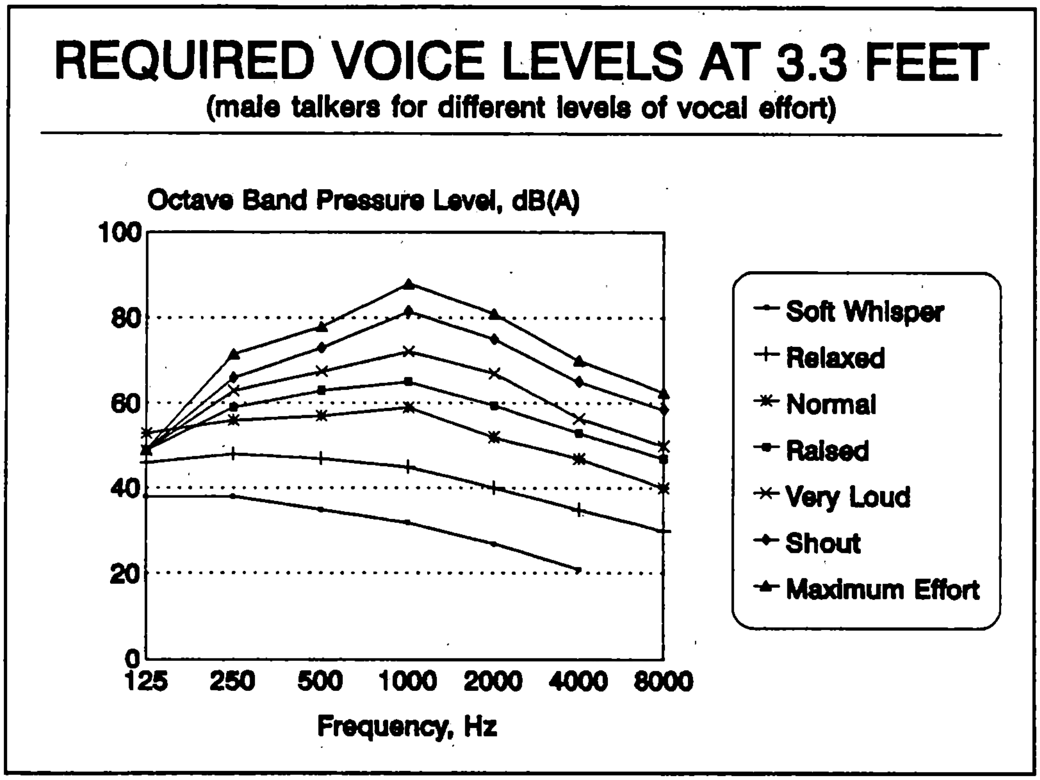

Figure 6.2 Human Voice Levels Required for Sustained Verbal Communication

Review of Past Noise-Related Incidents and Investigations

Noise-Related Incidents Reported to the FRA by Railroads

FRA searched its accident/incident data base for injuries or illnesses reported by the railroads of locomotive crew members due to excessive noise in the cab. Railroads reported no such incidents prior to 1992. However, railroads reported 23 incidents during 1992, and 18 incidents of hearing problems due to noise in the cab in 1993. FRA believes this increase in reported incidents may be due to an increased awareness on the part of railroads and their locomotive crews that excessive noise in locomotive cabs can pose health and safety problems.

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[8] Human Factors Guidelines for Nuclear Power Plant Control Room Development, Electric Power Research Institute, NP-3659, Research Project 1637-1, Final Report, August 1984

FRA further believes that this increased awareness is not uniform throughout the industry, and therefore FRA probably does not receive reports of all hearing loss cases associated with locomotive cab noise. Inadequate transfer of information within railroad organizations as a result of pending claims may also limit the value of reported data.

Investigation of Complaints

Complaints received by FRA alleging noise violations in the cab from crew members or their labor organizations provide an indication of the extent of the problem caused by high locomotive cab noise levels. Table 6-3 summarizes the cab noise complaints investigated by Federal inspectors between 1989 and 1993.

Table 6-3 LOCOMOTIVE CAB NOISE COMPLAINT INVESTIGATIONS: 1989-1993

Reg	Unit #	Date	RR	ST	Service	Lead / Trail	A/C	Window	Ill-ness
4	CR 1608	Feb 93	CR	IN	Freight	Lead	Ukn	Ukn	Yes
3	CSX 2507	Jun 92	CSX	GA	Freight	Lead	Ukn	Ukn	Yes
8	UP 3489	Nov 92	UP	ID/ WY	Freight	Lead	Ukn	Ukn	No
8	ATK 450	May 92	ATK	MT	Pass	Lead	Ukn	Ukn	No
6	ATK 250	Nov 91	ATK	MO	Pass	Lead	Ukn	Ukn	No
4	GE-Dash 8's	Mar 92	ATK	IL	Pass	Lead	Ukn	Ukn	No
4	Locomotive(s)	Mar 90	ATK	MI	Pass	Lead	Ukn	Ukn	No
7	Locomotive(s)	Mar 91	SP	CA	Freight	Lead	Ukn	Ukn	No
3	CSX 3314	Apr 89	CSX	GA	Freight	Lead	Ukn	Ukn	No
8	Locomotive(s)	Feb 93	UP	ID	Freight	Both	Ukn	Ukn	No
7	Locomotive(s)	Oct 91	MET	CA	Freight	Lead	Ukn	Ukn	No

Upon receipt of a complaint, FRA inspected the locomotive to determine whether the cause of the complaint was still present. If FRA found an unsafe or unhealthful condition, it was promptly reported to railroad officials. However, because of the time elapsed between the reported condition and the time required for FRA to inspect the subject locomotive, the lack of electronic monitoring equipment on-board the locomotive to provide real-time recording, or the lack of appropriate equipment such as electronic analysis tools available to evaluate the reported condition, the cause could not be determined in many cases. Consequently, the complaint often could not be verified. FRA chose to pursue a civil penalty in three cases regarding excessive noise. The newer monitoring equipment used by FRA, first utilized in 1992, provides better capability in detecting and documenting cases of excessive noise.

Industry Programs

Several railroads have addressed concerns regarding employee noise exposure by establishing mandatory hearing protection programs. Some of these programs address hearing conservation needs of a wide range of employees who may be exposed to high noise levels (e.g., maintenance-of-way employees), while others appear to be limited to train and engine services employees.

FRA contacted industrial hygienists of several Class 1 railroads to conduct an informal telephone inquiry of their respective hearing protection programs. All of the railroads contacted stated that their companies have comprehensive hearing conservation programs that include mandatory hearing protection in hazardous noise areas. All of the railroads contacted are conducting audiometric exams, although some programs are more complete than others. The industrial hygienists also stated that hearing conservation training is being given to both locomotive crews and ground crews that work in excessively noisy areas. However, most of the industrial hygienists readily admitted that their hearing protection program had not gained any momentum until the last couple of years and are not fully developed.

The following is a summary of the hearing conservation programs implemented by the railroads contacted by FRA:

Railroad "A" Contractors are conducting baseline noise surveys and conducting training on a major route. Hearing protection is required. As soon as the hearing conservation program is completed on its major route, it will be implemented on all portions of their railroad.

Railroad "B" This railroad does not have a written program; however, it conducts audiometric tests on an annual basis via a mobile test lab in the Chicago area. This includes locomotive crews and shop employees who work in high noise environments. Hearing protective devices are made available to the employees.

Railroad "C" This railroad conducts noise surveys of its locomotives and it has characterized the noise environment of its noisy jobs to determine which jobs require hearing protection. It is implementing the 85 decibel OSHA hearing conservation program. Audiometric testing and training is conducted on an annual basis by its contractor. Pre-employment audiometric exams are conducted before new employees are exposed to railroad generated noise. Only approved hearing protection devices are used. Hearing protection is mandatory for all moving locomotives.

Railroad "D" Railroad D's program is nearly identical to Railroad C. It is using the same contractor.

Railroad "E" This railroad started a hearing conservation program in 1987. It requires annual audiometric exams for all its train crews and mechanical forces.

Railroad "F" As a result of the FRA comprehensive survey of its locomotive noise, this railroad requires that all train crews wear hearing protection when within 100 feet of an operating locomotive. Railroad F conducts audiometric exams.

An official from the Brotherhood of Locomotive Engineers (BLE) international office stated that the union supports railroad hearing conservation programs as temporary or interim measures to protect the hearing of their members while the perceived long-term solution—the quieting of locomotive cabs through design—is pursued.

Labor organizations have alleged that excessive noise levels within the cab, especially in older locomotives, contribute to hearing loss. Measures have been taken to reduce the effects of noise in the cab, including piping automatic brake valve exhaust outside the cab and relocating the horn away from the cab during retrofit.

In recent years, many carriers have required the use of either ear plugs or ear muffs to protect employees. However, train crew members suffering from perceived or diagnosed hearing loss state that they cannot monitor the radio adequately while wearing hearing protection. This poses a dilemma because most railroads require the use of hearing protection by rule. Thus, in addition to increased hearing loss, employees who do not use hearing protection run the risk of disciplinary action.

Locomotive builders are responding to pressure from railroads to design and build new locomotives with better sound reduction techniques and lower noise levels in the cabs. Many new locomotives include the following features that have reduced the cab noise level:

- moving the horn back to the center of the locomotive;
- insulating the inside of the locomotive cab to reduce both transmission of noise and vibration;
- insulating the locomotive cab floor;
- piping the exhaust of the air brake system outside of the locomotive cab; and
- air conditioning of locomotive cab which allows cab windows to remain closed.

In addition, major locomotive manufacturers claim major advances in technology will soon be applied to quiet locomotive cabs. Cabs seismically isolated from the locomotive body have been developed that result in substantially less vibrations and noise in the cab. Manufacturers claim normal noise levels of 75 dB(A)[10] in locomotive cabs are achievable, as is cited in the December 1994 edition of "Trains."

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[10] "Trains," December 1994, page 17.

FRA Survey of Cab Working Conditions - Noise

During 1994, FRA implemented a test plan (See Appendix H - Guidance to Inspectors for Conducting Locomotive Cab Surveys) which required FRA field inspectors to conduct a formal survey of cab working conditions by traveling aboard 234 locomotives—during typical and also environmentally extreme working conditions—to determine whether existing in-cab working conditions cause impairments in the ability of the crew to operate the locomotive safely. A primary objective of this survey was the evaluation of the noise levels measured in locomotive cabs.

Details of the procedures used to conduct this broad survey are given in Chapter 4. FRA made cab noise measurements using Metrosonics Db-3100 Metrologgers, which were pre-calibrated before testing and post-calibrated after testing using a Metrosonics Calibrator, Model CL-304. FRA asked the crew to operate the locomotive in a "normal" fashion (i.e., as though FRA test personnel were not present), and placed the microphones used for the measuring devices either on the hat or shoulder of the crew member. Crews controlled the window position—opened or closed—based on their own preferences without FRA direction or interference.

A total of 350 locomotive noise measurements were conducted. They included 234 locomotive measurements that were evaluated during the 1994 winter/summer test phases and 116 locomotive measurements that were evaluated since January 1992, in response to inquiries and complaints. The latter were collected in the same manner as the 1994 winter/summer tests. The inclusion of these data increases the size of the sample. However, it should be noted that complaint investigations and summer tests conducted in very hot weather—often with windows open—places emphasis on those portions of railroad operations more likely to present unacceptable noise environments. Accordingly, the measurements assembled for this report do not constitute a random sample of locomotives or locomotive operating conditions, and appropriate caution must be exercised in characterizing the significance of the findings.

Summary of Noise Measurement Results

Figure 6.3 illustrates the results of the locomotive cab noise survey, showing the distribution of results for both TWA and average noise level (Lav) measured by FRA inspectors. While FRA intended to run the noise tests over 8-hour time periods, this was not always possible due to the varying length of routes. In general, tests performed in the eastern United States tended to be shorter in length, while the western routes—especially in Texas—tended to be longer. The average duration of the 350 tests performed was approximately 6.5 hours. Accordingly, Figure 6.3 shows that the TWA and Lav curves are similar, with the TWA curve shifted slightly to the left (indicating slightly lower decibel levels) because the average exposure duration was less than the 8 hours used to calculate TWA levels.

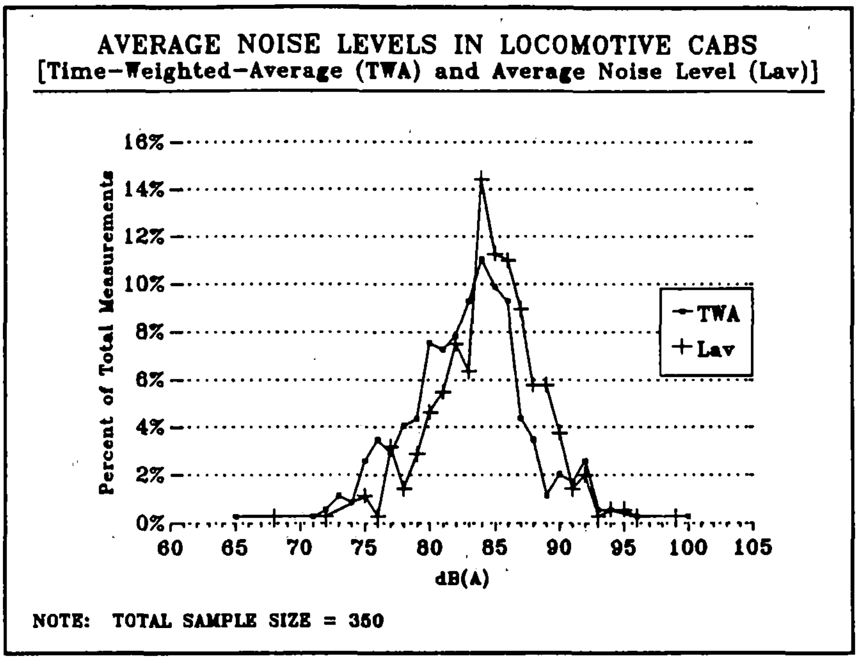

Figure 6.3 Average Noise Levels in Locomotive Cabs

During the survey, FRA inspectors found the following to be the major contributors to high average cab noise levels, and to significant peak readings of 95 dB(A) or higher:

- radios
- audible warning devices (horns, particularly at highway-rail crossings)
- diesel engines (including heavy loading in high throttle settings)
- tunnels, sheds, and bridges
- close embankments
- open windows
- dynamic braking
- loose cab sheet metal
- loose side windows
- miscellaneous loose and/or poorly fitted cab equipment

Figures 6.4 and 6.5 illustrate the results of the noise survey, showing the percentage of measurements obtained for various crew locations and locomotive positions. These results are shown for selected ranges of TWA noise levels. These specific TWA levels were chosen to illustrate varying limits established by OSHA, FRA, and industry practice as follows:

- o TWA < 85 dB(A) — Measurements below the established OSHA hearing conservation level.
- o 85 ≤ TWA ≤ 87 — Measurements between the established OSHA hearing conservation level and the FRA 12-hour TWA limit.
- o 87 < TWA < 88 — Measurements between the FRA 12-hour TWA limit but below the upper limit for verbal communication.
- o 88 ≤ TWA ≤ 90 — Measurements between the upper limit for verbal communication and the FRA/OSHA 8-hour TWA limit.
- o TWA > 90 dB(A) — Measurements above the FRA and OSHA 8-hour TWA limit.

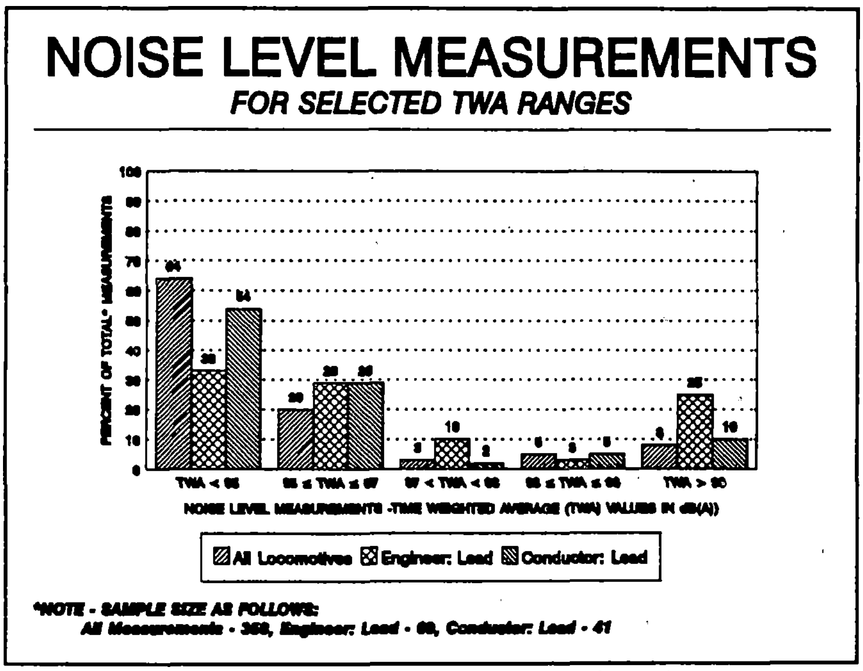

Figure 6.4 Noise Level Measurements for Selected TWA Ranges

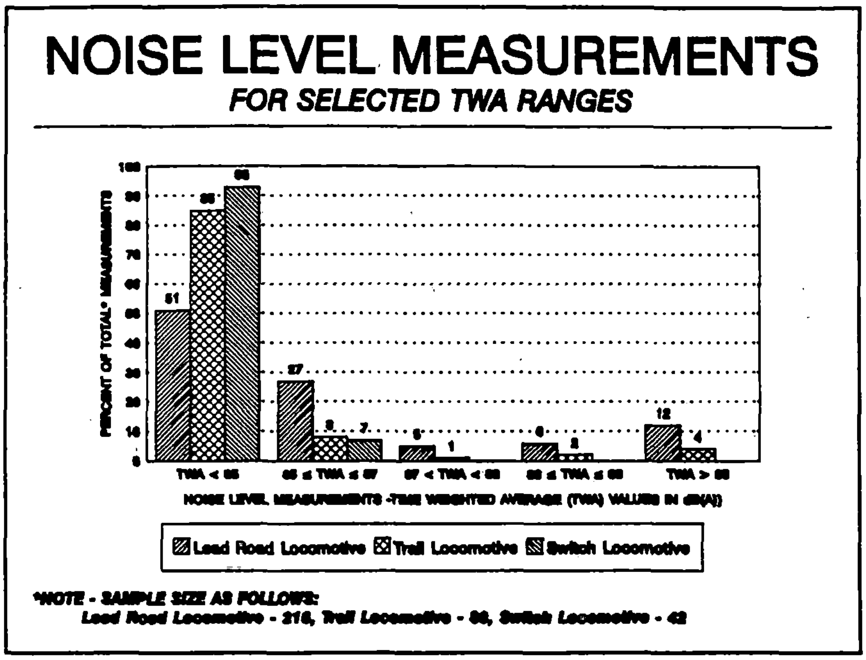

Figure 6.5 Noise Level Measurements for Selected TWA Ranges

From the data provided in Figures 6.4 and 6.5, Table 6-4 shows the cumulative percentage of measurements that exceeded established limits for noise exposure for both crew position and locomotive position.

As shown in Figure 6.4, approximately one-third or 39 percent (10 percent + 3 percent + 25 percent) of the 69 measured locomotive engineers had TWAs greater than 87dB, while 62 percent (33 percent + 29 percent) of the measured locomotive engineers had TWAs equal to or less than 87 dB. [Note: In Figure 6.4, the bar numbers are shown as percentages and may not equal 100 due to rounding.]

As shown in Figure 6.5, approximately one-fourth or 23 percent (5 percent + 6 percent + 12 percent) of the 216 measured leading locomotives had in-cab had TWAs greater than 87dB, while 78 percent (51 percent + 27 percent) of the measured leading locomotives had in-cab TWAs equal to or less than 87 dB. [Note: In Figure 6.5, the bar numbers are shown as percentages and may not equal 100 due to rounding.]

The data presented in Table 6-4 is representative of the 350 measurements taken as described earlier. As shown in this table, 16 percent of the 350 total measurements exceed 87 dB and 38 percent of the 73 Engineer measurements exceed 87 dB. As noted above, the locomotive assignments in question should not be considered to be representative of the railroad industry in its entirety. Train and engine crews generally work on a modified mileage basis, and few routinely work full 12-hour days as permitted by law. An employee working the full 12 hours allowed by law would not likely be fully engaged in moving a train during the entire period in every case, due to delays at the initial terminal and arrival at a crew change point before completing paperwork to go off duty. Nevertheless, the data can be a useful guide in providing insight into adverse conditions in the locomotive cab environment.

FRA's current regulation for train-borne audible warning devices (49 CFR 229.129) requires the horn to produce a minimum sound of 96 db(A) at a location 100 feet ahead of the engine. Depending upon the location of the horn, individuals riding in the cab of a locomotive can be exposed to a repetitive, high noise level when the horn is sounded. As an example, a trip between San Antonio and Fort Worth, Texas, requires the engineer to sound the air horn approximately 1,600 to 1,800 times while traversing 425 crossings[11]. However, review of the logs maintained by the inspectors during the testing provides revealing information about the noise levels attributable to the locomotive horn. For example, one inspector noted that the noise level from the horn measured inside the cab of a EMD GP39-2 locomotive with the window open was 106 dB(A), with the window ½ open was 97 dB(A), and with the window closed was 93 dB(A). The 13 dB(A) differential is substantial, indicating the value of keeping the windows closed; however, during the summer in some areas of the United States, ambient temperatures may necessitate some type of cooling for the cab occupants.

In most cases, FRA observed train crews wearing hearing protection in noise environments exceeding the current FRA standard. Most railroads have chosen to use hearing protectors—either ear muffs or ear plugs—as the chief means to protect their locomotive crews from excessive noise. Although hearing protectors are not the permanent answer to noise exposure reduction, OSHA noise regulations require their use as a temporary solution until an adequate engineering control is implemented to reduce the noise hazard.

The Noise Control Act mandated that EPA develop a rating system to identify the degree to which hearing protectors will provide attenuation of noise. EPA selected the Noise Reduction Rating (NRR) as the measure of a hearing protector's noise reducing capabilities. The range of ratings for existing hearing protectors is approximately 6 to 30 decibels when used as directed by the manufacturer. The NRRs are determined under ideal conditions in the controlled laboratory environment.

Studies have demonstrated that the protection afforded to users in the field should be approximately half of the NRR. This conservative reduction is based on knowledge that the hearing protectors are not worn in an ideal environment. Often, the hearing protectors are not worn in accordance with the manufacturers' recommendations, and they may not always be used at all times in a loud environment. Users will often remove hearing protectors to hear a conversation.[12]

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[11] Memorandum to FRA from a locomotive engineer regarding excessive cab noise

[12] Lempert, B.L., Edwards, R.G.: Field Investigations of Noise Reduction Afforded by Insert-Type Hearing Protectors. Am. Ind. Hyg. Assoc. J. 44(12): 894-902(1983)

Measured Category (Units measured)	OSHA Hearing Conservation Level per 29 CFR §1910.95(c) ≥85 dB(A)	FRA 12-hour TWA Limit >87 dB(A)	Sustained Verbal Communication Limit ≥88 dB(A)	FRA & OSHA 8-Hour TWA Limit >90 dB(A)
All Locomotives: Lead, Trail, Switch, & Non-specified (350)	36% (126/350)	16% (57/350)	13% (45/350)	8% (29/350)
Engineer: Lead Locomotive (69)	67% (46/69)	38% (26/69)	28% (19/69)	25% (17/69)
Conductor: Lead Locomotive (41)	46% (19/41)	17% (7/41)	15% (6/41)	10% (4/41)
Lead Road Locomotive (216)	49% (106/216)	22% (48/216)	17% (37/216)	12% (25/216)
Trail Locomotive (80)	15% (12/80)	8% (6/80)	6% (5/80)	4% (3/80)
Switch Locomotive (42)	7% (3/42)	0% (0/42)	0% (0/42)	0% (0/42)

Table 6-4: Percentage of Measurements Exceeding Established Noise Limits

Without proper training and close supervision, only half of the protection provided by earplugs is achieved. While this will provide adequate protection in locomotive cabs, better protection could readily be achieved through increased training and reinforced supervision.

Discussion of Results

The current FRA cab noise standard of 90 dB(A) for an 8-hour TWA exposure and 87 dB(A) for an 12-hour TWA exposure is equivalent to OSHA's limit for other workplaces. However, the limit on exposure is not accompanied by hearing conservation program requirements of the kind adopted by OSHA in 1983. Noise measurements taken by FRA during complaint investigations and in support of this report indicate that train and engine crew members are not subject to excessive noise during a majority of their assignments working in the locomotive cabs. However, a minority of locomotive assignments involve potential noise exposure above the OSHA threshold for hearing conservation programs and—in a small percentage of actual assignments—above the absolute FRA and OSHA exposure limits. Factors that influence crew exposure include locomotive type and condition, route (e.g., requirements for heavy loading of the diesel engines and operation of braking systems, tunnels), operation of audible warning devices, radio use, status of cab side windows, and crew member position in cab.

Occupational hearing loss results from repetitive exposure, and exposure limits are established with the objective of preventing hearing loss over a working lifetime. Thus, an engineer or conductor who occasionally draws locomotive and train assignments that involve excessive exposure might not suffer detectable hearing loss, even if personal protective equipment is not employed. By contrast, a crew member who regularly operates noisy locomotives over a route with frequent highway-rail grade crossings and with cab windows open might suffer hearing loss over a working lifetime absent proper use of personal protective equipment. Well-managed hearing conservation programs can identify employees at risk for hearing loss and ensure that personal protective equipment or environmental controls are employed before damage occurs.

FRA was not able to determine the extent to which cab noise exposure may be leading to actual hearing loss. FRA conducted a modest literature search from 1985 to the present and found only two references addressing hearing loss in locomotive crews. A short synopsis of each is presented below:

- A study employing benchmark data from a major railroad's hearing conservation program concluded that the population of operating employees on that railroad had not experienced significant occupational hearing loss. A total of 9427 crewmen were tested. Furthermore, it was concluded that the findings were supported by a national study (Kilmer report) which shows typical exposure levels of 78 dBA for an 8-hour workday for train crewmen.[13] It should be noted that the Kilmer report tabulated and analyzed the field test program of 18 test runs with 16 locomotives.[14]

- Another study analyzed 9778 male railroad traincrew workers. This report concluded that the comparison of the hearing levels, adjusted for nosocusis, of trainmen who had used no guns, with the hearing levels of otologically and noise screened males revealed significant losses due to railroad noise. This report stated that it appeared that the effective 8-hour exposure level of trainmen to railroad noise is about 92 dBA. It concluded these results are in general agreement with those of a study of railway workers by Prosser et al. [Br. J. Audiology. 22, 85-91 (1988)].[15]

A quotation from an authoritative reference best summarizes the above information: "It is stressed that despite the millions of audiometric records gathered from exposed workers, the relations between noise exposure and the resultant noise-induced permanent threshold shift are still imprecise and the data from field and laboratory studies, on which the present damage and risk criteria and standards are based, are imperfect and controversial."[16]

Hearing loss is not the only concern generated by noisy locomotive cabs. Studies in other industries suggest that two individuals cannot verbally communicate in an environment with an ambient decibel level of 88 d(B)A, because the human vocal system cannot sustain a decibel level to override the noisy environment[17]. Reports by FRA personnel confirm that noise levels in some cabs during some assignments are sufficiently high to make effective voice communication very difficult. The average noise level in a significant number locomotive assignments—especially those operated with cab windows open—reaches

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[13] Clark, William W., and Popelka, Gerald R., "Hearing Levels of Railroad Trainmen," Laryngoscope 99:1151 (Nov. 1989).

[14] Kilmer, R. D.: Assessment of Locomotive Crew IN-Cab Occupational Noise Exposure. National Bureau of Standards, Report No. FRA/ORD-80/91. United States Department of Transportation, 1980.

[15] Kryter, K. D., Hearing loss from gun and railroad noise--relations with ISO standard 1999., J Acoust Soc Am (United States) Dec 1991 (6) p3180-95, ISSN 0001-4966

[16] Robert Thayer Sataloff, Occupational Hearing Loss, 2nd. ed., Marcel Dekker, Inc., New York, 1993, p. 550 & 551.

[17] A study based upon the Electric Power Research Institute's Human Factors Guide for Nuclear Power Plant Control Room Development (EPRI NP-3659, Project 1637-1, Final Report, August 1984).

88 dB(A). Effective voice communication between crew members in the cab, and between crew members and other responsible parties such as the dispatcher, is required for safe operation of the locomotive.

Major railroads have responded to occupational noise exposure by requiring use of personal protective devices (ear plugs or headsets), ordering new locomotives with improved cabs that offer a quieter environment, and instituting hearing conservation programs. However, railroad programs to limit occupational hearing loss do not conform to uniform minimum criteria. Use of ear plugs does not usually improve crew communication, and data derived from hearing conservation programs is not widely shared.

Conclusions

Based upon a review of occupational noise exposure standards, a review of historical data for noise-related incidents and investigations, consideration of the effect of noise on human performance, and a survey which measured actual noise levels in locomotive cabs during operation, the following conclusions are provided:

- A group of locomotive crew assignments involve exposure to noise levels that raise concerns with respect to crew communication and repeated exposure that might lead to partial hearing loss.

- Many factors, including the sounding of the horn, locomotive engine noise, and increased volume of the radio contribute to noise levels that can equal or exceed 85 dB(A) for a group of locomotive assignments.

- Current FRA noise regulations have not been updated to adopt a preventive "hearing conservation" approach to high noise levels in locomotives.

- Measured cab noise levels for some locomotive assignments would be expected to inhibit communication necessary for the safe operation of trains. Actual effects of this noise and the success of efforts by crew members to compensate have not been documented, but neither have the effects been excluded.

- Many railroads have implemented hearing conservation programs, including mandatory use of personal protective equipment, in an effort to educate and protect these workers.

- Human factors literature suggests that excessive noise levels can impair mental processes and increase both fatigue and the number of errors, while decreasing vigilance.

In light of the information provided above, FRA will initiate consultations with representatives of railroad employees, the railroads, and other interested parties to develop proposed amendments to FRA regulations on noise exposure for railroad operating employees, including appropriate attention to hearing conservation programs. Additionally, FRA's Office of Research and Development will conduct research in an effort to develop alternative methods to be used in reducing sound levels in locomotive cabs.

Other specific recommendations that may contribute to reducing the exposure of operating crews to excessive noise levels are provided below:

- Railroads that have not undertaken hearing conservation programs should seriously consider development and implementation of appropriate programs.

- To the extent practicable, measures should be taken to reduce the levels of noise in older model locomotives, which typically exhibit higher levels of noise than current models. This should include ensuring that all metal comprising the "skin" of the locomotive is securely fastened to the locomotive structure.

- In the long-term, railroads and locomotive builders need to work together to minimize noise exposure in locomotive cabs through design efforts that incorporate new technology.

- In operating territories subject to extreme heat, railroads should make reasonable efforts to maintain air conditioning systems on locomotives so equipped to allow closed-window operations.

- Railroads should evaluate their options to improve working conditions in locomotive cabs.

- Where conditions warrant, railroads should evaluate use of sound insulated headsets with microphones to provide hearing protection, to help ensure effective radio communications, and to facilitate intra-crew communication.

CHAPTER 7

Locomotive Cab Air Quality

Poor cab air quality can be caused by the entry of diesel exhaust gases into the cab. The causes are exhaust system leaks and vented gas entering through the cab windows and other apertures. Concerns often arise when the locomotive is idling or moving through enclosed spaces such as tunnels or deep cuts. Exposure may be greatest for employees while occupying cabs of trailing (non-lead) locomotives.

The diesel engine emissions of primary concern are carbon monoxide (CO), oxides of nitrogen (as NO_2), and hydrocarbon (HC) vapors and particulates. Tests under "worst case" conditions indicate that personnel in the cabs of trailing locomotives may occasionally be exposed to concentration levels of oxides of nitrogen air contaminants in excess of recognized occupational exposure limits. Continued vigilance is needed to prevent exposure to harmful exhaust emissions.

The potential entry of diesel exhaust gases into spaces occupied by the crew is a primary concern with respect to locomotive air quality. Two modes of entry exist. First, exhaust system leaks may allow exhaust to enter the cab prior to being vented up the stack. Current FRA regulations cover locomotive exhaust system leaks of this type. Second, a possibility exists that properly vented exhaust gases may enter the cab. Stacks are generally high enough, or located aft to the direction of travel of the cab, so that entry of properly vented exhaust gases into cabs of lead locomotives moving outside of enclosed spaces—such as tunnels—is not a problem. The highest potential for cab contamination by properly vented exhaust gases exists with idling locomotives, locomotives moving through enclosed spaces such as tunnels or deep cuts, and occupied cabs of trailing locomotives. This chapter addresses the findings of a study conducted by FRA in an effort to identify and quantify problems such as these. This study consisted of a review of existing regulations, a study of the effects of air quality on human performance, a review of injury/illness data due to fumes reported to FRA between 1990 and 1994, and air quality testing in the Cascade Tunnel.

Review of Existing Federal Regulations and Standards

FRA reviewed the existing Federal regulations and standards covering workplace and vehicle air quality. The existing FRA regulation covering locomotive cab air quality is contained in 49 CFR 229.43(a) and (b) as follows:

> <u>Exhaust and Battery Gases</u>
>
> *(a) Products of combustion shall be released entirely outside the cab and other compartments. Exhaust stacks shall be of sufficient height or other means provided to*

prevent entry of products of combustion into the cab or other compartments under usual operating conditions.

(b) Battery containers shall be vented and batteries kept from gassing excessively.

FRA does not specify limits for the concentration of the products of diesel fuel combustion, and does not require air exchange rates for locomotive cabs. However, the Occupational Safety and Health Administration (OSHA) does specify workplace concentration limits in 29 CFR §1910.1000 (Air Contaminants) for the common products of diesel fuel combustion listed in Table 7-1:

OSHA Limits for Air Contaminants

GAS	MAXIMUM 8-HOUR TIME WEIGHTED AVERAGE (TWA) EXPOSURE CONCENTRATION
Nitric Oxide (NO)	25 parts per million (ppm)
Nitrogen Dioxide (NO_2)	5 ppm - at no time shall exposure exceed
Sulfur Dioxide (SO_2)	5 ppm
Carbon Monoxide (CO)	50 ppm
Carbon Dioxide (CO_2)	5000 ppm

Table 7-1

FRA employs the OHSA criteria to determine compliance with the Locomotive Inspection Act[1]:

§20701. Requirements for use

A railroad carrier may use or allow to be used a locomotive or tender on its railroad line only when the locomotive or tender and its parts and appurtenances:

(1) are in proper condition and safe to operate without unnecessary danger of personal injury;

(2) have been inspected as required under this chapter and regulations prescribed by the Secretary of Transportation under this chapter; and

(3) can withstand every test prescribed by the Secretary under this chapter.

[1] Public Law 103-272, July 5, 1994

The U.S. Military specifies the following air quality standards for crew spaces of military vehicles in MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities:

- o Outside fresh air shall be supplied at minimum rate of 20 ft^3 per minute per person. Air flow rates for hot-climate operation temperatures above 90° F shall be maintained between 150 ft^3 and 200 ft^3 per minute per person, unless air conditioning is provided. Air velocity at each person's head location shall be adjustable either continuously or with not less than three ratings (off, low, and high) from near zero to at least 400 feet per minute.

- o Air shall be moved past personnel at a velocity not more that 200 feet per minute. When manuals or loose papers are used, airspeed past these items shall not be more than 100 feet per minute, if possible, to preclude pages in manuals from being turned by the air or papers from being blown off of work surfaces.

- o Ventilation or other protective measures shall be provided to keep gases, vapors, dust, and fumes within the Permissible Exposure Limits specified by 29 CFR §1910 and the limits specified in the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV). Intakes for ventilation systems shall be located to minimize the introduction of contaminated air from such sources as exhaust pipes.

FRA also investigated how FAA regulates aircraft cabin air quality. Discussions with FAA human factors engineering staff responsible for aircraft heating, ventilation and air conditioning (HVAC) revealed that FAA has only very general HVAC requirements because the commercial sector is very competitive in this area, and is therefore market-driven. Current aircraft designs greatly outperform the only two criteria specified by FAA, listed as follows:

- o Each crew compartment must be ventilated, and each crew compartment must have enough fresh air (but not less than 10 cubic feet per minute per crew member) to enable crew members to perform their duties without undue discomfort or fatigue.

- o Crew compartment air must be free from harmful or hazardous concentrations of gases or vapors. In meeting this requirement, the following apply:

  - Carbon monoxide concentrations in excess of one part in 20,000 parts (or 50 ppm) of air are considered hazardous.

  - Carbon dioxide in excess of three percent by volume (sea level equivalent) is considered hazardous in the case of crew members.

Higher concentrations of carbon dioxide may be allowed in crew compartments if appropriate protective breathing equipment is available.

Effects of Air Quality on Human Performance

The diesel engine emissions of primary concern are carbon monoxide (CO), oxides of nitrogen (as NO_2), oxides of sulfur (SO_2), and hydrocarbon (HC) vapors and particulates. Concentrations of these pollutants in any situation will vary according to the nature of the fuel and engine operating parameters.

Fossil fuel combustion sources may also produce trace amounts of irritants such as aldehydes. Other sources of gases and particulate matter associated with the locomotive are vapor discharges from air brake compressors (hydrocarbons), batteries used for starting (sulfuric acid and stibine[2] as a toxic hazard and hydrogen as an explosive hazard), chemical toilets (human waste smells, formaldehyde, and excessive chlorine odors), and oil and fuel leaks from the engines (hydrocarbons). Based on earlier studies[3], other external and miscellaneous sources of air contaminants not directly associated to the operation of the locomotive are less of a potential health hazard to the locomotive crew, and are therefore not considered contaminants of concern for this evaluation.

Oxides of nitrogen such as nitric oxide (NO), nitrous oxide (N_2O), nitrogen trioxide (N_2O_3), and nitrogen dioxide (NO_2 and N_2O_4) can all be found in diesel exhaust gases. The two forms of nitrogen dioxide, N_2O_4 (colorless) and NO_2 (dark brown), are highly toxic. The color of the gaseous oxides varies from colorless to chocolate brown depending upon the percentage composition of the mixture, which is largely a function of temperature. A toxic concentration of the gaseous oxides therefore may be dark brown or colorless. The intensity of color is not an indicator of the degree of danger.

The following describes the effects of the commonly found diesel exhaust toxins, NO_2 and NO:

Nitrogen Dioxide (NO_2) Nitrogen dioxide (NO_2) is a gas which, on inhalation, can cause lung damage[4]. In low concentrations, the gas is a respiratory irritant. The immediate symptoms following inhalation depend on the concentration of the gas, and vary from none to intense choking. With a sufficient dose, there follows an episode

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[2] Stibine also known as antimony hydride (SbH_3), a colorless toxic gas

[3] 1972 FAA evaluation of the Cascade Tunnel per FRA direction

[4] American Industrial Hygiene Association, Hygienic Guide Series, Nitrogen Dioxide, Feb. 1978

of coughing, mucoid or frothy sputum production and increasing shortness of breath. Within 1 or 2 hours, the individual many develop frank pulmonary edema[5], manifested by cyanosis[6], rapid breathing, rapid heart rate and acute distress. Alternately, the worker may simply suffer an increase in shortness of breath and cough over several hours and these symptoms gradually improve several days to several weeks. A delayed reaction in the lungs many occur 2 to 3 weeks after the initial exposure and is characterized by fever, chills, and increasing shortness of breath and an apparent relapse of the disease. Death from respiratory failure many occur either in the initial or the second stage of the disease. A second stage with death may occur even in the absence of a severe initial illness. Pathological examination of the acute lesion shows extensive edema and inflammatory cell exudation[7] in the lungs. The pathological changes noted in the delayed reactions show obliteration of small bronchi and bronchioles with inflammatory exudates which organizes with fibrin obliterating the lumen. Acute exposures many also irritate the eyes, nose, throat, and wet skin, and produce coughing.

Nitric Oxide (NO) Nitric Oxide (NO) is colorless gas which readily reacts with oxygen at room temperature to form nitrogen dioxide, NO_2, a reddish brown gas. The hazards are highly toxic by inhalation, strong irritant to skin and mucous membranes and supports combustion.

Although a healthy worker can adapt quite readily to a considerable variation in cab air quality, the stress of compensating for poor air quality is sometimes cumulative and can lead to irritation, which can cause increasing conflict among crew members, and confusion or even collapse in the event of a sudden task stress. Possible health effects of frequent exposure to high concentrations of diesel exhaust gases include respiratory disabilities, increased risk of respiratory system cancer, and severe headaches.

Review of FRA Complaints Data Base

The complaints alleging poor locomotive cab air quality submitted by locomotive crew members or the labor organizations representing them, and the illnesses reported by railroads due to fumes in the cab, are an indication of the extent of the problem caused by poor air quality. Table 7-2 summarizes the cab air quality complaints investigated by Federal inspectors between 1989 and 1993.

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[5] frank pulmonary edema is the presence of abnormally large amounts of fluid in intercellular spaces within the lungs.

[6] cyanosis is a bluish discoloration, especially of skin and mucous membranes, owing to excessive concentration of reduced hemoglobin in the blood.

[7] exudation is the discharge of fluid through pores or cuts.

CAB AIR QUALITY COMPLAINTS (LOCOMOTIVES): 1989 to 1993

Reg.	Date	ST	Type	Service	Lead/Trail	A/C	Window	Illness
HQ	Apr 93	CA	Fumes	Freight	N/A	Ukn	Ukn	No
7	Dec. 93	CA	Fumes	Freight	Trail	Ukn	Ukn	Yes
7	Jan 93	NV	Fumes	Pass	Trail	Yes	Closed	Yes
6	Mar 93	NE	Fumes	Freight	Trail	Unk	Open	No
6	May 93	MO	Fumes	Freight	Lead	Ukn	Ukn	No
8	Jul 93	WY	Fumes	Freight	Both	Ukn	Ukn	Yes
2	Mar 92	OH	Fumes	Freight	Trail	Ukn	Ukn	Yes
6	Jul 92	MO	Fumes	Freight	Trail	Ukn	Ukn	Yes
7	Jan 92	CA	Fumes	Freight	Lead	Ukn	Ukn	No
4	Jan 91	IL	Fumes	Freight	Lead	Ukn	Ukn	Yes
6	Nov 91	IA	Fumes	Freight	Lead	Ukn	Ukn	Yes
4	May 91	IN	Fumes	Freight	Lead	Ukn	Ukn	Yes
7	Sept 91	AZ	Fumes	Freight	Trail	Ukn	Open	No
6	Dec 90	MO	Fumes	Freight	Both	Ukn	Open	Yes
4	Dec 89	WI	Fumes	Freight	Lead	Ukn	Open	No
3	June 90	VA	Fumes	Pass	Trail	Yes	No	No
3	July 90	GA	Fumes	Freight	Lead	Ukn	Ukn	No
6	Aug 90	CO	Fumes	Freight	Lead	Ukn	Ukn	No
6	Dec 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	March 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	June 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	July 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
1	Sept 89	NY	Fumes	Freight	Lead	Ukn	Ukn	Yes
3	Feb 89	TN	Fumes	Freight	Lead	Ukn	Ukn	No
3	March 89	TN	Fumes	Freight	Lead	Ukn	Ukn	No
6	March 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	Sept 89	KS	Fumes	Freight	Lead	Ukn	Ukn	No
6	Aug 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	Nov 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
6	Nov 89	MO	Fumes	Freight	Lead	Ukn	Ukn	No
7	July 89	CA	Fumes	Freight	Lead	Ukn	Ukn	No
7	Feb 89	CA	Fumes	Freight	Lead	Ukn	Ukn	No
7	Oct 91	CA	Fumes	Freight	Lead	Ukn	Ukn	No
1	April 89	NY	Fumes	Freight	Lead	Ukn	Ukn	No

Table 7-2

Upon receipt of a complaint, FRA inspected the locomotive to determine whether the cause of the complaint was still present. If an unsafe or unhealthful condition was found, it was promptly reported. However, in many cases the cause could not be determined because of the time that elapsed between the reported condition and the time required for FRA to inspect the subject locomotive, the lack of electronic monitoring equipment on-board the locomotive to provide real-time recording, or the lack of appropriate equipment such as electronic analysis tools to evaluate the reported condition. Therefore, the complaint often could not be verified.

Between 1989 and 1993, FRA investigated 34 complaints concerning fumes in the cab. These complaints were spread over freight and passenger locomotives, lead and trail positions, with the windows either opened or closed, and in air-conditioned and non-air-conditioned cabs. In 10 cases, illnesses (such as vomiting) occurred among the crew. In two cases, FRA pursued civil penalties against the railroads involved.

Figure 7.1 plots the injuries or illnesses to crew members due to fumes in the cab reported to the FRA by railroads for the five year time period from 1990 to 1994. These data show that approximately 50 crew members per year report illnesses due to cab air quality resulting in almost 1000 days lost time per year. Many of the complaints and reported illnesses were due to locomotives operating through different tunnels. Crew members frequently report eye and throat irritation caused by diesel fumes accumulating in the cabs of locomotives traveling through tunnels. The air quality complaint and reported illness caused the FRA to undertake a program to measure the air quality in locomotive cabs as they traverse a long tunnel.

Cascade Tunnel Locomotive Cab Air Quality Tests

Measurement of the concentrations of diesel exhaust gases in locomotive cabs is difficult, time consuming, and expensive to conduct. In an effort to determine the upper bound of this problem, while conserving resources, FRA designed a measurement program focused on evaluating what was envisioned to be the most severe environment likely to be encountered with respect to exhaust fumes. A lead hauling locomotive generally has the exhaust outlet from the diesel engine located behind the cab. As cabooses are no longer used, off-duty crew members often ride in the cab of trailing locomotives. The exhaust gas from the lead locomotive can swirl into trailing cabs. This effect is exacerbated in volumes with restricted available air exchange such as in tunnels.

FRA sponsored two separate industrial hygiene evaluations (April and December 1994) that focused on locomotive crew exposure to air contaminants while aboard trains traveling through a long tunnel. Based on previous investigations regarding in-cab locomotive air quality[8], operation of diesel freight trains in tunnels is likely one of the worst-case situations with regard to air contaminant levels in the locomotive crew compartment. FRA selected the

[8] In 1972, the FRA sponsored a Cascade Tunnel Air Quality test conducted by the FAA

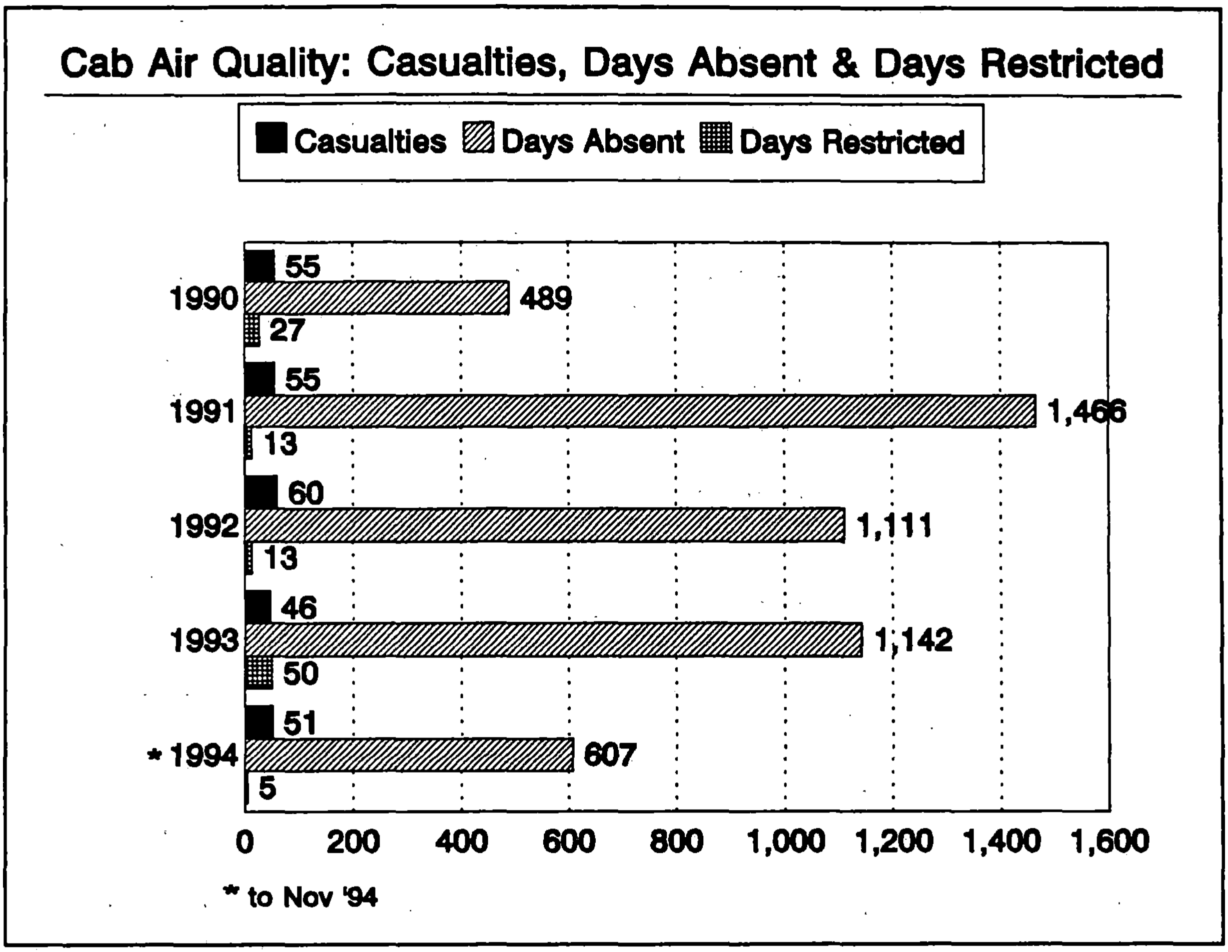

Figure 7.1 Injuries/Illnesses Reported to FRA Due to Fumes in the Cab (1990 - 1994)

Cascade Tunnel on the Burlington Northern (BN) Railroad to measure the locomotive crew's exposure to diesel exhaust gases during operational situations in a long tunnel. This tunnel was chosen as the site for the subject test for a variety of reasons, including (1) it is the longest railroad tunnel in the U.S.—longest enclosure available; (2) there is evidence that trains overheat due to idling in the tunnel—overheating leads to dieseling which produces numerous gases; and (3) diesel engines must strain to traverse the length of the tunnel.

Specific characteristics of the Cascade Tunnel include the following:

- The longest railroad tunnel in the U.S. at 7.8 miles, and is located in the Cascade Mountains between Skyomish and Leavenworth, WA.

- The grade is 1.57 percent ascending eastward in the tunnel at an altitude of 2600 feet.

- o It is located between mileposts 1700.4 (east end) and 1708.17 (west end). For reference, Everett, WA is located about milepost 1784.

- o Maximum authorized speed in the tunnel is 25 mph for freight trains and 30 mph for passenger trains.

- o Air in the tunnel must be evacuated between trains in order to eliminate noxious fumes and provide adequate air for employees and aspiration of locomotives. The method used for operation in the tunnel is as follows:

  - When an eastbound train enters the tunnel, doors on the east end close and large fans near the east portal blow air into the tunnel, forming a positive pressure ahead of the train. Doors on the east portal open automatically when the train is about 1/4 mile from the east end. When the train exits the tunnel, the doors close and the fans then blow air into the tunnel and force fumes and smoke out the west end. The tunnel must be "flushed" between trains.

  - For westbound trains, the doors open as the train approaches and the train pushes a "block" of clean air ahead of it through the tunnel, accelerating the flushing process. Because the grade descends westward in the tunnel, less power is needed and less contamination occurs. As a result, BN tries to operate a train in one direction then a train in the other direction, etc. Using this method maximizes the number of trains they can operate through the tunnel. The longest flushing process is required for consecutive eastbound train movements: Flushing may take up to 45 minutes.

  - Doors, fans and train operation are controlled by the dispatcher located in Seattle. Method of operation in the area is by a traffic control system (TCS).

With the full cooperation of BN, FRA conducted two separate sets of air quality evaluations on trains traveling through the Cascade Tunnel. Measurements were made in the lead locomotive cabs only of six BN trains on April 12 and 13, 1994, and in cabs of 11 BN trains—to include 22 locomotives, both leading and trailing positions—on December 19 and 20, 1994.

Both the April and December tests included measurement of the concentration of the following compounds present in the cab:

- o hydrocarbons, including benzene vaporized from diesel fuel;

- combustion gases such as carbon monoxide (CO), nitric oxide (NO); nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) from diesel exhaust;
- particulates from engine exhaust and braking; and
- stibine from battery recharging.

Vapors from chemical toilets were included in the measurements only during the April set of tests.

April 1994

Field samples were taken by an industrial hygiene contractor and provided to an American Industrial Hygiene-certified laboratory for analysis for the April cab air quality measurements. Via collected samples evaluated at their certified facility, the contractor evaluated the air quality with respect to sources of chemical air contaminants in the cab:

- internal (toilet emissions)
  - chemical deodorizers/cleaners; and
  - human waste odors.
- external (diesel fumes)
  - NO, NO_2, CO, CO_2, O_3, SO_2, HCH, and CH_3CHO.

Table 7-3 summarizes the configurations of the trains included in the set of measurements made during April.

Based on the April measurements, the contractor concluded, "All air sampling results, including the calculated 8-hour exposure limits, were below all OSHA and ACGIH exposure limits," and "This investigation did not include research on the potential effects of diesel combustion products nor did it consider potential carcinogenic effects of diesel exhaust."

After reviewing the contractor's test report regarding the six lead locomotives evaluated during the April test, FRA elected to conduct a larger scale test involving both leading and trailing locomotives, and assembled its own team to conduct a diesel exhaust study of the Cascade tunnel.

December 1994

FRA evaluated only air contaminates due to external sources during the December cab air quality measurements. Trained FRA inspectors used GASTEC Precision Gas Detector

CASCADE TUNNEL TRAINS CHARACTERISTICS (SAMPLE)

Run	Board/ Depart	Train #	Loco #	Mnf	Model #	Year Built	HP	Total HP Consist	Length (ft)	Trail (tons)	# of Cars	Cargo
1	Scenic/ Fan House	G80-12	BN6801	EMD	SD40-2	1973	3,000	9,000	5,815	3,087	98	Empty Grain
2	Scenic/ Fan House	604-12	BN7859	EMD	SD40-2	1978	3,000	9,000	1,800	3,790	29	Loaded
3	Skyo-mish/ Merrit	6-12	BN7812	EMD	SD40-2	1977	3,000	9,000	4,614	4,130	16*	Inter-modal
4	Skyo-mish/ Fan House	G80-13	BN7106	EMD	SD40-2	1978	3,000	9,000	4,580	2,342	74	Empty Grain
5	Scenic/ Fan House	604-13	BN7830	EMD	SD40-2	1977	3,000	9,000	1,900	3,400	29	Loaded Ore
6	Scenic/ Merrit	600-13	BN8748	EMD	SD40-2	1980	3,000	12,000	4,792	4,765	70	Inter-modal

Table 7-3

Systems to sample concentrations of diesel exhaust products in the cab. The GASTEC pump does not have flow-rate orifices that can malfunction by either clogging or leaking. A friction-proof piston gasket (lubricant seal packing) provides leak proof sampling at all times. This system provides a nearly instant response regarding the gas level sampled. A disposable, one-use tube is used for the type of gas to be sampled.

This method was chosen because it is a reliable method that is quick to deploy for tests. It is a system that is easy to learn, and it is difficult to make a procedural mistake. It is also a very economical way to screen for a problem. In short, the method is usually the first to be employed to find a problem, but it is not sufficiently reliable or of long enough duration to completely define an environmental condition.

The inspectors brought any significant readings to the attention of the FRA industrial hygienist. After a series of runs were completed, the tubes were delivered to the industrial hygienist for recording. A gas sampling method of this type is used to screen for high concentrations of a particular gas. If concentration levels of concern are detected, more sophisticated repetitive sampling methods should be used to determine concentration variation with time.

FRA assigned six personnel trained in the use of the GASTEC Precision Gas Detector Systems to three teams of two inspectors. To take advantage of train scheduling, one team worked days and two teams worked an afternoon to midnight shift. Each team rode trains through the tunnel with one inspector in the leading locomotive and the other in a trailing unit. Personnel conducting the tests used the following preparations and procedures to ensure valid measurements:

- o Before any tests were conducted, the Industrial Hygienist (IH) provided each inspector with instructions on how to use and test the sampling air pumps and test tubes.

- o Each inspector performed a "dry run" of the testing that would be conducted in the tunnel.

- o The IH verified that each inspector could properly perform the test.

- o Data was collected in accordance with specific instructions from the FRA certified Industrial Hygienist (IH).

- o MP&E inspectors conducted, prior to each run, the normal locomotive safety inspections, placing emphasis on exhaust problems and/or leaks.

- o Each inspector was provided with three pumps so that all gases could be tested simultaneously during each test session.

- o Each sample tube was labeled to indicate lead or trailing locomotive and position in the tunnel in which the data was collected.

- o The IH accompanied each team, at random intervals, to ensure all testing was being performed properly.

- o At the conclusion of each trip, the IH verified and recorded the test results.

The inspectors made measurements to determine the concentrations of NO, NO_2, CO, CO_2, O_3, SO_2, HCH, and CH_3CHO.

Inspectors aboard lead and trailing locomotives in the same train took time-synchronized samples at 2, 10 and 20 minutes after entering the tunnel, measuring the concentrations of three primary gases: NO, NO_2 and CO. Inspectors took samples measuring the concentrations of the secondary gases, as time permitted, between the synchronized measurements for the three primary gases. Time and instrumentation constraints prevented inspectors from taking samples for all secondary gases aboard all locomotives.

Table 7-4 shows a rating scale developed by FRA, based on the OSHA 8-hour time weighted average (TWA) permissible exposure levels (PEL), to rate the air quality in the cab of these 22 locomotives. FRA chose to deem any measured concentration of a gas that exceeded the

Table 7-4 Rating Scale for Locomotive Cab Air Quality

Gas/FRA Rating	Cause for Concern Rating		Acceptable Rating		
	1	2	3	4	5
Nitric Oxide (NO)	35	25	5	2.5	Not Detected
Nitrogen Dioxide (NO_2)	5	5	1	0.5	Not Detected
Sulfur Dioxide (SO_2)	5	5	1	1	Not Detected
Carbon Monoxide (CO)	400	50	25	15	Not Detected
Carbon Dioxide (CO_2)	30000	5000	5000	1000	Not Detected

Note: All measurements are gas concentrations in parts per million (ppm).

OSHA 8-hour time weighted PEL to be a cause for concern, even if that concentration was present for only a short period of time.

Values identified for a rating of (2) in Table 7-4 correspond to the OSHA 8-hour time weighted average permissible exposure level. Values identified for a rating of (1) correspond to a value obtained through adjusting the levels established for a rating of (2) for the fact that the actual exposure time in the tunnel was less than 8 hours. The actual exposure time ranged from ten minutes to an hour or longer for the gas to be cleared from the cab. The concentrations for NO_2 and SO_2 do not differ between ratings of (1) and (2), as the given concentration should not be exceeded for even a short period of time. Any measured concentration less than the value given in rating column (2) is considered acceptable, and should cause no concern for an 8-hour exposure.

Table 7-5 gives the FRA ratings for the concentrations of NO, NO_2, & CO at each of the three times measured for each lead and first trailing locomotive as each train moved through the tunnel. Table 7-6 gives the ratings for the measured concentrations of O_3, SO_2, CO_2, CH_3CHO, and hydrocarbons (HCH) that were taken as time and sampling devices permitted aboard some of the locomotives. A blank in a matrix cell of Table 7-6 indicates that no concentration of that gas was measured aboard that locomotive.

<u>Meaning of Cascade Tunnel Cab Air Quality Measurements</u>

The April 1994 diesel fume evaluations, which included only lead locomotives, found the locomotives to have air contaminant levels within OSHA and ACGIH levels. The December 1994 tests found no detectible concentrations of any diesel combustion gases in lead locomotives. However, during the December tests, FRA detected measurable levels of combustion gases in several of the trailing locomotives. The measured level of NO in one trailing locomotive, and of NO_2 in one trailing locomotive, were high enough to be a cause for concern.

Table 7-5 CASCADE TUNNEL TESTS (DEC 19-20, 1994): NO, NO_2, & CO

Time (Mn)	Gas	1 T	2 T	3 T	4 T	5 L	6 L	7 L	8 T	9 T	10 T	11 L	12 T	13 L	14 L	15 T	16 L	17 L	18 T	19 T	20 T	21 L	22 L
2	NO_2	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2	CO	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5
2	NO	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	NO_2	5	5	3	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
10	CO	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5
10	NO	3	5	3	3	5	5	5	5	3	5	5	1	5	5	4	5	5	5	5	5	3	5
20	NO_2	5	1	3	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
20	CO	4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5
20	NO	3	5	5	5	5	5	5	4	3	5	5	1	5	5	5	5	5	5	5	5	5	5

Note: T = Trail and L = Lead

Table 7-6. CASCADE TUNNEL TESTS (DEC 19-20, 1994): O_3, SO_2, CO_2, CH_3CHO, and Hydrocarbon (HCH)

Gas	2/trail	4/trail	8/trail	18/trail	20/trail
O_3	5 (ND)	5 (ND)	5 (ND)		
SO_2	4 (0.12)		4 (0.1)		
CO_2	3 (2500)	3 (3300)	3 (3000)		
Hydrocarbon (HCH)	3 (100)	3 (110)	3 (110)		
CH_3CHO				5 (ND)	5 (ND)

These measurements causing concern are summarized as follows:

- o After 20 minutes in the tunnel, the cab NO_2 level was measured to be 11 ppm aboard the trailing locomotive of train #2. According to OSHA standards, the exposure level to NO_2 should not exceed 5 ppm at any time.

- o At 10 minutes into the tunnel, the NO level was measured at 50 ppm aboard the trailing locomotive of train #12. Twenty minutes into the tunnel, the NO level decreased to 25 ppm. The OSHA 8-hour time weighted average permissible exposure level is 25 ppm.

The results must be reviewed with prudence because the equipment employed for the tests provides semi-quantitative data, nevertheless, the December test results suggest that high and potentially harmful levels of some diesel exhaust products can possibly build up in trailing locomotives traveling through volumes with restricted air exchange, such as long tunnels.

This is a situation that approaches a worst case, and is by no means indicative of a widespread problem of high levels of diesel exhaust present in locomotive cabs.

Cab Air Quality Measurement Conclusions

Data submitted to FRA by railroads shows approximately 50 railroad employees per year become ill due to exposure to poor air quality in locomotive cabs, resulting in approximately 1000 days per year of lost time. This is a problem that railroads should not ignore. However, several sets of gas sampling measurements taken over the past 25 years have failed to confirm a widespread problem with cab air quality, even under conditions tested to closely simulate a worst case scenario.

FRA concludes that personnel in the cabs of trailing locomotives may be occasionally exposed to concentration levels of oxides of nitrogen air contaminants in excess of recognized occupational exposure limits, under certain adverse train operating conditions such as passing through long tunnels. Due to the high levels of gases found in the trailing cab of trains passing through regions of restricted air exchange such as long tunnels, railroads should monitor cab air quality and take appropriate responsive action. For instance, a railroad could either:

- o provide a means for providing suitable air quality for the crew riding in the trailing locomotive, with means such as positive air pressure in the cab to inhibit the entry of air contaminants; or

- o not permit the crew to ride in the trailing locomotive while passing through tunnels or similar environments.

The new locomotives may provide a better air quality environment for the crew. As the older locomotives are replaced with newer units, the trend of air quality is improving.

FRA recommends that railroads conduct a study of their operations to determine sites and types of operations that pose a high risk for unacceptable cab air quality. Railroads should take operational steps to prevent exposure of personnel to high levels of diesel exhaust gases in trailing locomotive cabs at each site or during each type of operation identified.

FRA will continue to enforce requirements of FRA regulations that require exhaust gases to be properly vented. FRA will also continue to apply OSHA criteria as reference standards to determine compliance with the Locomotive Inspection Act, as codified. FRA does not intend to pursue further rulemakings that addresses cab air quality at this time. However, FRA will continue to monitor the number of reported illnesses due to cab air quality. If industry efforts do not result in a decrease in the number of incidents attributable to poor air quality, further actions will be taken.

CHAPTER 8

Locomotive Cab Sanitary Facilities

FRA conducted a survey of the cab sanitary facilities (toilets) and an evaluation of the chemicals use to clean, disinfectant, and deodorize the toilets. Sanitary facilities are not required by Federal law, so some locomotives are not so equipped.

FRA inspectors found many toilet compartments to be unsanitary and extremely unpleasant, while others were totally inoperative. During the winter phase of the survey, instances were recorded in which temperatures in the toilet compartment were well below freezing, which rendered the system inoperative.

FRA identified 87 different "over-the-counter" compounds used to clean, disinfect, and deodorize the locomotive toilets. Based upon the railroad-provided Material Safety Data Sheets (MSDS), 12 percent of the compounds were found to be in the highest risk rating based on:

- *the chemical safety training required for use (this training must be documented);*
- *the potential for fire and/or explosion; and*
- *the health hazard/reactivity.*

Railroads and crews have a responsibility to maintain facilities in a responsible fashion. Maintenance procedures are needed to ensure that safe chemicals are used and safe practices are implemented.

Sanitary facilities and conditions were addressed in the study as directed by Congress in RSERA. FRA assessed the extent to which environmental, sanitary, and other working conditions in the cab affect productivity, health, and the safe operation of locomotives. Three of the letters cited in Chapter 4 expressing Congressional concern with locomotive cab working conditions specifically mention poor environmental conditions, and are summarized as follows:

- requested an investigation into carbon monoxide exposure from diesel exhaust that forced a train crew to abandon the train on the tracks and seek medical treatment;

- o expressed concern regarding excessive cab temperatures; and
- o suitability of using a dry hopper toilet.

Review of Existing Regulations

FRA does not have regulations that require sanitary facilities, toilets or food storage (i.e., coolers or refrigerators) on locomotives. Section 2 of the Locomotive Inspection Law of 1968 states that:

> *"It shall be unlawful for any carrier to use or permit to be used on its line any locomotive unless said locomotive, its boiler, tender, and all parts and appurtenances thereof are in proper condition and safe to operate in the service to which the same are put, that the same may be employed in the active service of such carrier without unnecessary peril to life or limb, and unless said locomotive, its boiler, tender, and all parts and appurtenances thereof have been inspected from time to time in accordance with the provisions of this Act and are able to withstand such test or tests as may be prescribed in the rules and regulations hereinafter provided for."*

The Federal Government has two primary sources of guidance with respect to sanitary conditions and facilities. The Occupational Safety and Health Administration (OSHA), Department of Labor (DOL), provides generally accepted guidance on workplace sanitation in 29 CFR 1910.141, and the Department of Health and Human Services regulates the sanitation of passenger trains in 21 CFR 1250[1]. OSHA's sanitation standards apply to permanent places of employment, and it has been determined that locomotive cabs constitute a "permanent place of employment" for enforcement purposes[2]. However, by operation of a legislative option that many states have taken in which they may withdraw from the Federal OSHA enforcement scheme to develop and enforce OSHA regulations at the state level, application of OSHA's Federal sanitation standard varies according to where the locomotive is situated. If the unsanitary locomotive is located in a 'Federal OSHA state,' OSHA's Federal sanitation regulation applies. However, if the subject locomotive sits in a state-plan OSHA state, any existing state sanitation standard will probably be nullified because the Locomotive Inspection Act preempts most state provisions relating to appurtenances in locomotives. The result is an uneven and somewhat arbitrary regulatory scheme for

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[1] Food and Drug Administration, Department of Health and Human Services, Part 1250 "Interstate Conveyance Sanitation"

[2] State of Maine, et al. vs. Springfield Terminal Railway Company, CV-90-258, citing Gade v. National Solid Waste Management Association, 112 S.Ct. 2374 (1992).

sanitation in locomotives, which causes FRA concern. Appendix K provides several consensus standards and best practices guidelines developed by industrial associations for sanitary facilities.

Indications of Concern

There are several indicators which can be used to gage the level of concern regarding locomotive sanitary facilities: (1) complaints; (2) union letters of inquiry; and (3) Congressional interest. As detailed below, there has been considerable interest generated with respect to locomotive cab sanitary facilities.

The FRA accident/incident data base is constructed such that any current or past injury or illness due to a faulty sanitary condition cannot be specifically identified, and consequently, contains no reports from railroads of employee injuries or illnesses directly attributable to locomotive cab sanitary conditions. FRA has developed accident codes similar to those developed by DOL's Bureau of Labor Statistics for general industry accident/incident reporting. The system employs a huge number of codes, requiring users to take considerable time to search in order to accurately report all the different sources of accidents, damage caused by the accident, and location of the accident. Several years ago, FRA met with DOL to improve the FRA reporting system, while still keeping it from becoming so complicated and burdensome that the end user—the railroad supervisor—would not become overwhelmed with the complexity of the system. The system was modified, but injuries due to sanitary conditions are still not required to be identified as it was decided that codes covering other sources of injuries would provide FRA with more valuable railroad accident/incident data.

Labor organizations often turn to the FRA in frustration when they feel the railroad company fails to provide a sanitary working environment aboard its locomotives. Individual railroad operations can differ considerably regarding sanitary facilities. Sanitary facilities aboard locomotives may be provided through a labor-management agreement, or as a standard operating practice of the railroad company. This is found primarily with the Class 1 railroads because their crews may operate on long runs. Small railroads or yard locomotives that have local facilities readily available may not be equipped with sanitary facilities.

Survey of Cab Sanitary Facilities and Toilet Chemical Evaluation

During 1993 and 1994, FRA conducted a survey of the cab working conditions by having inspectors travel aboard 234 locomotive assignments during environmentally extreme and typical working conditions. Two primary objectives were established for this survey. First, inspectors were to evaluate the condition of the sanitary facilities in a significant number of locomotive cabs. Second, inspectors were to evaluate the hazards presented by the use of chemical products to clean, disinfect, and deodorize the locomotive cab sanitary facilities.

Details of the procedures used to conduct this survey that simultaneously address several locomotive cab working conditions are given in Chapter 4. For the sanitary facility portion of the survey, FRA instructed inspectors to describe the type of toilet facility, the condition of the toilet space, and how the toilet space is ventilated. This portion of the evaluation was necessarily subjective, and inspectors were instructed to exercise professional judgement in the rating of sanitary facilities. An important aspect of the inspection was to determine if the locomotive sanitary facilities were being maintained in accordance with accepted public health sanitary practice, which requires that toilets be kept clean, sanitary, and operational, and hand washing facilities be kept clean and sanitary with potable water. Appendix K gives several references that provide examples of accepted public health sanitary practices.

The evaluation of hazards presented by the chemical products used to maintain toilets consisted of three steps. First, FRA Motive Power & Equipment (MP&E) regional specialists contacted the railroad companies operating in their respective Regions to identify and catalog the chemical products used to clean, disinfect, and deodorize the toilets aboard their locomotives. Second, FRA obtained the Material Safety Data Sheets (MSDS) for each of the chemical products used. Third, FRA evaluated the information on the MSDS, using several toxicological references to estimate the hazard of using each chemical product. The relative risk rating scheme used to evaluate these chemical products was based on criteria very similar to the scheme used in the reference Dangerous Properties of Industrial Materials, N. Irving Sax and Richard J. Lewis, Sr., 7th Edition:

- o The number "3" indicates an LD_{50}[3] below 400 mg/kg or an LC_{50}[4] below 100 ppm; or that the material is explosive, spontaneously flammable, or highly reactive.
- o The number "2" indicates an LD_{50} of 400 to 4,000 mg/kg or an LC_{50} of 100 to 500 ppm; or that the material is highly flammable or reactive.
- o The number "1" indicates an LD_{50} of 4,000 to 40,000 mg/kg or an LC_{50} of 4,000 to 40,000 ppm; or that the material is combustible.

Results of Cab Sanitary Facility Survey

Findings

FRA inspectors found three types of toilets commonly in use aboard locomotives, and a wide variety of chemical products being used to support the operation and maintenance of these

[3] LD_{50}: The dose that will produce death in 50% of the test population.

[4] LC_{50}: The concentration in the air that may be expected to kill 50% of the test population exposed for a specified length of time.

toilets. Older locomotives tend to be equipped with a type of port-a-let. This toilet consists of a 15- to 20-gallon holding tank and a seat. Water, chlorine, and disinfectant are used on this type of toilet facility. In the wintertime, antifreeze is added to keep the liquid from freezing.

Newer locomotives tend to be equipped with a Microphor toilet. This is a waste treatment system, which breaks down solid wastes by bacteria into liquid and gas. The gas escapes out the tank vent, while the liquid flows through a filter and is then chlorinated, killing the bacteria. The liquid is then discharged to the roadbed. Figure 8.1 depicts a typical Microphor toilet installation aboard a locomotive.

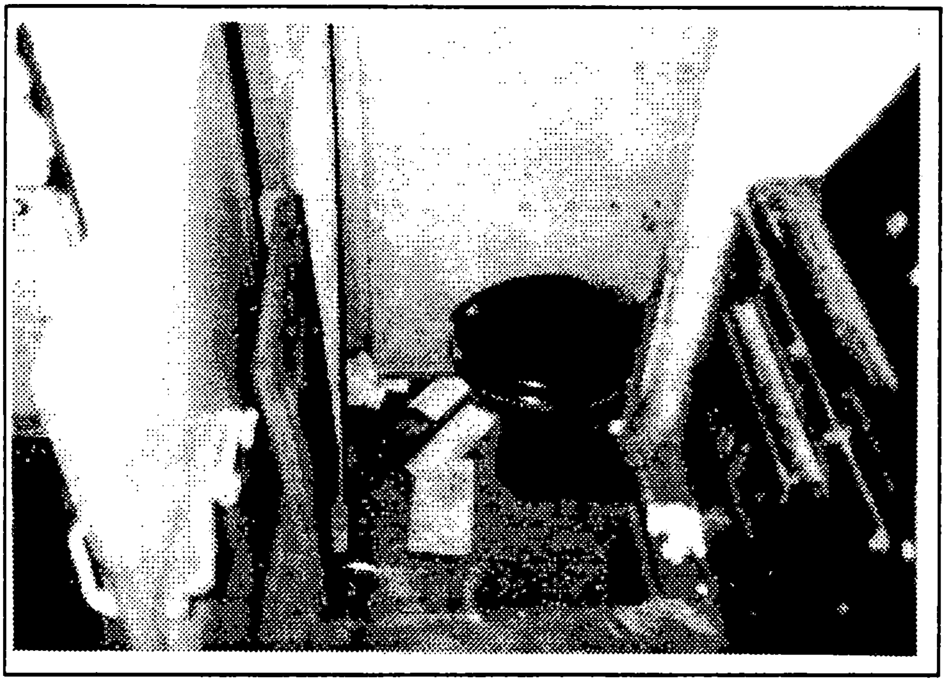

Figure 8.1: Microphor Toilet Installation Aboard a Locomotive

One Class 1 railroad equips locomotives with a "dry hopper" sanitation system. In this system, a plastic seat is placed over a 5-gallon bucket with a plastic bag. After use, the bag is tied and, upon arrival at a final terminal, the employee places the bag at a holding facility and it is disposed of later. The urinal consists of two parts. The upper portion is used for the washing of hands while the lower portion is used for urination. Both fluids are drained directly to the ground. Figure 8.2 depicts a typical "dry hopper" toilet.

FRA inspectors reported many toilet compartments to be unsanitary and extremely unpleasant, while others were totally inoperative. Many instances were recorded in which temperatures in the toilet compartment were well below freezing, which rendered the system inoperative, and permitted the bowl to fill to capacity with human waste. Additionally, some toilet compartments did not provide a means for crew members to wash their hands.

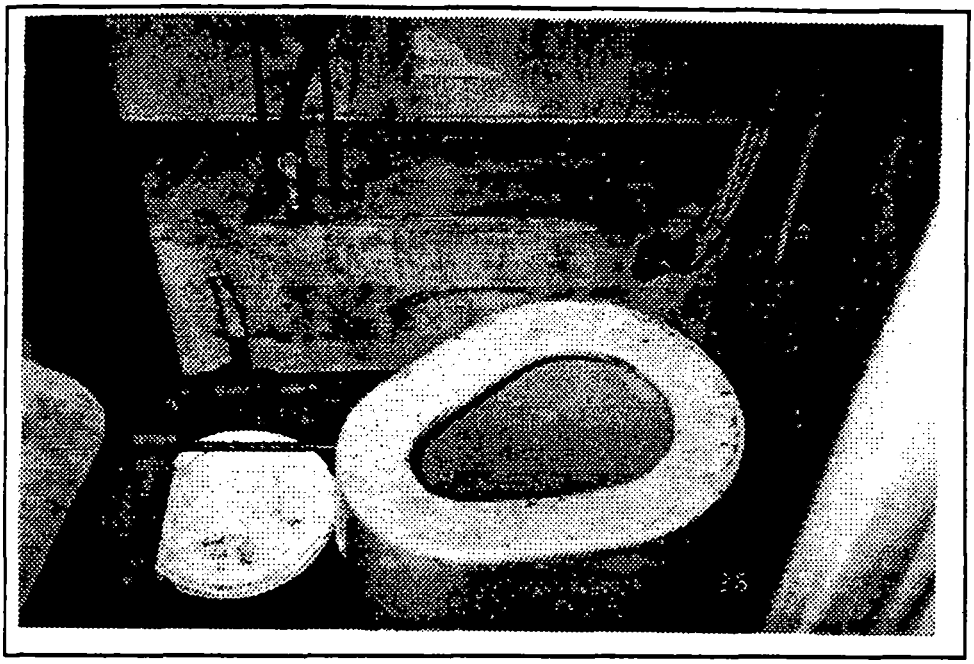

Figure 8.2: Dry Hopper Toilet Installation Aboard a Locomotive

Common observations made by the inspectors included:

- o dirty floors;
- o dirty/missing seats;
- o no toilet paper;
- o offensive, and sometimes nauseating odors; and
- o poor or no ventilation.

In one region, most crews surveyed said that they would rather not use the toilets on the locomotives, simply because they were not clean. Most of the toilets are confined to a poorly lit and very cramped compartment, with little or no heating/air conditioning.

The numerical evaluation of the five categories pertaining to sanitary facilities—toilet condition, toilet space ventilation, potable water supply, food storage, and general cab area—is provided in Appendix I. These results are based on the subjective judgements of FRA inspectors, which is the same method used by other Federal and state agencies to evaluate sanitary facilities. Thirty percent (58 of 197) of the locomotives equipped with toilets were rated as unacceptable or poor, and thirty percent (60 of 197) had toilet spaces rated to have unacceptable or poor ventilation. Thirty-two percent (75 of 234) of the locomotives were not equipped with water coolers, 27 percent (60 of 234) were not equipped with food storage facilities, and 16 percent (37 of 234) had cab interiors that were judged to be inadequate for general sanitation.

Figures 8.3 through 8.5 depict some of the sanitary facility conditions found by FRA inspectors aboard the locomotives surveyed.

Locomotive servicing (fuel, water, and sand) is being achieved at many locations through the use of mobile servicing trucks, which do service the sanitary facilities. Also, maintenance and cleaning of the toilet compartments is primarily done during periodic inspections. Frequently, inspectors found that toilets receive attention only after the odor becomes unbearable. At this time, the toilet compartment may be cleaned by thoroughly washing the compartment and applying a disinfectant and deodorant spray.

Inspectors found that railroads with toilet-equipped locomotives generally have established maintenance procedures for servicing toilets. Railroad procedures generally call for toilets to be maintained on a service level schedule of 15, 30 and 90 days. However, many inspector observations indicated that local maintenance personnel chose to disregard carrier maintenance procedures. Adherence to a firm schedule does not appear to be a high priority for the maintenance agenda. In many cases, locomotive cabs are serviced and cleaned only when locomotives are positioned at service facilities. Locomotives very often go through several crew changes, and sometimes several days, before they are removed from trains for cleaning service.

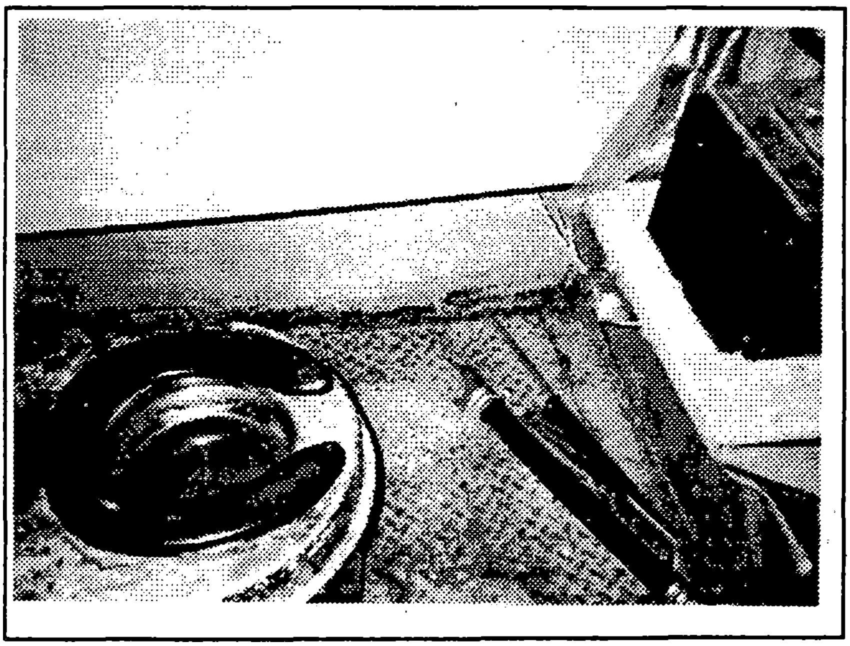

Figure 8.3: Toilet Frozen and Full of Human Waste

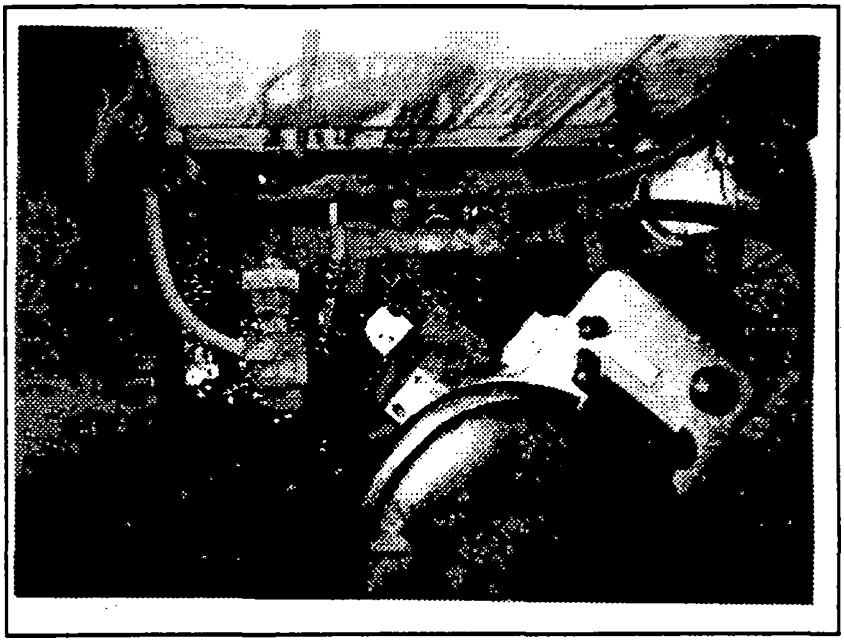

Figure 8.4: 1/2-inch Standing Water in Toilet Compartment

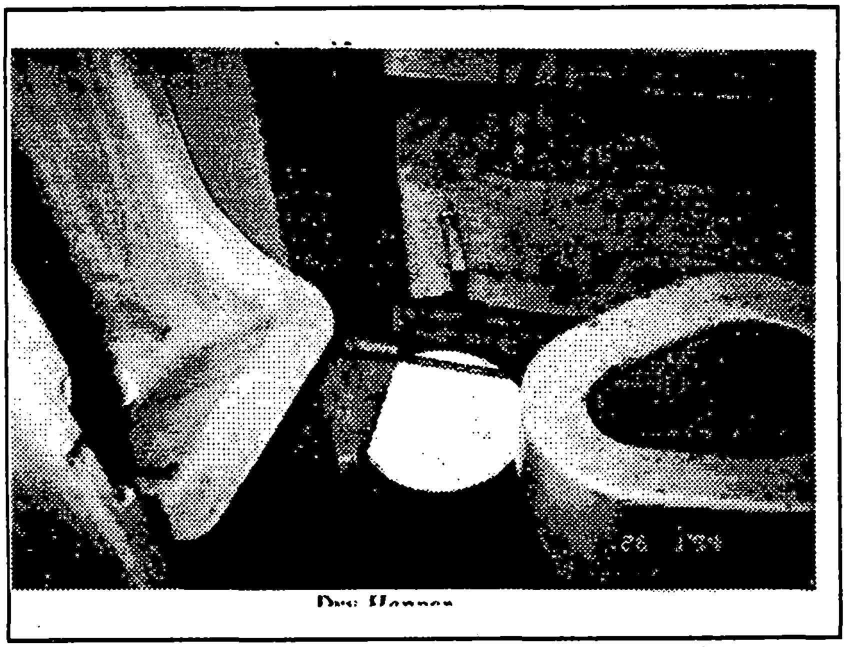

Figure 8.5: Individual Faces the Urinal at a Short Distance

Results of Toilet Chemical Evaluation

While identifying the chemical products used in locomotive cabs and collecting the corresponding MSDS was easily accomplished, conducting a toxicological evaluation of all the chemicals used in locomotive cab toilet systems proved to be difficult. An initial attempt was made to estimate the potential hazard of the product based on the manufacturer-supplied MSDS, also known as OSHA Form 20. The information obtained from the MSDS was evaluated using several toxicological references to derive the potential risk.

FRA inspectors identified 87 different "over-the-counter" compounds being used to clean, disinfect, and deodorize locomotive toilets. Table 8-1 gives the number of compounds receiving each relative risk rating. It should be noted that less than 12 percent of the chemical products were placed in the most severe proposed relative risk category 3.

Table 8-1 PROPOSED RELATIVE RISK RATING OF TOILET CHEMICALS

RELATIVE RISK RATING	DEFINITIONS	NUMBER OF TOILET CHEMICALS RATED
1	Low	57
2	Medium: Chemical safety training recommended	9
3	High: Fire/explosive reactivity/health hazard Chemical safety training required and must be documented	10
D	Unknown: Insufficient data	11

The chemical products used to clean, disinfect, and sanitize locomotive sanitary facilities can fit into six chemical types of products. Each of the groups may be characterized by a hazard common to the chemicals in the group as illustrated below.

- o **Chlorine Releasing Cleaners** The hazard associated with these products is due to the chlorine released by the cleaner. The hazard may be:
  - minor and commonplace, such as household bleach containing a weak solution of sodium hypochlorite, or
  - solid complexed chlorine tablets which can react very quickly and violently to release chlorine.

- **Aerosol Deodorants/Cleaners** Many of these aerosol products are moderately to extremely flammable and can irritate the skin.

- **Insecticide** The insecticide used is very toxic; however, it will not present a hazard to personnel if it is used properly to minimize train crew contact with the applied oil/pesticide spray.

- **Antifreeze** The chief hazard with this type of product is fire. Two types of antifreeze are used: alcohol-based and a glycol-based.

- **Heavy Duty Industrial Cleaners** These are generally composed of quaternary ammonium compounds whose chief hazard is skin irritation.

- **Formaldehyde Releasing Compounds** Several products are in use to sanitize toilets that contain paraformaldehyde, which is a polymer that slowly releases formaldehyde. Formaldehyde is tumorigenic and carcinogenic. This type of chemical cleaner serves a useful purpose in disinfecting and sanitizing sanitary facilities, and it is probably no more carcinogenic than the benzene in gasoline to which people are routinely exposed.

Conclusions

In the absence of FRA regulations addressing sanitary conditions, FRA researched other government guidelines on the subject and performed an extensive survey of locomotive cab working conditions to assess any productivity, health, and safety impacts that deficient facilities may have on the crew. A number of general observations resulting from this work are as follows:

Cab Sanitary Facilities

- Both crews and railroads play a role in for the condition of sanitary facilities;

- Poor sanitary conditions aboard locomotives are caused by poor maintenance by railroads and/or abuse by operating crews.

- Poor maintenance of sanitary facilities exists on many locomotives leading to unpleasant odors and in some cases, deplorable sanitary conditions.

- Poorly maintained or improperly operated chemical toilets pose potential health hazards from human waste and improperly used chemicals.

- Toilet compartments should be large enough for an individual to comfortably stand, turn around, and wash their hands.

- o Toilet spaces need positive ventilation with air exchange to the outside atmosphere.

- o Toilet spaces, as part of the cab, need to be properly ventilated and protected from temperature extreme.

- o The disease-transmitting potential from failure to clean the hands after defecating presents an occupational health threat to the crew. This could lead to sickness, which would interfere with work performance and result in loss of time.

Toilet Chemical Evaluation

- o All of the chemicals used to clean, disinfect, and deodorize locomotive cabs are commercial products that are available over-the-counter to the general public.

- o FRA found that fewer than 12 percent of the chemical products used fall in the most severe relative risk category, where handling requires management supervision. Industrial use of these products necessitates that users must receive training in their safe use.

- o FRA believes this assessment should serve only as a starting point or reminder for railroads to use proper care when handling the chemical products used to support the operation and maintenance of sanitary facilities onboard locomotives.

- o FRA believes in most cases, the MSDS provides useful information, if the users are trained and familiar with them.

Summary and Recommendations

Sanitation must be properly managed and integrated with the railroads' productivity, as it has a direct effect on employee occupational health. The issue of sanitary conditions aboard locomotives is one that can be solved by labor and management cooperation without intervention. Railroads have a responsibility to provide all of their employees with a safe and sanitary working environment.

Chemical products used in the maintenance of locomotive sanitary facilities and toilets are commonly available over-the-counter to the public. Close attention and adherence to manufacturer-provided warnings and restrictions should minimize the risk of injury or illness to operating crew members. FRA will monitor the conditions of locomotive facilities to ensure locomotive cab environments are given appropriate attention.

CHAPTER 9

Locomotive Cab Layout (Ergonomics)

As crews change frequently aboard locomotives, there is a need for a standardized and optimized human-cab interface, especially for emergency controls. This interface would alleviate problems due to the frequent interchange of locomotives among railroad companies. In addition to safety improvements, a standardized design would provide for increased proficiency among locomotive engineers who frequently operate numerous locomotives with different controls, layouts, arrangements, color-coding, and functions. The following provides a partial list of crew needs:

- *standardized controls and displays for safe control/operation;*
- *supportive seats which absorb vibrations and reflect size considerations;*
- *storage for personal articles and refuse (to prevent tripping hazards and alleviate the potential for flying objects during an accident); and*
- *drinking water and food storage.*

Through the Locomotive Control Compartment Committee and industry associations, some degree of standardization and attention to ergonomic design has been achieved. However, additional work is needed to attain a higher level of standardization.

There is increasing research and evidence supporting beliefs that the standardization of workplace layouts may directly improve performance, quickens response time, reduces training costs, increases operator retention, and provides other safety-related benefits. Many industries, including the automobile and airline industries, have adopted detailed guidelines governing the orientation, size, color, and other characteristics of operator controls in the workplace. This chapter provides an overview of current FRA regulations pertaining to the layout of locomotive cabs, steps that have been taken by both the railroad and other industries to improve the ergonomic design of workplaces, and recommendations for continued improvements in cab design that may enhance safety.

Current FRA Requirements

Current FRA regulations pertaining to cab layout and design features are very limited, and provide minimal guidance with respect to specific design features to be incorporated in the locomotive cab. The pertinent language in 49 CFR 229.119 states:

Cabs, floors, and passageways (Section 229.119)

a) Cab seats shall be securely mounted and braced. Cab doors shall be equipped with a secure and operable latching device.

b) Cab windows of the lead locomotive shall provide an undistorted view of the right of way for the crew from their normal position in the cab. (See also, Safety Glazing Standards, 49 CFR Part 223, 44 FR 77348, 31 Dec 1979)

c) Floors of cabs, passageways, and compartments shall be free from oil, water, waste or any obstruction that creates a slipping, tripping, or fire hazard. Floors shall be properly treated to provide secure footing.

e) Similar locomotives with open end platforms coupled in multiple control and use in road service shall have a means of safe passage between them; no passageway is required through the nose of carbody locomotives. There shall be a continuous barrier across the full width of the end of a locomotive or a continuous barrier between locomotives.

f) Containers shall be provided for carrying fusees and torpedoes. A single container may be used if it has a partition to separate fusees from torpedoes. Torpedoes shall be kept in a closed metal container.

Standardized Human-System Interface for Controls

The Federal Government has vehicle safety standards in place to govern the primary control location, identification, and illumination for automobile passenger cars, multi-purpose vehicles, trucks, buses and airplanes. However, a similar applicable safety standard for locomotives does not exist. Table 9-1 provides examples of standards utilized in the automobile and airline industries.

Rationale for Cab Layout Standardization

As crews change frequently aboard locomotives, there is a need for standardized and optimized human-system interface, especially for emergency controls. This standardization would also alleviate problems due to the frequent interchange of locomotives among railroad companies. In addition to safety improvements, a standardized design would provide for increased proficiency among operators who frequently operate numerous locomotives with different controls, layouts, arrangements, color-coding, and functions.

Standardization of controls directly affects the safety of operations by reducing the likelihood of operator error and improving response time, and should be implemented as an integral

Table 9-1 Representative Standards for Controls

Federal Motor Vehicle Safety Standards (FMVSS)	Federal Aviation Administration (FAA)
101: Control location, identification, and illumination - passenger cars, multipurpose passenger vehicles, trucks, and buses.	§25.771: Cockpit compartment
102: Transmission shift lever sequence, starter interlock, and transmission braking effect - passenger cars, multipurpose passenger vehicles, trucks, and buses.	§25.773: Cockpit compartment view
107: Reflecting surfaces - passenger cars, multipurpose passenger vehicles, trucks, and buses.	§25.777: Cockpit controls
108: Lamps, reflective devices, and associated equipment - passenger cars, multipurpose passenger vehicles, trucks, trailers, buses, and motorcycles.	§25.779: Motion and effect of cockpit controls
202: Head restraints - passenger cars	§25.781:Cockpit control knob shape
207: Seating systems - passenger cars, multipurpose passenger vehicles, trucks and buses	§25.805:Flight crew emergency exits
208: Occupant crash protection	§25.809:Emergency exit arrangement
302: Flammability of interior materials - passenger cars, multipurpose passenger vehicles, trucks and buses	§25.811:Emergency exit marking
	§25.812:Emergency lighting
	§25.1381:Instrument lights

part of the locomotive design process. A layout optimized for the operator results in the following advantages:

- increased safety and control;
- increased productivity;
- quickened response time;
- reduced training;
- decreased fatigue; and
- increased job satisfaction.

A user-based locomotive cab layout will provide quicker response times and better monitoring of both radio and internal cab communications. Safety benefits such as reduced stress and increased crew attentiveness that are not easily quantified may be derived from improved cab working conditions. User-centered designs have the potential to reduce overall operating costs while increasing safety and productivity through the prevention of inadvertent actions. A user-centered design puts the operator in charge instead of having the operator respond to the direction of the system. In general, when a design requires the operator to conform to the system, the operator (in this case, the engineer in the cab) fatigues more easily, endures high stress levels, and is more likely to make mistakes.

Two key design enhancements should be incorporated into the locomotive controls to ensure that proper action can be made quickly and safely, unwanted action can be prevented, or the likelihood of unwanted action is greatly reduced:

- redundancy—increases the likelihood that the operator correctly receives and executes the wanted action; and

- feedback—provides positive feedback that the action was taken.

Locomotive Control Compartment Committee (LCCC)

The Locomotive Control Compartment Committee (LCCC) is a group consisting of industry, government, and union representatives that addresses problems related to cab safety through an objective, informal forum in an effort to provide improvements. The committee has strived to bring about improvements in cab design by urging railroad-associated organizations to carry out safety research. The LCCC was formed on June 9, 1971, and since its inception has consisted of representatives from Association of American Railroad (AAR), FRA, United Transportation Union (UTU), and Brotherhood of Locomotive Engineers (BLE). The LCCC's stated purpose is to "explore the possibility and/or feasibility of effective improvements in the design, location, and construction of locomotive control compartments to enhance the safety of cab occupants in the event of collisions or derailments, and to achieve an optimum environment under normal operating conditions."

The committee has initiated and been involved in numerous activities since its formation in 1971. Examples of these include:

- assisting FRA to develop locomotive cab safety studies;

- assisting in the development of locomotive cab mock-ups by both EMD and GE;

- assisting FRA in the design of crashworthiness testing performed at the Transportation Test Center;

- monitoring the development of improved locomotive cab designs by the Canadian National Railway;

- encouraging FRA to survey railroads to obtain a consensus concerning safety improvements that could be standardized in new locomotives; and

- advocating the adoption of Standards for Locomotive Crashworthiness Requirements (AAR S-580) by AAR in support of the results of the FRA inquiry into locomotive cab safety.

Numerous LCCC recommendations have led directly to developments and improvements in locomotive cab design. Examples of these include the following:

- installation of door closure bar
- cab flooring
- flexible hinge guard on cab door
- cushion pad on cab door frame
- rounded cab window latches
- recessed cab equipment
- ventilation in toilet compartment
- standard location of conductor's emergency brake valve
- rounding all exposed edges and corners
- outside walk plates specifications
- standard radio mounting frames
- fuel tank performance standards
- protective cover on windshield wiper motor
- soft rubber grip on windshield wiper motor handle and on horn valve handle
- standard dimensions for alcove and installation of drinking water coolers
- cab seat performance and design
- minimum dimensions of toilet compartment doorway
- elimination of access door to light boxes, etc.
- car floor latch type fasteners
- locomotive crashworthiness standards

Review of Past Investigations and Casualties

Investigation of Complaints

Table 9-1 summarizes the complaints investigated by Federal inspectors pertaining to the locomotive cab layout from 1989 to 1993. Upon receipt of a complaint, FRA inspected the locomotive to determine whether the condition prompting the complaint was still present. If an unsafe or unhealthful condition was found, it was promptly reported.

Complaints were reported for widely varying conditions—on freight and passenger locomotives, in leading and trailing positions, with the windows either opened or closed, and in air-conditioned and non-air-conditioned cabs. Complaints were received on various aspects of the cab design and layout, such as:

- seats (broken, malfunctioning, or missing);

- slippery floors or trip hazards;

LOCOMOTIVE CAB, FLOOR, AND PASSAGEWAY INVESTIGATIONS: 1989-1993

Reg	Unit #	Date	RR	ST	Type	Service	LD/ TL	Ill-ness
2	CR 3312	Jan 93	CR	OH	Slip Hazard	Freight	Lead	No
8	BN 3149	Mar 93	MRL	MT	Slip Hazard	Freight	Trail	No
2	NS 8598	Jun 93	CR	MO	Garbage	Freight	Lead	No
4	NSSR 652	Apr 93	NSSR	MN	Obstruction	Pass	Lead	No
2	WC 1701	Oct 92	WE	OH	Trip Hazard	Freight	Lead	Yes
6	Locom.(s)	Mar 92	UP	NE	Slip/ Trip Hazard	Freight	Lead	No
6	BN 375	Mar 92	BN	NE	Cab Seat	Freight	Lead	Yes
8	ATK 215	Feb 92	ATK	WA	Cab Seat	Pass	Lead	Yes
7	Locom.(s)	Oct 91	UP	CA	Cab Seats	Freight	Lead	No
4	Locom.(s)	May 90	MDT	DC	Cab Seats	Pass	Lead	No
7	ATK 9631	Jul 89	ATK	CA	Cab Seats	Pass	Lead	No
2	NS 1334	Dec 88	NS	OH	Cab Seats	Freight	Lead	Yes
7	Locom.(s)	Mar 91	SP	CA	Cab Seats	Pass	Lead	No
7	Locom.(s)	Oct 91	MET	CA	Cab Seats	Freight	Lead	No
8	UP 3616	May 93	UP	WY	Door Latch	Freight	Lead	No
6	CNW 7024	Jun 91	CNW	IA	Door Latch	Freight	Lead	No
7	Locom.(s)	Sep 90	SP	CA	Door Latch	Freight	Lead	No
7	Locom.(s)	Sep 90	ATSF	CA	Water Chest	Freight	Lead	No
7	Locom.(s)	Jul 89	ATSF	CA	Drink Water	Freight	Lead	No
8	Locom.(s)	Feb 93	UP	ID	Gauge lights	Freight	Both	No
8	Locom.(s)	Dec 92	UP	ID	Gauge Lights	Freight	Both	No

Table 9-1

- o garbage;
- o missing or non-functioning door latches; and
- o defective or missing gauge lights.

In several cases, both illnesses and violations resulted.

Cab Layout Injuries/Illnesses

Table 9-2 summarizes the casualties (injuries and fatalities) and loss of locomotive personnel work time (days absent and restricted) attributed to the general cab layout, and Table 9-3 provides the same information for broken, malfunctioning, or missing seats. The tables contain information reported to FRA by railroads between January 1990 and November 1994. All events connected with the operation of a railroad resulting in one or more of the following consequences were reported to FRA, and recorded on FRA Form F 6180-55a:

- o death of a person within 365 calendar days of the accident/incident;
- o injury to a person, other than a railroad employee, that required medical treatment;
- o injury to a railroad employee that required medical treatment; resulted in restriction of work or motion for one or more work days; the loss of one or more work days; termination of employment; transfer to another job, or loss of consciousness; and
- o any occupational illness of a railroad employee reportable when it is diagnosed as being work-related by a physician or other qualified health care professional.

The following FRA Illness/Injury codes were used to develop the charts:

- o Cab Layout
  - 101: Burn or electrical shock (equipment standing).
  - 101T: Burn or electrical shock (equipment moving).
  - 102: Striking parts of body against equipment while moving about locomotive (equipment standing).
  - 102T: Striking parts of body against equipment while moving about the locomotive (equipment moving).
  - 103: Struck by tools or other falling objects (equipment standing).

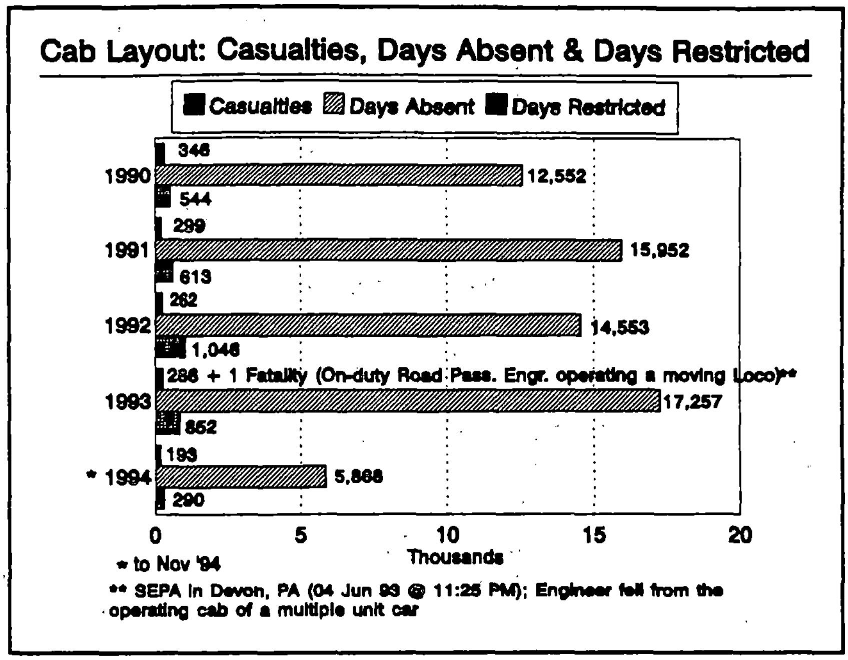

Table 9-2

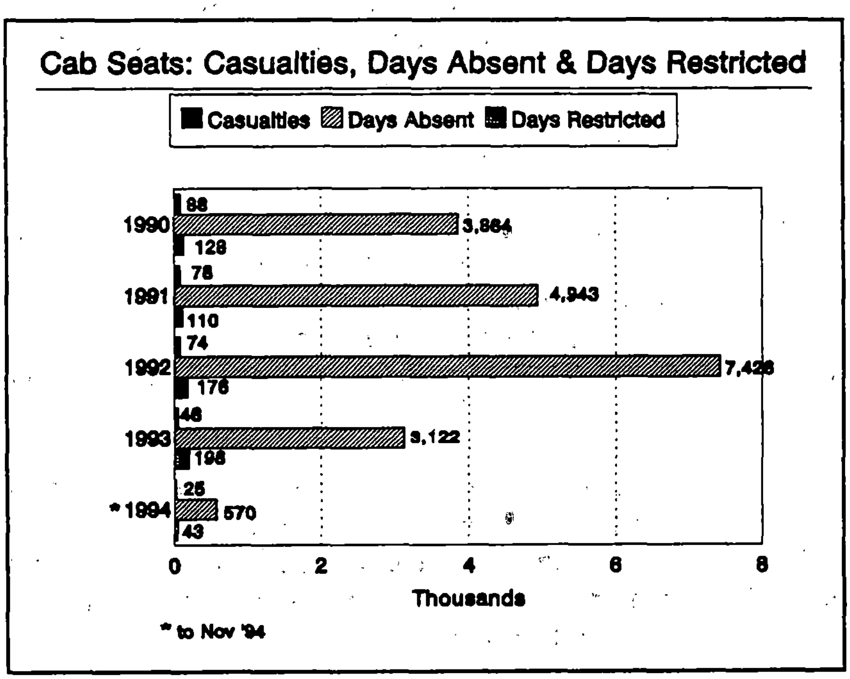

Table 9-3

- 103T: Struck by tools or other falling objects (equipment moving).
- 104: Stumbled, slipped, fell or stepped on foreign object or irregular surface (equipment standing).
- 104T: Stumbled, slipped, fell or stepped on foreign object or irregular surface (equipment moving).
- 119: Other accidents/incidents; operating locomotive (equipment standing).
- 119T: Other accidents/incidents; operating locomotive (equipment moving).
- 914: Opening or closing locomotive doors (equipment standing).
- 914T: Opening or closing locomotive doors (equipment moving).
- 915: Opening or closing locomotive windows (equipment standing).
- 915T: Opening or closing locomotive windows (equipment moving).

o Seats

- 110: Defective locomotive seat (equipment standing).
- 110T: Defective locomotive seat (equipment moving).
- 111: Adjusting locomotive seat (equipment standing).
- 111T: Adjusting locomotive seat (equipment moving).

Human Factors Evaluation of Cab Design

FRA and VNTSC developed a set of human factors engineering guidelines to be used in the design and development of a locomotive cab to improve safety and operator proficiency. The guidelines are intended to serve as a decision-making tool for evaluating current and proposed locomotive designs, and in particular, standards developed by the AAR for defining basic industry requirements in cab design. Selected guidelines resulting from this evaluation are provided in Appendix L.

In developing these guidelines, a review of existing literature was conducted and discussions were held with representatives of the major railroads, locomotive manufacturers, AAR and BLE. Numerous papers, handbooks, reference guides and materials specific to the problems of locomotive cab design and operation were reviewed in this process. To make the guidelines as thorough as possible, technical discussions were held with members of the railroad community to better understand their vision for the locomotive, their needs, and how the locomotive can best be designed.

Until recently, locomotive cab designs evolved without the benefit of human factors support (Gamst, 1975[1]). Crew comfort in the cab compartment trailed that found in passenger compartments and other working environments. Excessive noise (sustained over 85 decibels), ventilation (or the lack thereof), and improper seating are three examples of problem areas that affect the crew.

The locomotive cab provides the primary work environment for the engineer and houses other cab crew. While the work requirement of tasks executed in the cab has to be met, there are also requirements that apply for the long-term housing of crews under widely varying environmental conditions. In the design of the locomotive and its control, size considerations of potential users have to be met to ensure that individuals of varying stature can operate and control the locomotive while being able to view through the windows. The 95th percentile male dimensions are used to set clearances, and the 5th percentile dimensions are used to set reach envelopes. With the growing number of female crew members, the 50th percentile female measurements are often used in lieu of the 5th percentile male dimensions for these design considerations. Accommodation of a wider range of sizes is encouraged, but implementation may exceed the point of diminishing returns with respect to the cost expended.

Hazards should be designed out of the configuration during the initial stages of development. The "clean cab" concept emphasizes avoiding protruding parts and sharp edges that can cause injury when they are struck. When practical, the cab should be designed with shock absorbing surfaces to prevent injury should the crew strike the interior of the cab. Wilde and Stinson (1978) note the contribution that the floor makes to injuries. Elimination of tripping hazards caused by changes in the floor level, and use of a surface that provides traction even if shoe soles are oily, are considerations.

The reasonable comfort requirements of the cab crew have to be addressed to ensure the focus of the crew is on the safe operation of the train. The need for water, luggage/food storage, toilet facilities, and other conveniences are reasonable expectations. Aesthetic needs and cleanliness are other areas that need attention. The railroad industry has a tradition of austere working conditions.

Provided as guidelines in Appendix L, concerns for incorporating new information technology into the locomotive revolve around the interface with which the locomotive engineer will interact to receive information and control train movements. In the past, this interface consisted of electro-mechanical dials, gauges, levers, and control knobs found in conventional control stands. This interface is being replaced with workstations that incorporate computer displays and controls utilizing keyboards. The following provides several brief guidelines:

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[1] "Human Factors Guidelines for Evaluation of the Locomotive Cab," prepared by Jordan Multer, Robert Rudich, and Kevin Yearwood, U.S. Department of Transportation, Research and Special Programs Administration, John A. Volpe, Volpe National Transportation Systems Center, Cambridge, MA 02142

- o A display or visual target should be placed within a viewing angle between 5 degrees above the horizontal plane and 30 degrees below the horizontal plane in establishing the height of the seat in relationship to the windows and the visual displays in the cab.
- o The primary displays and controls should be placed so that the engineer may view them without changing eye or head position from the normal line of sight.
- o Controls and displays of secondary importance may be located so that eye movements are necessary, but head movements are not.
- o Non-critical displays and controls may be located outside the normal line of sight.
- o Consider the use of angled work surfaces when there are many controls and displays to arrange in the workstation.
- o Place controls on an angled surface to allow placement of a greater number of controls within easy reach.
- o The movement of the control (e.g. left, right, up, down, clockwise, counter clockwise) should be consistent with the movement shown on the display or with system response.
- o Control size and spacing should permit the engineer to operate the controls without accidentally activating neighboring controls.

Miscellaneous Cab Design Observations

Many carriers have removed water coolers and use disposable, 8-ounce water bottles that are stored in portable ice chests. The survey inspections showed the overall cleanliness of the ice chests to be severely deficient, resulting in inadequate sanitary conditions for water and food storage. There are different types of food storage containers utilized throughout the industry, the most popular and economical being a styrofoam or hard plastic 5- to 10-gallon chest. However, because of the lack of maintenance and sanitary conditions, crews prefer the plastic chest over an expensive electric refrigerator.

A lack of adequate storage compartments for personal belongings, as shown in Figure 9.1, exists in the locomotive. A permanent storage area for luggage and supplies (refrigerator, water cooler, locker for water bottles, etc.) is needed. Unsecured items present a potential tripping hazard during operation, and can turn into dangerous flying debris during a collision or emergency braking operations. Sharp objects, such as the hangers for clothes, must be designed to prevent injuries in the event of an accident.

Figure 9.1. Crew's Luggage in Cab

Inoperative or improperly adjusted window wipers are frequently found aboard locomotives. Most cab lights are not shielded, and create a distraction at night. Unshielded cab order lights create a glare on the windows, making it difficult to see. The optional sun visors are not well maintained.

Cab Seat

A variety of cab seats are used in the cabs. Figure 9.2 illustrates that in one instance, a brakeman had to resort to using an old bucket as a seat. The Jagger seat is the most commonly installed seat aboard locomotives. Figure 9.3 shows a Jaggar Seat with a round button, without armrests or adjustment capability. Several varieties of the Jaggar Seat can be obtained, from a bottom round cushion without arms or back rest, to an "easy chair" type seat with a high back and adjustable armrests. Based upon limited interviews with the crews, the most preferred seat is the USSC Group's Model 9010, which is equipped with a lumbar adjustment, adjustable arms, and back recliner with spring loaded adjustment for easy adjustment. Most cab seats are mounted to a guide rail on the side wall of the cab. This arrangement is designed to allow the seat to be adjusted horizontally, forwards, and backwards.

It is very difficult, and sometimes impossible to make seating position adjustments. Most carriers are addressing this issue of poor seating, and are trying to (1) upgrade to a more comfortable seat, and (2) isolate the seat from the high levels of vibration that can be experienced. Currently, the individual railroad is responsible for selecting the type of seat to be installed in the locomotive cabs. In the past, some railroads have discussed possible seat type selection with the operating unions, and agreed upon a standard seat. In the purchase of new

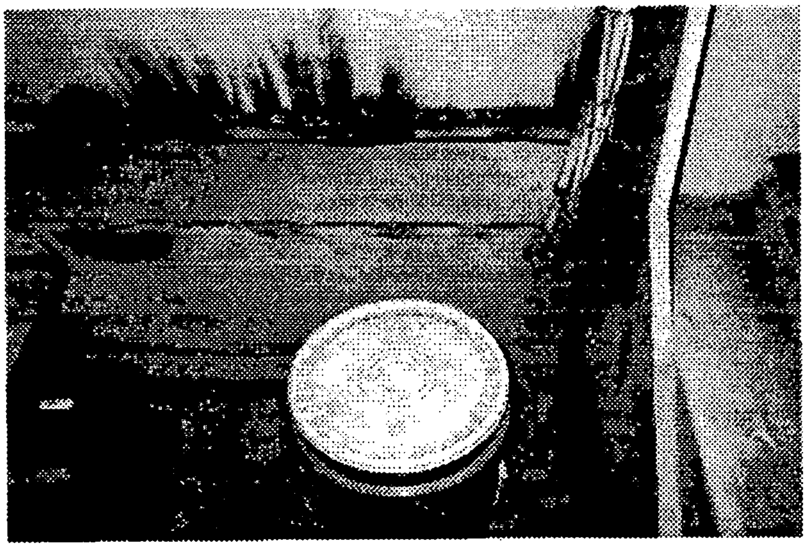

Figure 9.2 Old Bucket Used as a Brakeman's Seat

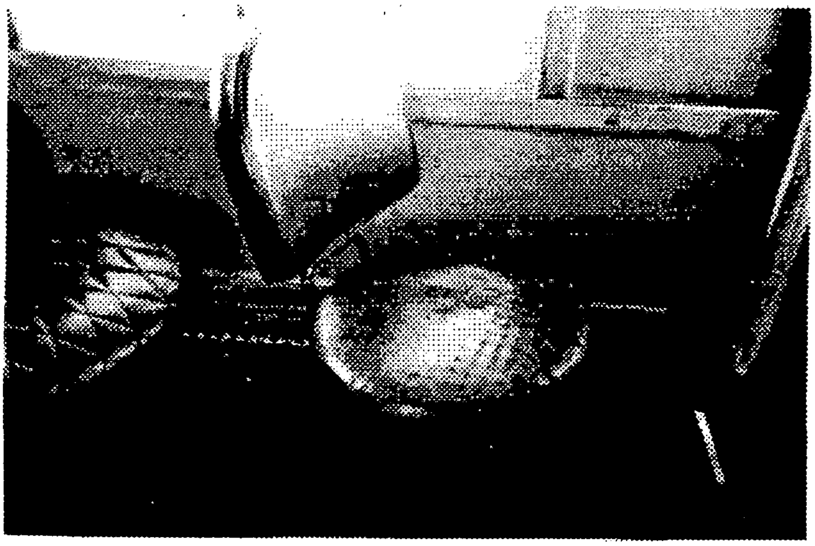

Figure 9.3. Jaggar Seat with Round Bottom, No Armrests/Adjustments

locomotives today, some railroads have permitted their operating unions to decide upon a particular seat design. Currently, Federal guidelines do not cover seat design or installation. Poor seating can cause improper posture, which can lead to lower back pain. In addition, some seat designs can amplify vibrational effects, which can lead to additional concerns as discussed in Chapter 10.

Appendix M provides more detailed information regarding cab seat design concepts for consideration. The concepts presented in the appendix represent a compilation of numerous seat design guidelines garnered from several engineering design references.

In-Cab Refuse Container

Complaints have been received by FRA regarding the trash blowing about the cab and/or lying on the cab floor causing potential safety hazards. Based upon the findings of the survey, the current practice typically consists of attaching an ordinary black garbage bag in a convenient position within the cab.

Colors for Marking Safety Hazards

To ensure the locomotive crew always knows where to look for safety/emergency devices and controls and safety hazards, a standardized color coding design needs to be implemented aboard locomotive cabs. ANSI Standard Z53.1, "Safety Color Code for Marking Physical Hazards" is an example of an appropriate guideline that can be used as guidance for developing such a color coding scheme in the locomotive cab . The colors and appropriate uses are provided in Table 9-4. As a note, this safety color code does not conflict with current railroad color coding.

Conclusions

Based upon the research and information gathered, the basic needs of the locomotive crew seem to directly parallel those of commercial aircraft pilots and interstate truck drivers who must perform similar workplace tasks given comparable constraints. These needs are as follows:

- standardized controls and displays for safe control/operation;
- supportive seats which absorb vibrations and reflect size considerations;
- external viewing capability via clear windows;
- storage for personal articles;
- instrument panel and general cab illumination;
- in-cab permanent refuse container;

TABLE 9-4 PHYSICAL HAZARDS SAFETY COLOR CODE

COLOR	APPROPRIATE USES
Red	• Fire protection equipment • Fire extinguisher • Cans containing flammable liquids (with flash points at/below 86°F) • Stop bars
Orange	• Dangerous parts of machines or energized equipment which may cut, crush, or shock (such as, a starting button)
Yellow	• Possible physical hazards such as being struck, falling, stumbling, tripping or being caught between moving and stationary devices. Yellow and black striping around the hazard is recommended.
Green	• Safety and first-aid equipment
Blue	• Electrical circuit boxes
Purple	• Radiation hazards
Black & White	• Traffic and housekeeping markings

- o standardized cab markings;
- o in-cab hazard avoidance;
- o drinking water/food storage; and
- o cab lighting for safety, the reading of documents, and cab ingress/egress.

The following recommendations are provided addressing identified deficiencies in the locomotive cab layout and design. FRA recommends the initiation of a cooperative effort between FRA, the railroad industry, and labor organizations to resolve the following technical issues:

- o Standardized color coding of safety hazards should be mandatory.
- o Critical safety features such as door handles, safety latches, light switches, etc. should always be illuminated so that they can be located and operated at night.

- o Standard safety devices such as light switches, door handles, fire extinguishers, first-aid boxes, etc., should be located in a designated location where the crew can always expect to find them.

- o Safety signs and signals should be located where the crew is normally looking, and they must not have the potential of being hidden by an object placed in front of them, or by individuals standing in front of them, at a critical moment.

- o Safety devices should operate in a predictable and standardized manner, i.e., one device should not have a switch or handle that moves in one direction, while another similar device has a handle that moves in the opposite direction. The split second required to initiate a corrective action may result in injury.

- o Standardization of crew controls in trains so properly trained individuals can operate any train, any place, any time in the United States. This process would improve performance, quicken response time and lower training costs.

- o The cab should be constructed, to the maximum extent practical, with shock absorbent and flame-resistant materials and rounded edges to minimize personal injuries in the event of an accident and/or fire.

- o FRA and industry should work together to standardize an ergonomic redesign of the entire cab and toilet compartment configuration, including implementation of a vibration and shock absorbing seat and mounting bracket, which is designed to accommodate, as a minimum, the 5th percentile female to the 95th percentile male with the following design characteristics:

  - standardized locomotive controls and placement for ease-of-use, ease-of-learning and ease-of-training;

  - emergency lighting and exits;

  - secure and sealable storage for the crew's personal belongings, water, and food to prevent flying debris in the event of an accident;

  - a secure and sealable garbage container for the locomotive to prevent flying debris and sharp objects from being loose inside the cab;

  - sun visors and/or window shading to facilitate less eye fatigue and better viewing of tracks and signals; and

  - windshield wipers.

- On trains operating at night faced with the problem of reflections on windshields emanating from the lighted instruments and the illuminated structure, the following techniques should be considered:

  - Keep illumination levels no higher than is required to provide adequate viewing.
  - Locate luminaries so that they cannot be seen in the windshield.
  - Use glare shields over instrument panels.
  - Recess instruments that are to be illuminated.
  - Control the slope of the windshield so that reflections do not occur.
  - Use surfaces on structures that prevent reflections on the windshield.
  - Provide continuously controllable illumination at the command of the crew.

- Potential areas for locomotive system-human interface standardization, which will require in-depth technical analysis and thorough ergonomic evaluations, are as follows:

  - cab ingress and egress;
  - control workstations;
  - system compartment access;
  - environmental control; and
  - exterior visibility.

CHAPTER 10

Other Factors Affecting Locomotive Cab Working Conditions

FRA examined locomotive crew exposure to vibration and asbestos. Vibration can cause visual acuity problems and, when significant and/or combined with other factors, physiological effects. FRA conducted a review of open literature on the subject matter, and this chapter provides a summary of the findings.

FRA believes the best way to evaluate cab vibration is to conduct instrumented vibration measurements and studies, evaluate whether new cab designs successfully reduce vibration levels, and—if applicable— develop vibration guidelines.

The two primary locomotive manufacturers stopped using asbestos in their locomotives in the 1970's, and FRA has not identified sources of friable asbestos to which crew members could be exposed. Based on this fact and the small number of earlier vintage locomotives still in use, asbestos is not considered an issue.

In addition to the working conditions addressed in previous chapters, FRA also evaluated two other factors that are not currently covered in FRA regulations, but which can affect the working conditions aboard locomotives—vibration and asbestos. This chapter discusses the source of vibration and asbestos in current locomotives, the health and safety effects associated with their presence, and recommended actions to minimize or eliminate these effects on the performance of the locomotive crew.

Vibration

Vibration—and its associated effects on health, proficiency, and comfort—is inescapable given current locomotive design. The Volpe National Transportation Systems Center (VNTSC) and FRA have identified three major sources of vibration in locomotive cabs[1]:

- o reciprocating equipment (engines, compressors, alternators, superchargers and the like);

[1] "Human Factors Guidelines for Evaluation of the Locomotive Cab," prepared by Jordan Multer, Robert Rudich, and Kevin Yearwood, U.S. Department of Transportation, Research and Special Programs Administration, John A. Volpe, Volpe National Transportation Systems Center, Cambridge, MA 02142

- o suspension system; and
- o irregularities in the track.

Reciprocating engines, along with rotating drive shafts and generators, need only slight imbalances to generate vibrations which are transferred directly to the vehicle body. Engine loading and vehicle speed cause these vibrations to vary in intensity. Engine maintenance and wear can also affect vibration.

Track which is not perfectly level vertically or straight laterally combines with gravity and inertia to create vehicle body accelerations that result in vibration. Relatively sharp changes in track conditions or train velocity typically result in very short duration or individual accelerations, commonly referred to as "jerks".

The train speed control skills of the engineer and the make up of the train have the greatest impact on jerks felt by cab occupants. While both jerks and vibration affect the ride quality felt by cab occupants, jerks are less controllable by locomotive design.

The seat, especially if mounted to the frame, is the primary means through which vibrations are transferred to cab occupants, although vibrating controls or surfaces can affect hands and arms locally. Popular thought (e.g., American Society of Mechanical Engineers) is that incorporation of seat padding reduces the effects of vibration. However, cushioning of the seat can actually amplify or change the frequency of vehicle vibrations, and worsen their effects. The response of a seat to vibration is dependent on numerous factors including the compression properties of seat cushions, the amount of compression, and breakdown from age.

In similar vintage locomotives, train speed is the one of the most significant factors influencing vibration exposure levels[2]. In the past, many attempts have been made to link vibration exposure to specific diseases.

In the case of hand-arm or segmental vibration experienced by the operators of hand-held power tools, such as an asphalt drill, there is an undisputed relationship between vibration exposure and white-finger syndrome.[3]

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[2] "Whole-body Vibration Exposure: A Comprehensive Field Study" by Nibat Özkaya, Bernardus Willems, and David Goldsheyder of the Occupational & Industrial Orthopaedic Center, Hospital for Joint Diseases, Program of Ergonomics and Biomechanics at New York University. Article published in American Industrial Hygiene Association, Dec 1994.

[3] Dupuis, H. and G. Zerlett: The Effects of Whole-body Vibration. New York: Springer-Verlag, 1986.

To date, it has not been possible to link whole-body[4] vibration exposure, such as that experienced by locomotive cab occupants, to a specific disease, and a need exists for additional studies to determine the actual health effects of whole-body vibration exposure.

Review of Existing Vibration Research and Literature

FRA reviewed guidelines published by the widely recognized subject matter experts in the field of vibration, such as, the International Organization for Standardization (ISO) and the U.S. Military.

ISO 2631: Human Exposure to Whole-Body Vibration[5]

ISO 2631 establishes a recommended standard for whole-body vibration. This standard was developed because it is believed that whole-body vibration over a number of years causes physiological and psychological disturbances. Some of the adverse effects resulting from such extended exposure to vibration include low-back pain, early degeneration of the lumbar spine, and herniated disks. To date, ISO 2631 is the most widely used whole-body vibration standard. This standard defines a set of limits for the acceptability of whole-body vibration exposure, with the tolerance decreasing for increasing exposure duration within 24 hours.

Figure 10.1 shows the fatigue-decreased proficiency boundaries for vertical vibration stated in ISO 2631. Each line represents an estimate of the upper limits that people generally can tolerate before the onset of fatigue. Amplitudes of about 10 dB less than those indicated tend to characterize the upper boundary of comfort, and the safe exposure limits are about 6 dB higher than the values shown.

This standard sets exposure limits according to three criteria:

- o health and safety (chronic health problems);
- o working efficiency (fatigue); and
- o preserving comfort.

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[4] Whole-body is defined as "the entire material structure and substance of a human being."

[5] The 1984 version is cited in this report. The latest proposed version of this standard has not yet received international approval and is not addressed in this study; however, it should be noted that the new guidance rejects an approach based on time exposure and a fatigue-decreased proficiency.

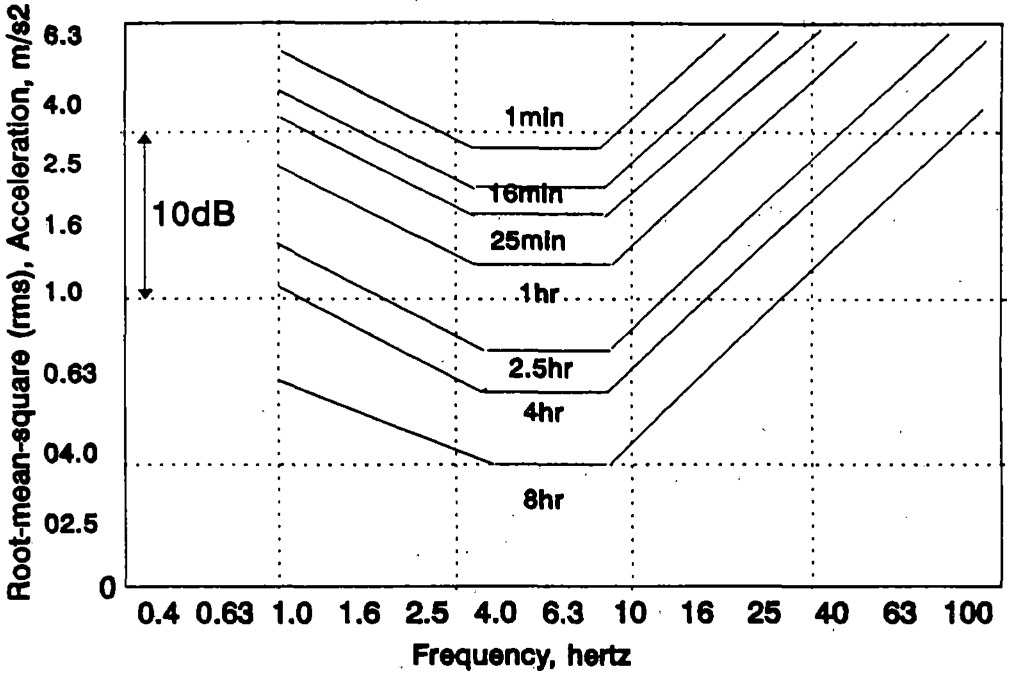

Figure 10.1 ISO Standard 2631: Vertical Vibration Fatigue-Decreased Proficiency Boundaries

U.S. Military: MIL-STD-1472

The U.S. Military has published a complete outline of allowable vibration limits for Army, Navy, Air Force and Marine Corps personnel in MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. MIL-STD-1472, which agrees with the limits set forth in ISO 2631, outlines specific areas of concern with respect to vibration as follows:

- o range of acceptable reverberation time [reverberation time (sec) vs volume of room (m^3)];
- o vibration exposure criteria for longitudinal and transverse directions with respect to body axis [acceleration (rms) vs frequency (Hz)]; and

- o 90 percent motion sickness protection limits for human exposure to very low frequency vibration [RMS Acceleration (m/sec^2) vs center frequency of third-octave band (Hz)].

Vibration Impacts on Operational Issues

Vibration has three potential types of impact: (1) health; (2) proficiency in certain tasks (e.g., tracking and visual acuity); and (3) comfort. There are increasingly restrictive tolerance levels associated with each type. Frequency of the vibration also alters the intensity levels. Muscles are used to overcome vibration effects on the body, and this can produce fatigue and overuse syndromes, depending on the effort expended and length of exposure. Occupant position (standing versus seated) and the direction of the vibration (vertical versus horizontal) are also important factors. In general, the crew is more susceptible to vibration in the seated position and horizontal vibration is slightly more bothersome. Locomotive cab occupants experience low frequency vibrations (200 Hz and below) as a mix of noise and vibration. It is in this range that locomotives have the most intense output, primarily from the engines. In terms of loss of comfort, the human body is most sensitive to vibrations in the 0.1 to 20 Hz range, and especially between 2 and 6 Hz. Locomotive characteristics, engine loading, and track characteristics all affect vibration levels. Operational vibration levels experienced by cab crews have not been evaluated and measured. Detailed studies using instrument testing to measure the vibration levels in the locomotive cab should be completed to justify any need and associated expense for increased vibration control.

<u>**Methods to Reduce Cab Vibration**</u>

Methods used to dampen these vibrations have not changed significantly over time. Engines incorporate mounts that reduce the transmission of vibration to the vehicle body. Locomotive trucks have passive suspension systems to dampen vertical motion, but motions in other directions and from motors are not reduced.

Passive Isolation

Passive isolation is a basic design method utilized to reduce vibration. A prime example of such a passive isolation system is the vehicle/wheel suspension system. The primary benefit of passive isolation is a reduction in amplitude, but a downward shift in frequency can also occur. The isolated cab provides an additional benefit over vehicle suspension. While vehicle suspension only affects vibration from the track and the wheels, isolated cab affects all vibrations from the frame, including those generated by the engines. Additionally, a reduction in cab noise will be observed.

Jankovich (1972) describes two different seat post vibration dampers used by the German and Swiss Railroads which isolate the seat from the frame. While less expensive than cab isolation, a difference in relative vibration between the engineer and the controls and displays can cause problems in some conditions, especially in more severe vibration conditions when the seat damper provides the most comfort benefit. Additionally, use of dampers at the seat post can reduce the vibration exposure to the operator. However, this can create a difference in relative vibration between the operator and the controls and displays. Operation and legibility problems can result if this difference is great enough. Active systems can provide greater vibration control than passive systems and have potential applications to locomotive suspension, cabs, and seat posts.

Active Control

An increased level of vibration reduction effectiveness can be achieved through implementation of active controls. Instead of using inertia and energy dissipation for reduction, this method uses opposing motion to cancel vibration. Active suspension has been discussed to improve rail passenger comfort, and could be similarly applied for locomotive cab crews. Jankovich also describes an active seat post isolation system designed for aviation use. Since passive cab isolation is a "new" option, active cab isolation is not yet being considered, but it could be a possibility in future designs. Active systems involve additional costs, and may require more maintenance resources. Until an accurate assessment of cab vibration is made, the benefits delivered by active systems cannot be adequately judged.

Isolated Cab

Isolated cabs represent a recent design that reduces vibration by limiting vibrations between the frame and the cab structure. Isolated cabs use special mounts to prevent the frame from transmitting vibrations into the cab enclosure. This method complements current noise insulation. Insulation is less effective in dampening low frequencies, and the isolation achieved through the special mounts provides a barrier to low frequency transfer. Limiting vibrations can also reduce the sympathetic vibration of loose components in the cab that sometimes produce internal noise. However, normal service wear and the loosening of fasteners often causes these reduction methods to lose effectiveness over time.

Locomotive Manufacturer's Vibration Efforts

Manufacturers currently measure cab vibrations as a quality control step. However, this measurement appears to be limited in scope and does not reflect operational conditions or human factors concerns. For example, EMD measures only vertical vibrations, both GE and EMD perform only static tests, vibrations below 10 Hz are not included in the evaluations, and the manufacturer's acceptance cutoff levels are near the threshold for uncomfortable ride quality. Additionally, static testing is based on the premise that the suspension eliminates track induced vibration.

Riley, et al. (1991)[6] describe the vibration levels in the EMD SD-60M locomotive. Increased vibration occurred when the locomotive was moving and when the engine loading was increased. An upward shift in frequency also accompanied these intensity changes. Therefore, current measurement does not seem to accurately reflect operational vibration conditions. With acceptance limits near discomfiting ride levels for static testing, Riley's subjective descriptions of increased vibration during motion indicate that acceptable ride quality levels may be exceeded during operation. Riley also received comments from crews that cab vibrations are a source of fatigue.

Vibration Effects on Humans

Body Effects

The body is most sensitive to vibration in the 2 to 20 Hz range, especially the 2 to 6 Hz range. The body reacts differently to various vibration frequencies by resonating according to the frequency and the specific body part affected. Up to 2 Hz, the body acts as a single mass. As frequency rises, various organs and body parts have individual resonances which cause them to be more affected than the rest of the body. For example, the arms, abdomen, and legs (when seated) resonate at about 4.5 Hz and the head resonates in the 20 to 30 Hz range. The relative motions of body parts caused by vibration are discomforting, and cause a person to tense muscles to combat the vibration. This tensing causes muscle fatigue and possible overuse conditions after just 10 minutes.

Direction of vibration and posture also contribute to the effects felt by the body. For instance, the rigidity of the spine reduces relative body part motion in the horizontal plane, but lowers the resonant frequency. This can allow the horizontal motion to be in different phases, such as the head moving forward while the hips move backward at one instant—and visa versa the next—causing the use of muscular effort to add more rigidity. However, in the case of vertical vibration, compressibility of the spinal disks allows stretching and compression of the spine which provides some damping, but causes wear. Differences in posture also change the body's response to vibration. Sitting erect gives the body its highest resonant frequency and provides the least natural damping force. It also removes the damping capacity of the legs, and transmits vibration directly to the trunk from the seat surface.

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[6] Riley, M.W., Stentz, T.L., Moore B., McMullin, D., and Glismann, C. (1991). SD-60M *Locomotive American Wide-cab Ergonomics Study. Final Report and Study.* Lincoln, NE: Burlington Northern Railroad.

Health Impacts

Both Jankovich (1972)[7] and Wilde and Stinson (1980)[8] describe possible health impacts of vibration with references from other reports. Much of the evidence presented is anecdotal, and concludes that in most instances, vibration may be a contributor but not the sole cause of health problems. One "illness" caused by vibration is motion sickness. Motion sickness is induced by very low vibration frequencies (0.1 to 0.5 Hz), with the effects increased by exposure time. Other problems attributed to vibration include gastrointestinal pains, backaches, spinal degeneration, and leg numbness. In the case of back problems, vibration may worsen the shearing forces on spinal disks occurring as a result of poor seating posture, as well as the mechanical wear from the vertical damping action. Wilde and Stinson (1980) note that a relaxed and slumped sitting posture increases the body's damping factor, particularly for head vibrations. Thus, a response to lessen the immediate discomfort of vibration may set the stage for more chronic problems caused by poor seating posture.

The more severe health effects listed above are typically associated with very high levels of vibration experienced over extended periods of time. Even then, a direct connection between vibration and health effects has not been positively established. However, until it can be proven that vibration has no pathological effects, a conservative approach should be taken to address locomotive cab occupants and their exposure to vibration.

Physiological Effects of Vibrations[9]

Evidence suggests that short-term exposure to vibration causes only very small physiological effects which are of little practical significance. A slight degree of hyperventilation has been reported, and increases in heart rate are found during the early periods of exposure. The elevated heart rate appears to be an anticipatory general stress response. No significant changes are found in blood chemistry or endocrine chemical composition.

The physiological effects of long-term exposure to whole-body vibration are not clear. Most of the evidence is based on epidemiological investigations of truck drivers and heavy-equipment operators. These workers have disproportional incidences of lumbar spinal disorders, hemorrhoids, hernias, and digestive and urinary problems. However, it is difficult

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[7] Jankovich, J. (1972). *Human Factors Survey of Locomotive Cabs*. FRA-OPP-73-1. U.S. Department of Transportation, Federal Railroad Administration.

[8] Wilde, G.J.S. and Stinson, J.F. (1980). (i) *Human Factors Considerations in Locomotive Cab Design*. Ontario: Canadian Institute of Guided Ground Transport, Queen's Institute of Guided Ground Transport, Queen's University at Kingston, Report No. 80-9. (ii) "Injuries in Locomotive Cabs" Journal of Safety Research Vol, 12 (4), pp. 179-184.

[9] Human Factors in Engineering and Design, Fifth Edition; Ernest J. McCormick & Mark Sanders, 1982

to positively attribute these health problems directly to the effects of vibration, as there are a number of other factors—including sitting for extended periods of time and loading and unloading vehicles—which may also contribute to the above conditions.

Visual Acuity

The level of visual acuity and certain visual tracking tasks can be affected by vibration. Relative motion resulting from vibration causes the retinal image to move more than the brain can compensate for, and results in blurring. This effect varies with the frequency, amplitude, and direction of vibration, viewing distance, viewing angle, object size, nature of the visual task, and illumination. Because of the multitude of parameters listed above, it is difficult to predict results for specific situations. The large visual component of the engineer's task, along with the increasing introduction of electronic displays in locomotive cabs makes this a concern in current and future cab designs.

Comfort Level

Vibration levels have a direct impact on the comfort level of cab occupants. Frequency and strength, measured in acceleration or displacement, of the vibration are the critical factors in evaluating the level of discomfort felt. People typically tense muscles to dampen the vibration and/or assume a posture that reduces the vibration effects (e.g., stand or slump while seated). Over an extended period of time during a work shift, this results in muscle fatigue which adds to vibration discomfort. When experienced over a period of days or weeks, the fatigue can develop into a more persistent ache or worse.

Conclusions

FRA did not conduct instrumented vibration testing of locomotive cab compartments as part of this report. Instead, FRA examined existing standards and guidelines adopted by other organizations regarding the definition of acceptable vibration exposure limits, vibrational effects studies performed on similar occupational groups subject to a comparable working environment, and current efforts by locomotive manufacturers to control vibration. The knowledge base correlating vibrational effects to health, safety, and performance deterioration is very limited, especially in the railroad industry. However, it is generally acknowledged that a high vibration environment has a negative effect on human performance and health. Given the above, it is recommended that FRA and the rail industry initiate a cooperative program to accomplish the following recommendations concerning vibration effects in locomotive cabs:

- o conduct vibration measurements and studies[10];
- o determine whether vibration may physiologically and/or psychologically harm the locomotive crew over an extended period of time;
- o evaluate whether new cab designs successfully address reduced vibration levels in locomotive cabs; and
- o develop applicable vibration guidelines.

Asbestos

Review of Existing Asbestos Research and Literature[11]

Asbestos is a filamentous mineral useful because of its resistance to heat. Its primary use earlier in this century was as an insulating material, but in more recent years it has found widespread use in a number of other industries.

When asbestos is inhaled and deposited in the alveoli[12], it is ingested by macrophages[13], and via mechanisms that are not currently clear, lead to the development of diffuse lung damage and the formation of fibrosis. Asbestos can lead to the development of a malignant tumor of the lining of the chest cavity and lung surface called mesothelioma, and, in association with cigarette smoking, can lead to an increased incidence of bronchogenic carcinoma.

The diagnosis of asbestosis depends upon a well-documented history of exposure, an accurate estimate of the degree of exposure, and a characteristic clinical picture. The patterns of impairment seen with asbestos exposure usually take 20 to 40 years to develop. There is evidence that lower exposure can lead to the development of mesothelioma. Individuals who develop moderate to severe degrees of asbestosis have a poor prognosis, and those who

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[10] Measurements of operational vibrations on all three axes, including those in the 1 to 10 Hz range, are needed to determine actual vibration conditions in the cab. Once these levels are known, the need and potential benefit of more extensive—and expensive—control can be determined.

[11] Industrial Toxicology: Safety and Health Applications in the Workplace; Edited by Phillip L. Williams & James L. Burson, 1985

[12] Alveoli is an air sac of the lungs at the termination of a bronchiole.

[13] Macrophage is a large phagocytic cell of the reticuloendothelial system.

develop malignant mesothelioma have an exceedingly poor outlook in that mesothelioma cannot be removed surgically, nor is it amenable to irradiation therapy or chemotherapy. The outlook for those individuals who develop associated bronchogenic carcinoma is the same for those who develop lung cancer and who have not been exposed to asbestos—that is, the 5-year survival rate is about 5 to 10 percent.

The long-term health consequences of this exposure are unknown. It is highly unlikely that this small degree of exposure could lead to the development of the interstitial fibrotic pattern of impairment, but there is a possibility that such exposure could lead to an increased incidence of mesothelioma and, in smokers, to an increased incidence of bronchogenic carcinoma.

OSHA: Final Asbestos Rules[14]

In the August 10, 1994 Federal Register, OSHA published final regulations to protect workers from exposure to asbestos. The rules, which cover four million workers and are estimated to cost $361.2 million annually, went into effect on October 11, 1994. This OSHA rule applies to railroad operating employees.

At a press conference at OSHA headquarters, Assistant Secretary of Labor (OSHA), Joseph A. Dear said the rules will ensure effective long-term management of asbestos. OSHA has reduced the permissible exposure limit (PEL) from 0.2 fibers per cubic centimeter of air as an 8-hour time-weighted average to 0.1 fibers per cubic centimeter.

Asbestos in the Locomotive Cab

When steam generators were used on locomotives in passenger service, asbestos cement was used to insulate the heater coils to prevent loss of heat and contain the fire. Whenever the steam generator was disassembled and the coils had to be removed, the asbestos cement was broken up and removed, releasing asbestos particles which could be inhaled into the lungs. This source of asbestos was eliminated in the 1970's, when the head end power system was developed for the heating of passenger trains with electricity.

GE and EMD, the two primary manufacturers of current locomotives, made the following statements regarding asbestos in their locomotives:

- GE[15] stated that asbestos has not been permitted in any facet of their locomotive production since October 1979. In addition, GE stated that there is no record of asbestos ever being used in the cab environment of its

[14] Occupational Hazards, Sept 1994, OSHA: Final Asbestos Rule Covers 4 Million Workers

[15] Mr. R. Shults, Manager-Product & Environment Impact, General Electric Company (GE)

locomotives. Further, GE informed each of their outside suppliers in mid-1987 that all sub-assemblies provided for the production of locomotives must be free of asbestos.

- EMD[16] stated that of their 12 specifications for sound and thermal insulation applications, only one contained asbestos as a filler with a resin bonded fiberglass and only fiberglass was used as a loose insulating material. An EMD service bulletin was issued on April 6, 1984, prohibiting the use of asbestos for any purpose in locomotive construction. This restriction also is applied to outside contractors supplying sub-assemblies for the production of locomotives. In the 1970's, EMD began to curtail the use of asbestos in locomotive construction depending upon the location. EMD had identified 60 pages of part numbers which contained asbestos in some form in previous locomotive construction; however, these parts have been discontinued.

Conclusions

FRA has reviewed literature outlining the known health and safety effects of asbestos exposure, and contacted representatives from both primary locomotive manufacturers regarding the present and past use of asbestos in the construction of locomotives. While previous locomotive design incorporated the use of asbestos, and older locomotives remaining in service may still contain limited amounts of asbestos, there is no evidence that the presence of asbestos poses a problem to humans or the environment. The use of asbestos in locomotive production was terminated many years ago, and both primary manufacturers currently have policy statements prohibiting the use of asbestos in locomotive construction. Based on the above, FRA does not feel that further action with respect to the presence of asbestos in locomotive cabs is warranted at this time.

[16] Mr. Widdman, Electro Motive Division (EMD)

CHAPTER 11

Effect of Cab Working Conditions on Locomotive Productivity

> *Extensive research, drawing on the fields of medicine and ergonomics, has established that conditions in the work environment are important to an individual's comfort, health, and ability to maintain and improve job performance. In performing their duties, the locomotive crew can be exposed to noise and vibrations, poor air quality, and changes in ambient air temperature and humidity. If any one, or combination of these environmental factors exceeds a level of reasonable human tolerance, the engineer's job performance and locomotive productivity may be adversely affected. Quantitative measures of this effect are not currently available.*

Section 10 of the Rail Safety Enforcement and Review Act of 1992 specifically required an assessment of the effects of environmental, sanitary, and other working conditions on productivity, health, and safe operation of the locomotive. This chapter addresses the effect of environmental conditions on individual performance and, by inference, the productivity of the locomotive.

The locomotive engineer is responsible for ensuring safe and efficient transportation of passengers and goods over the Nation's railways. The job requires constant attention to train operation, in a setting of operating complexities that vary with terrain and the length and weight of the train. Expert job performance assures safe passage while minimizing the risk of financial liabilities from derailments and collisions. In addition, a highly skilled locomotive engineer helps control railroad operating cost and contributes to productivity by being attentive to engine throttling and braking, dispatcher's instructions, and surrounding conditions that might affect operations.

Extensive research, drawing on the fields of medicine and ergonomics, has established that conditions in the work environment are important to an individual's comfort, health and ability to maintain and improve job performance. In performing his duties, the locomotive engineer is exposed to a variety of sounds and vibrations, the effects of engine exhaust on air quality, and changes in ambient air temperature and humidity. If any one, or combination of these environmental factors exceeds a level of reasonable human tolerance, the engineer's job performance and locomotive productivity may be adversely affected.

Assumptions Underlying Evaluation

Productivity is a measure of the efficiency with which resources are used, customarily expressed as the ratio of output to inputs used in the production process. Measurement of the direct, separable effect of environmental conditions on locomotive productivity, however, is extremely difficult, and perhaps impossible with existing analytical tools. Railroads use a number of indicators to gauge locomotive productivity, such as fuel consumed per horsepower hour, or revenue per horsepower mile. Neither of these yardsticks, nor others considered, are sufficiently sensitive to the effects of varying levels of noise, temperature and humidity, and air quality to measure any associated changes in output. Consequently, an indirect, more qualitative approach is employed to assess the probable effects of environmental conditions on locomotive productivity.

The working assumption adopted is that output, however measured, is constant, and that changes in the productivity ratio, whatever its value, are due entirely to improved or deteriorating efficiency in the use of resource inputs to the production process. The job performance of the locomotive engineer, as noted, is an important resource input. If environmental conditions in the locomotive cab adversely affect engineer performance, efficiency deteriorates, leading to a presumed though unquantifiable decline in locomotive productivity.

Evaluation

The linkage of environmental factors to productivity is partly through the fatigue-inducing effects of relatively severe, persistent levels of noise, temperature and humidity, and air pollution on the engineer's performance. Hours of service and diurnal tests, conducted with the FRA locomotive simulator, have shown that as fatigue progresses it causes observable changes in the frequency of safety and operating rules violations and deterioration in overall train handling. In the simulator tests, the parameters used for noise levels were moderate, for temperature and humidity comfortable, and for air quality excellent. Research on the workplace environment has shown that elevated levels of these factors can hasten the onset and increase the severity of fatigue.

FRA's field tests collected data on noise levels, temperature and humidity, and air quality from a varying number of locomotives and the season of the year. The locomotives tested, however, do not constitute a representative sample drawn randomly from the universe of locomotives; therefore, statistically valid inferences to the locomotive population cannot be made. By design, some locomotives were tested in environments considered to represent "worst case" conditions. For example, summertime temperature and humidity was tested in locomotives operating across southern and southwestern states, and air quality in the long Cascade tunnel in Washington state. FRA reasoned that if environmental conditions were found tolerable under worst case conditions, reasonable inferences could be made regarding locomotives operating under less onerous circumstances.

The balance of this section relates the findings of FRA's field testing to the threshold levels of environmental factors that mark the onset of fatigue. The thresholds are generally higher than the "optimal" level, since efficiency can be maintained with a moderate amount of additional effort. For some environmental factors, threshold levels are established in the literature, for others inferences must be made relative to higher, health damaging levels.

Noise Levels

An engineer is subjected to a variety of sounds associated with locomotive operation as well as radio and horn sounds, often in some combination. To protect workers from possible hearing loss, OSHA and FRA regulations specify an average of 90 dB(A), or less, as the acceptable standard for noise level exposure over a period of eight hours.[1] However, research on the physical effects of noise in the workplace suggests that a lower level of exposure, averaging 85 dB(A) over eight hours, may represent the threshold for commencement of fatigue and increasing problems with radio and face-to-face communication.[2]

To the extent the locomotives tested are representative of the locomotive fleet, the findings suggest that high levels of noise could be impairing the efficiency of engineers on over 25 percent of the trains operated, indicating a probable shortfall in locomotive productivity.

Temperature and Humidity[3]

While the ability to tolerate stress caused by conditions that are either too hot or too cold varies according to the individual, the body's physical and mental functions tend to endure cold to a greater extent than heat. In all situations, the body's circulatory system works to maintain a core temperature close to 98.6°F. If an engineer's body has to choose between overheating and continuing to perform physical work, it will choose to maintain core temperature, causing deterioration in the engineer's job performance.

The principal variables contributing to heat stress are ambient air temperature, relative humidity, and air flow, working in combination. Given a specified air flow, higher temperatures can be tolerated if humidity is low and lower temperatures if humidity is high.

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[1] A decibel (dB) is the unit commonly used to express the sound pressure level. It is equal to the logarithm of the ratio of the intensity of the sound to the intensity of an arbitrarily chosen standard sound. The abbreviation dB(A) means A-weighting of the sound with certain frequencies filtered out. A-weighted sound levels more accurately reflect frequency response of the human ear.

[2] NASA Standard-3000, Volume 1, Rev. A, p.5-44 through 5-47; National Aeronautics and Space Administration. *Transport Noise Reference Book*; Paul Nelson, Editor, pp.1/5-1/6; 1987.

[3] This section addresses the results of FRA's Summer Test Program, where high ambient temperatures were registered. FRA's testing of 204 locomotive cabs in its Fall/Winter Test Program found only one instance of an ambient temperature reading lower than the 50°F standard required by FRA regulations for locomotive cabs.

For this report, two indices are used to measure these effects: Effective temperature (ET) and the Wet Bulb Globe Temperature (WBGT), both expressed in degrees fahrenheit.[4]

Of the seven locomotives tested using the WBGT, all registered readings lower than the 86°F WBGT threshold for the onset of fatigue, including two that were equipped with A/C.[5] The ET's calculated for the eight tests where temperature and humidity were provided indicate that five locomotives exceeded the 80°F ET threshold, with readings ranging from 81°F ET to 89°F ET. As for the 13 tests where only temperature was measured, readings were among the highest of all the locomotives tested. For example, in one 6-hour run, from Yuma to Tucson, Arizona, the temperature inside the locomotive cab averaged 115°F. Even using a comfortable humidity assumption of 40 percent, and still air, the ET calculation would reach 96°F ET for this locomotive run.

Clearly, for some locomotives in some parts of the country, heat stress adversely affects the efficiency of the engineer. However, the extent of the problem is not clear from the data. The disparity between the poor results for calculated ET's, where relatively still air was assumed, and the positive results produced by the WBGT, where actual air flow was accounted for, suggests that the ET measures are overstated. While no firm conclusion can be drawn about the extent of adverse effects on locomotive productivity, it should be remembered that the fatigue thresholds used are higher than the levels established for a comfortable work environment that fosters optimal individual productivity.

Air Quality

The air breathed by an engineer contains various contaminants produced by locomotive operation. Hydrocarbon carbon vapors, combustion gases and particulate matter, generated by the burning of diesel fuel and engine braking, are the primary source of potential health damage. OSHA's permissible exposure limits (PELS) and American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) establish the maximum 8-hour exposure levels for these contaminants that can be tolerated without inducing adverse health effects. Persistent exposure to a contamination level lower than these limits, however, can cause eye and throat irritation as well as transient reductions in lung capacity and mental acuity, all of which lead to fatigue and deteriorating engineer efficiency.

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[4] The ET index is a weighted measure of ambient air temperature, humidity, and air flow; WBGT, considered the superior measure, is an algebraic approximation of ET, with the advantage that a direct measure of air flow is unnecessary.

[5] In 2 of the locomotives the crews experienced 1 hour of exposure above the threshold, however, average readings for the locomotive run averaged 84.5°F in one cab and 83.5°F in the other.

The engineer's performance in the lead locomotive is not materially affected by conditions in the trailing unit; based on the test results, therefore, the conclusion is that the engineer's health is not adversely affected by air quality in the locomotive cab. Lower, fatigue-inducing contaminant levels, however, are not well established in the research literature and a similar firm conclusion respecting effects on engineer performance cannot be made. Nevertheless, it can be inferred from the very low levels of contaminants found relative to permissible health limits that air quality in the locomotive cab is unlikely to cause a reduction in the engineer's efficiency and locomotive productivity.

Summary

The discussion and analysis has illustrated that elevated levels of noise, temperature and humidity and poor air quality can produce and hasten the onset of fatigue in the work place and affect worker performance. This is also true for the locomotive engineer, who can face relatively severe and persistent levels of any one or a combination of these conditions.

FRA research[6] has shown that as locomotive engineer fatigue increases it manifests itself in a greater frequency of safety and operating rules violations, and deterioration of overall train handling. As a consequence, locomotive productivity declines. However, determining the direct separable and quantitative effects that environmental conditions can have on locomotive productivity is extremely difficult and perhaps impossible.

While FRA has examined the existence of extreme environmental conditions in the locomotive cab, it is difficult to say how pervasive and how frequent those conditions can be found. There is a link, however, between elevated environmental conditions, fatigue, and worker performance, which leads to a decline in productivity.

Each factor is discussed separately. The overall exposure to these factors occurs simultaneously and the potential interactions are numerous.

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[6] U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, "Workload, Stress and Fatigue in Railroad Operations," Garold Thomas, Thomas Raslear, and George Kuehn, 29 June 1995

CHAPTER 12

Findings and Implementation Strategy

> *FRA believes railroad safety will be best served by having regulatory action that is founded on consensus among those who are benefitted and/or burdened by the agency's regulation. The actions are divided into one of three categories for each key area:*
>
> o *initiate rulemaking to either adopt new standard or revise existing standard;*
>
> o *work with industry to develop design/performance guidelines; or*
>
> o *take no action.*

Broad Implementation Strategy

The Rail Safety Enforcement and Review Act mandated that FRA conduct a proceeding to determine the need for action on locomotive crashworthiness and working conditions. This mandate followed frequent expressions of concern by employee organizations and recommendations of the National Transportation Safety Board.

FRA has conducted a detailed research and analysis program as described in the preceding chapters, and conducted field examinations and inspections in an effort to determine the benefits and, where available, the direct costs[1] of each crashworthiness feature or working condition improvement identified in the Act. Based on information obtained through these efforts, FRA identified the following general options for actions with respect to each individual area:

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[1]This report does not include a detailed, economic cost-benefit analysis for each identified alternative. Such analysis necessarily includes a quantified evaluation of the predicted cost savings based on expected decreases in future losses when compared to a historical review of accidents involving locomotives not equipped with advanced crashworthiness protection systems. As such, this report does not present a thorough examination of the "total" costs associated with implementation of a particular crashworthiness feature. Rather, the costs presented indicate only the costs associated with the physical construction and/or implementation of that feature onto an existing locomotive, and should not be misconstrued to provide an evaluation of the economic feasibility of implementing the particular crashworthiness feature.

- o initiate rulemaking to adopt new standards or revise existing standards;

- o cooperate with industry to develop private design or performance guidelines; or

- o recommend no action be taken.

During the same period that this study has been concluded, FRA has conducted outreach sessions and has reviewed its regulatory program under the President's Regulatory Reinvention Initiative and the National Performance Review. FRA concluded that railroad safety will be best served if the agency moves from a traditional "hear and decide" regulatory paradigm to a new paradigm that is founded on consensus among those who benefit from, and are burdened by, the agency's regulations.

Implicit in this "paradigm shift" is the concept that decisions regarding the best approach to resolution of safety issues should be made with the full participation of all affected parties. Although FRA has included affected parties in the factfinding portion of this report and has invited comment on the engineering research reported within these covers, this document is a status report regarding an ongoing activity. Accordingly, it contains some information and analysis not previously shared with interested parties. Dissemination of this report will set the stage for further conversation that will inform public and private actions over the next few years.

In order to promote productive conversation among interested persons, FRA has sought to avoid unilateral declarations that might create polarization and chill dialogue regarding appropriate options. However, where our study findings indicate that particular measures are clearly impractical or ineffective, we have so indicated. By separating potentially helpful ideas from those that will not bear close scrutiny, we seek to focus future discussions on those measures that offer real promise for risk reduction.

As the agency leads the affected parties into a period of more intensive collaboration on the topics identified as worthy of further effort, we will be guided by principles such as the following:

Regulatory action is generally a preferred alternative for measures that:

- o have a direct, well-established safety or health benefit;

- o are technically practical and economically feasible to implement;

- o require Federal action in order to ensure uniform and consistent implementation; and

- o have a strong potential for a favorable benefit-to-cost ratio.

Private design or performance guidelines, facilitated by FRA but privately adopted, are generally a more appropriate means of advancing safety when the measures involved:

- o will be uniformly and consistently implemented through private action;
- o have a probable safety or health benefit complemented by other, non-safety benefits; and
- o are technically practical and economically feasible to implement.

Private guidelines address safety or health concerns while allowing railroads and locomotive builders more flexibility than regulations. Guidelines can be put in place more quickly than regulations, are easier changed to keep pace with technology, and impose less perceived burden on industry, maintaining more favorable working relationships for future undertakings.

Where private sector action is determined to be the appropriate approach, FRA will seek to advance a coordinated industry effort to generate best practices for locomotive crashworthiness and a cab working environment conducive to safe operation of the locomotive. FRA is confident that a genuine cooperative effort with the industry will accomplish these objectives.

FRA will then monitor the progress of the voluntary actions implemented by the industry and assess their effectiveness. If voluntary industry actions are not sufficient, additional measures to achieve improvements may be necessary.

Some of ideas examined for this report lacked initial merit or were subject to major disadvantages. FRA recommends taking no action on those features or improvements that:

- o lack a strong link to a safety or health benefit; or
- o are not technically practical and/or economically feasible to implement.

However, the industry is urged to examine options which will provide partial improvement in these areas where possible. Private actions to include cab working conditions may be strongly warranted where improvements in productivity can be achieved, even if quantification of those improvements is difficult.

Locomotive Crashworthiness Feature Implementation

Partnership Opportunities

The technical investigation and evaluation conducted following numerous collisions and derailments, and the research and analysis done in response to the Act, indicate that the following locomotive crashworthiness features warrant examination for further improvements:

- o collision post strength;
- o corner post strength;
- o anticlimber design;
- o fuel tank design;
- o glazing requirements; and
- o other features, such as, emergency lighting provisions, optimal egress and sealed cabs.

FRA found that AAR Specification S-580 represents a significant advance in safety and that freight locomotives being built today significantly exceed the S-580 minimum criteria. Further attention to collision post strength, corner post strength, anticlimber performance and sealed cabs offer promise of additional improvements in safety at modest cost in initial investment and marginal weight. However, in order to realize these benefits it would be necessary to develop an integrated strategy that ensures the preservation of a viable crash refuge and to determine if crew members can be persuaded to utilize such a refuge in the critical decision period prior to impact.

Any such strategy must include attention to fuel tank integrity. If a significant reduction in loss of fuel can be achieved, collisions will be more survivable and crew members will be more likely to take advantage of a crash refuge. Reduced costs of environmental cleanup following derailments would constitute an important secondary benefit.

Although not mentioned in the Act, the design approach known as crash energy management could be incorporated into measures intended to preserve a viable crash refuge. Crash energy management seeks to control or mitigate the crash pulse experienced by a vehicle occupant in the event of a collision or other rapid deceleration of the vehicle. To make a collision of a locomotive survivable, two design features are required: (1) the spaces occupied by people must be strong enough to not collapse, crushing the people; and (2) the initial deceleration of the people must be limited so they are not thrown against the interior of the train with great force. The first of these objectives is addressed by requirements currently contained in 49 CFR section 229.141 and the locomotive crashworthiness features discussed in this report. Achieving the second of these general objectives is the more challenging and requires technology that is just starting to be developed for locomotives.

Crash energy management is a design technique whereby unoccupied spaces are intentionally designed to be slightly weaker than occupied spaces. This is done so that during a collision the unoccupied spaces will deform before the occupied spaces absorbing energy and allowing occupied spaces to be decelerated more slowly.

The primary value of a crash energy management design is not in the energy absorbed—only a few percent of the kinetic energy of a collision an be absorbed in a reasonable crush distance. The real safety benefit comes from allowing the occupied spaces to decelerate more slowly. If the occupied spaces are decelerated more slowly, people will be thrown about the interior of the cab with less force resulting in fewer and less severe injuries. Crash energy management techniques can benefit passenger, as well as crew safety.

To encourage the application of crash energy management technology to the design of future locomotives, FRA will work in partnership with industry representatives to determine feasible performance criteria. This work will benefit from the following efforts to date:

- FRA investigation of numerous passenger train accidents;
- experience gained through experience of operations of high speed passenger trains in Europe;
- research done by the Volpe National Transportation System Center; and
- discussions held with Amtrak over the procurement specification for high speed passenger trainsets.

Because the cab is generally placed at or near the very front of the locomotive, there may be limited options for creation of "crush zones" that will benefit crew members. Approaches such as permitting the cab to move to the rear on impact may offer options over the long term.

FRA found that existing technology is compatible with improvements in safety glazing regulations for locomotives in freight and conventional passenger service, offering the opportunity to address the concern expressed in the Act for "shatterproof" windows. In order to improve safety glazing, it will be necessary to address spalling, the strength of window frames, and testing and certification requirements. It should be emphasized that existing safety glazing requirements were the result of a joint commitment by railroads and employee organizations to address an employee safety concern in a preventive manner. FRA will seek the participation of those same parties in determining the specific course that should be taken in advancing the state of the technology.

The information obtained by FRA also indicates the desirability of exploring possible implementation of other locomotive safety features that meet the intent of the Act but were not specifically called out in the Act, such as roof egress and cab emergency lighting.

No Action

FRA recommends no action be taken on the following crashworthiness features listed in the Act:

- rollover protection;
- deflection plates; and
- uniform sill heights.

Rollover protection has theoretical value, and a concept is provided in Appendix E. However, FRA has not been able to identify any significant number of accidents in which crew injury resulted from complete rollover of the vehicle. Locomotive designs concentrate most of the weight low in the vehicle, and few accidents result in complete overturn of the vehicle. In most scenarios where overturn is possible, the danger of objects penetrating the cab is likely to predominate over instances in which crush might occur. Further, other measures discussed in this report, such as strengthening the structural members at the front of the locomotive and carrying some of that strength to the roof line, will also tend to protect crew members in the unlikely event of rollover.

In some situations deflection plates will greatly increase the risk of injury and increase the damage done during a collision. Implementation of deflection plates is not feasible given service requirements for coupling and operation around curves. FRA can not support rulemaking or guidelines for deflection plates.

Uniform sill heights have been suggested as a means of more fully involving the primary locomotive structural members in a collision. Neither accident investigation data nor computer modeling is conclusive that locomotives designed for uniform sill heights will help prevent override. However, the objective underlying this recommendation clearly warrants further exploration. Correctly designed and installed anticlimbers can be effective in preventing override for some collision closing speeds. FRA concludes that development of more effective anticlimbers providing uniform minimum ranges of engagement would more effectively address the intent of the Act.

Appendices to this report outline possible technical options for implementing the crashworthiness measures discussed in this report. For instance, FRA developed the rollover protection concept given in Appendix E and the crash refuge concept given in Appendix F based on the technical study and analysis of train accidents performed by Arthur D. Little Inc. under contract to FRA, and from discussions with Amtrak during the development of the specification for high speed passenger trainsets. The starting point for discussions on more stringent glazing requirements given in Appendix G is derived from discussions held with Amtrak during the development of the specification for high speed passenger trainsets.

The ideas set forth in the Appendices are neither standards nor guidelines, but rather concepts intended to provide the basis for concrete and detailed discussion of options for overall improvements in locomotive cab safety.

Locomotive Cab Working Condition Improvement Implementation

Partnership Opportunities

FRA found that locomotive builders and operating railroads are taking steps to improve the working conditions in locomotive cabs. However, historically railroad operations have required train crews to work for long periods of time in an environment that would be expected to accelerate the onset of fatigue. The noise level in many locomotives is not conducive to effective communication and may contribute to long-term hearing loss of crew members, if exposure is sustained and repetitive and if personal protective equipment is not properly employed.

In hot weather, the temperature in a locomotive cab can reach levels that are recognized to cause rapid heat exhaustion and an accompanying drop in human performance. A combination of lack of cleaning and maintenance by railroads and/or abuse by crew members causes the sanitary facilities in many locomotives to be in deplorable condition. The industry needs to take additional action to improve these conditions.

The research and analysis done in response to the Act supports further work in concert with the industry parties to address temperature extremes in the locomotive cab and toilet areas. Literature on human performance suggests that more strictly controlling cab temperature would provide greater confidence in the capacity of crew members to perform their duties safely and efficiently. Remedial measures based on use of the "heat stress index," which includes the combined effects of high temperature and high humidity on human performance, could offer several potential health and safety benefits including:

- minimizing human errors due to heat stress;
- reduced cab noise, because windows can be closed during warm weather;
- improved cab air quality; and
- reduced risk of flying or thrown objects entering the cab through open windows.

Avoiding extremes of temperature will also aid in providing adequate, functioning sanitary facilities.

The results of FRA's survey of locomotive cab noise levels, when compared with existing governmental standards and literature on noise-induced hearing loss, suggest that noise levels during some locomotive assignments are sufficiently high to raise significant concerns. In the past few years, major railroads have instructed employees to wear personal hearing protection and have placed employees in hearing conservation programs. Newer locomotives have been designed to reduce noise exposure, but retirement of older locomotives will take many years; and many regional and short line railroads use older locomotives as the mainstay of their fleets.

FRA will work with the industry parties and others having expertise in this field toward more appropriate noise exposure standards that are centered on prevention of hearing loss. The current noise standards for locomotive cabs given in 49 CFR 229 have not kept pace with standards applicable to other workplaces, and opportunities for sharing information within the railroad industry regarding positive approaches to hearing conservation have not yet been exploited. A more active response by FRA to occupational noise exposure will be a major outcome of this study.

Other issues that warrant concerted effort by FRA, employee organizations, manufacturers and suppliers, and the railroads include:

- cab sanitary facilities;
- cab ergonomics;
- cab seat design; and
- cab air quality.

Current regulations address these issues only with respect to basic cab seat safety and venting of exhaust gasses. Yet each falls clearly within the intent of the locomotive inspection statute to the extent it bears on the health and safety of crew members or the safe operation of the train.

Appendices K, L and M give respective examples of starting points for a cooperative effort with industry to develop approaches to each of these cab working condition improvements. FRA will work with our industry partners to develop appropriate approaches to these issues. FRA developed the cab sanitary facilities recommended practices given in Appendix K from the observations made by FRA inspectors during the cab working conditions survey done to support this report to Congress. The cab ergonomics guidelines given in Appendix L are based on a cab ergonomics study conducted by the Volpe National Transportation System Center, and discussions with Amtrak and the Burlington Northern Railroad. A concept for cab seat guidelines is given in Appendix M.

No Action

FRA recommends no action be taken on the issue of asbestos in locomotives, except to the extent any new information requires that the issue be reopened. FRA found that friable asbestos has not been used as a material in the construction of locomotives for ten years or more. Locomotive builders are careful to avoid the use of asbestos in new and rebuilt locomotives. Asbestos remaining in older units is believed to be encapsulated in individual components or systems. FRA could find no evidence of asbestos being a health problem for crews of older locomotives.

APPENDIX A

ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

AAR - Association of American Railroads

ACGIH - American Conference of Governmental Industrial Hygienists

ADL - Arthur D. Little, Inc.

AIS - Abbreviated Injury Scale

ANSI - American National Standards Institute

Anticlimber - Part of the end of adjoining coupled units that are designed to engage—when the units are subjected to large buff loads—to prevent lateral or vertical buckling of the train.

APTA - American Public Transit Association

ASTM - American Society for Testing and Materials

ATB - Articulated Total Body

ATCS - Advanced Train Control System: A microprocessor/communications/transponder-based system designed to provide both safety and business functions. Safety area capabilities are: (1) the digital transmission of track occupancy/movement authority to trains and an acknowledgement from the train crew via digital radio communications in lieu of voice communications, (2) provision of positive train separation control functions to preclude the train from exceeding its assigned limits of authority, (3) protection for maintenance-of-way and other workmen on track, (4) enforcement of authorized operating speed limits for trains consistent with civil engineering and other operating constraints, including temporary slow orders. In the business-related function area, ATCS enables the transmission of work order activity related to pick-ups, set-outs of individual and drafts of cars, locomotive health reporting, and other functions. ATCS is a joint program of the AAR and the Railway Association of Canada.

BLE - Brotherhood of Locomotive Engineers

CFR - Code of Federal Regulations

Collision Posts - Substantial, usually vertical structural members rising from, and firmly attached to the locomotive underframe intended to prevent the normally occupied volume of the locomotive from being compressed or penetrated by other objects as the result of a collision.

Comfort Index - The index of three variables (temperature, humidity, and air movement) in combination to determine the permissible heat exposure threshold.

Corner Post - A rail vehicle structural member that extends vertically from the floor support structure to the roof support structure located at the intersection of the front or rear surface with the side surface of the vehicle. Corner posts may be part of the end structure.

C_R - Resultant Chest Acceleration

Crash Energy Management System - Structural design techniques whereby unoccupied compartments or volumes of a rail vehicle are designed to be less strong than occupied compartments or volumes. The weaker compartments are designed to collapse in a controlled fashion to absorb or dissipate as much of the collision energy as possible.

Crash Refuge - A readily accessible, structurally reinforced volume within the cab designed to maximize the survivability of the crew members in the event of a collision.

Crush Distance - The distance a locomotive is shortened due to a collision.

Crush Force - The force causing a locomotive to be shortened during a collision.

Cyanosis - A bluish discoloration, especially of skin and mucous membranes, owing to excessive concentration of reduced hemoglobin in the blood.

dB - Decibel: A unit for expressing relative difference in power, between acoustic signals, equal to ten times the common logarithm of the ratio of the two levels.

Deflection Plate - An oblique structural member in the forward portion of a locomotive intended to deflect another train or road vehicle laterally from the path of the lead locomotive to reduce the energy which must be dissipated by the collision and minimize damage to the cab.

DOL - Department of Labor

DOT - Department of Transportation

Effective Temperature - The temperature as it feels to the human body.

EMD - Electro-Motive Division of General Motors

End Structure - The main support structure projecting upward from the floor or underframe, and securely attached to the underframe at each end of a locomotive.

EPA - Environmental Protection Agency

Ergonomics - The science that optimizes the human-system interface.

Exudation - The discharge of fluid through pores or cuts.

FAA - Federal Aviation Administration

FRA - Federal Railroad Administration

Frank Pulmonary Edema - The presence of abnormally large amounts of fluid in intercellular spaces within the lungs.

FTA - Federal Transit Administration

GE - General Electric Company

HazMat - Hazardous materials.

Heat Stress - Biological disorders in the human body due to excessive temperatures

HIC - Head Injury Criterion

HVAC - Heating, Ventilation, and Air Conditioning

IH - Industrial Hygienist

IITRI - IIT Research Institute

Lateral - The horizontal direction perpendicular to the direction of travel of a rail vehicle.

LCCC - Locomotive Control Compartment Committee

Locomotive - A piece of on-track equipment other than hi-rail, specialized maintenance, or other similar equipment (1) with one or more propelling motors designed for moving equipment, (2) with one or more propelling motors designed to carry freight or passenger traffic or both, or (3) without propelling motors but with one or more control stands designed to control movement of a train.

Locomotive Cab - The compartment or space aboard a locomotive where the control stand is located and is normally occupied by the engineer when the locomotive is being operated.

Longitudinal - The direction parallel to the normal direction of travel of a rolling stock unit.

MIL-STD-1472 - U.S. Military Standard, MIL-STD-1472, titled "Human Engineering Design Criteria for Military Systems, Equipment and Facilities."

MK - Morrison Knudsen

MP&E - Motive Power and Equipment

mph - Miles per hour

MSDS - Material Safety Data Sheet

NHSTA - National Highway Traffic Safety Administration

NPRM - Notice of Proposed Rulemaking

NRR - Noise Reduction Rating

NTSB - National Transportation Safety Board

Occupied Volume - The sections of a locomotive normally occupied by the crew.

OP - Operating Practices

OSHA - Occupational Safety and Health Administration

Override - Compressive forces causing a vehicle or unit to climb over the normal coupling or side buffers and linking mechanism and impact the end of the adjoining vehicle or unit above the underframe.

PEL - Permissible Exposure Limit

Permanent Deformation - A permanent change in shape of a structural member.

ppm - Parts per million

psi - Pounds per square inch

PTC - Positive Train Control: As applied to the next generation of train control systems, e.g., ATCS, the application of technology to control the movement of trains in a manner that precludes the occurrence of collisions. This term has also been employed by the Union Pacific and Burlington Northern Railroads to denote a test program for positive train control on certain of their main lines in the States of Oregon and Washington.

Rollover Protection Devices - Structural reinforcement of the sides and/or roof of a locomotive intended to make the cab volume less vulnerable to crushing or penetration in the event a locomotive rolls during a collision, and to a lesser extent in the event the locomotive is struck from the side.

RSERA - Rail Safety Enforcement and Review Act

Sone - A subjective unit of loudness, equal to the loudness of a pure tone having a frequency of 1,000 hertz at 40 decibels above the listener's threshold of audibility.

Spallation - Small pieces of glazing flying off the back surface of glazing due to an object striking the front surface.

Static End Load - The compressive force the underframe or the unit body structure or body space frame must be able to withstand without damage or permanent deformation of the occupied volume.

Thermal Overstrain - The condition in which a worker's physiological capacity to regulate body temperature is limited due to environmental heat exposure with worker's metabolic heat production.

TLV - Threshold Limit Value - The airborne concentrations of substances that nearly all workers may be repeatedly exposed to day after day without adverse health effects.

TWA - Time Weighted Average

Ultimate Strength - The ability of a structural member to resist fracture or total structural failure.

Underframe - The lower horizontal support structure of a carbody.

Unit Body (monocoque) Design - A type of vehicle construction where the shell or skin acts as a single unit with the supporting frame to resist and transmit the loads acting on the vehicle.

UTU - United Transportation Union

VNTSC - Volpe National Transportation System Center

WBGT - Wet Bulb Globe Temperature: Temperature is determined by the wet bulb thermometer of a standard sling psychrometer or its equivalent. This temperature is influenced by the evaporation rate of water, which in turn depends on the humidity (amount of water vapor) in the air.

Witness Plate - A thin foil placed behind a piece of glazing undergoing impact test. Any material spalled or broken from the back side of the glazing will dent or mark the witness plate.

Yield Strength - The ability of a structural member to resist a change in length caused by a heavy load. Exceeding the yield strength may cause permanent deformation of the member.

APPENDIX B

ASSOCIATION OF AMERICAN RAILROADS
SPECIFICATION S-580

LOCOMOTIVE CRASHWORTHINESS REQUIREMENTS STANDARD S-580

Adopted: 1989

Effective for New Road Type Locomotives
Built After August 1, 1990

1.0 SCOPE

These specifications for crashworthiness enhancements cover requirements applicable to all new road type locomotives built after August 1, 1990, for use on North American Railroads. The standards, stated in the form of design criteria, may be exceeded depending on the needs of individual users.

2.0 GENERAL

Designs and materials used in providing crashworthiness enhancements stipulated herein shall be such so as to minimize the effect of weight restrictions on the fuel capacity of the locomotive.

3.0 REQUIREMENTS

3.1 ANTI-CLIMBERS

An anti-climber arrangement will be standard on the short hood end of the locomotive and shall be designed to withstand a minimum of 200,000 pounds without exceeding the ultimate strength of material, when applied vertically and uniformly between the center sill webs under the anti-climbers of the locomotive. The anti-climber arrangement shall be attached to the underframe end plate in line with the center sill webs.

3.2 COLLISION POSTS

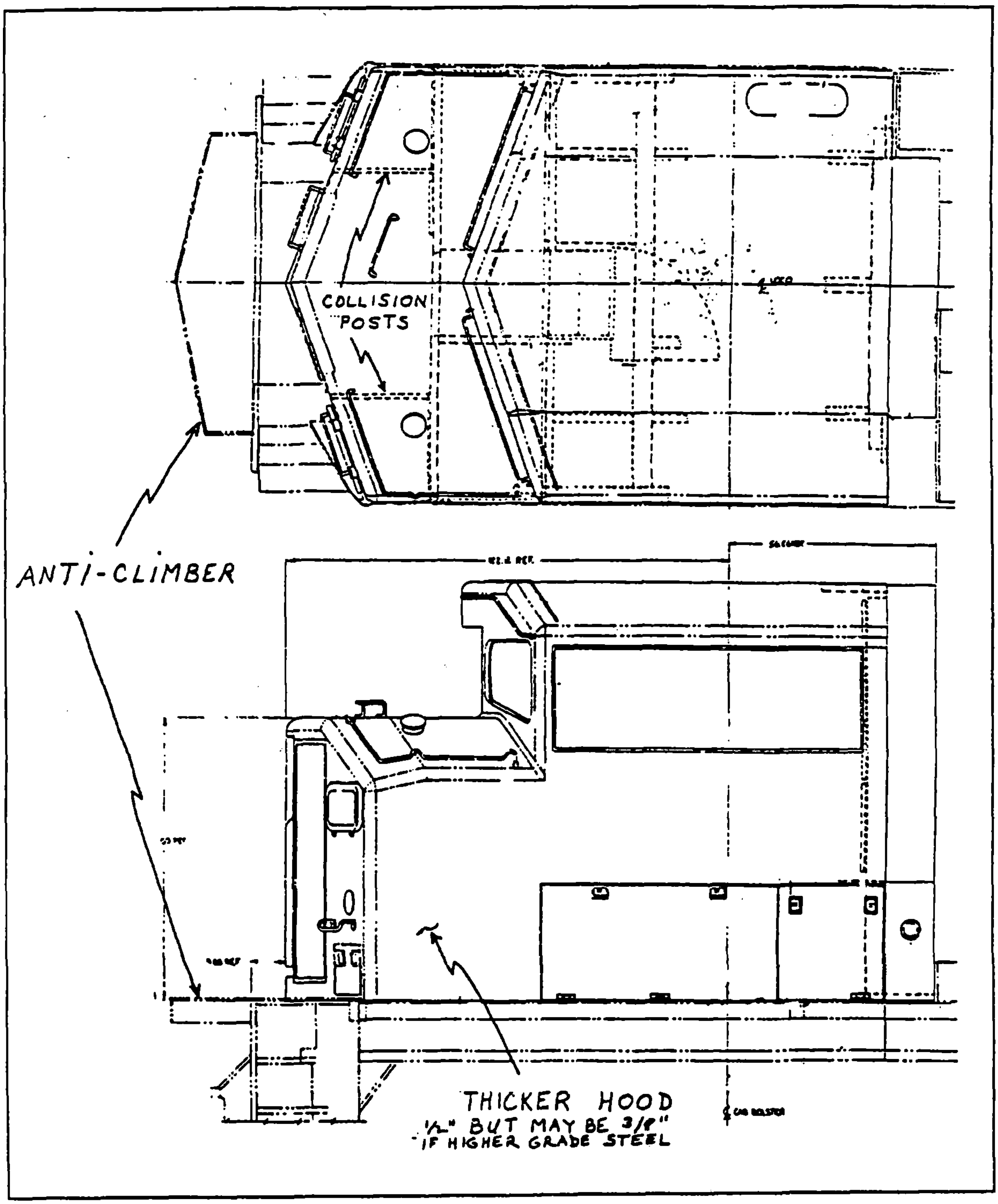
A minimum of two collision posts, located on the underframe longitudinales (center sills) shall be designed to withstand a longitudinal force of 200,000 pounds each at 30 inches above the deck and 500,000 pounds each at the underframe deck without exceeding the ultimate strength of the material.

3.3 SHORT HOOD STRUCTURE

The skin of the short hood end-facing area shall be equivalent to ½-inch steel plate at 25,000 psi yield strength (where thickness varies inversely with the square root of yield strength).

This end nose plate assembly shall be securely fastened to the collision posts.

Any personnel doors in the short hood end-facing area shall be suitably reinforced to the equivalent strength of the short hood. Any windows must meet FRA standards.



COLLISION POSTS
ANTI-CLIMBER
THICKER HOOD
1/2" BUT MAY BE 3/8"
IF HIGHER GRADE STEEL

APPENDIX C

CHARACTERIZATION OF IDEAL COLLISION

Taken from Safety of High Speed Guided Ground Transportation Systems, "Collision Avoidance and Accident Survivability, Volume 3: Accident Survivability" DOT/FRA/ORD-93/02.III, DOT-VNTSC-FRA-93-2.III, March 1993

Two fundamental physical concepts govern the overall structural response of vehicles involved in a collision: the laws of conservation of momentum and conservation of energy. The simple case of collinear impact[1] between two ground vehicles will be examined to derive expressions for the amount of kinetic energy that must be dissipated (primarily) by the vehicle structure and to illustrate other interesting facts about vehicle collisions in general. It should be noted that such impacts impose the most severe velocity change and energy absorption requirements on the striking vehicles of all inter-vehicular crash configurations.

The law of conservation of momentum (in this case, linear) requires that:

$$m_1V_1 + m_2V_2 = m_1V_1' + m_2V_2' \qquad (1)$$

while the conservation of energy (here, translational) mandates that:

$$1/2\ m_1V1^2 + 1/2\ m_2V_2^2 = 1/2\ m_1(V_1')^2 + 1/2\ m_2(V_2')^2 + E_d \qquad (2)$$

where

m_1, m_2 represent the mass of vehicles 1 and 2, respectively

V_1, V_2 are the pre-impact velocities of vehicles 1 and 2 respectively

V_1', V_2' are the post impact velocities of vehicles 1 and 2 respectively, and

E_d is the total energy dissipated in the two vehicles during the crash as a result of permanent deformation of their structures.

Consistent with common practice, the energy dissipated by frictional forces (e.g., from tire/roadway or wheel/track sliding action after impact) will be neglected in the derivation presented herein.

To simplify the problem further, assume that the structures of both vehicles possess totally plastic (i.e., without elastic recovery) material properties in the region where crush occurs. In that case, the two vehicles remain in contact after the collision and acquire a common, post-impact velocity, V_f, i.e.:

$$V_f = V_1' = V_2' \qquad (3)$$

Substitution of Equation (3) into Equation (1) leads to the solution for the common velocity V_f:

$$V_f = (m_1V_1 + m_2V_2) / (m_1 + m_2) \qquad (4)$$

Substitution of Equations (3) and (4) into Equation (2) results in an expression for the total amount of energy dissipated in the collision:

$$E_d = m_1m_2V_c^2 / 2(m_1 + m_2) \qquad (5)$$

where

$$V_c = V_1 - V_2$$

is the pre-impact closing velocity of the two vehicles.

It should be noted that E_d, the total energy absorbed in the collision, can be regarded as an indicator of potential damage that can be inflicted on the vehicles by the collision. Equation (5) shows that there will be less of this energy available to damage the vehicles for the case where one or both are lightweight compared to the case where both vehicles are heavy.

APPENDIX D

CRASH ENERGY MANAGEMENT CONCEPT

The following four general requirements state the goals for crashworthiness of locomotives:

- o maintain an envelope or minimum volume of survivability for crew members which resists extreme structural deformation and separation of main structural members;
- o protect against penetration of the occupied crew compartment;
- o protect against occupants being ejected from the crew compartment; and
- o protect the occupants from secondary impacts with the interior of the crew compartment.

To make an accident of a train survivable, two design features are required: (1) the spaces occupied by the crew must be strong enough not to collapse, crushing the crew; and (2) the initial deceleration of the crew must be limited so they are not thrown against the interior of the train with great force. Achieving these general objectives can be the most difficult challenge facing equipment designers.

Crash Energy Management

Crash energy management is a design technique to help equipment designers meet this challenge. The basic concept embodied by crash energy management is unoccupied spaces or lightly occupied spaces are intentionally designed to be slightly weaker than heavily occupied spaces. This is done so that during a collision the unoccupied spaces will deform before the occupied spaces allowing the trainset occupied spaces to initially decelerate more slowly and minimizing the uncontrolled deformation of occupied space.

Conventional practice has resulted in locomotives of essentially uniform longitudinal strength causing the structural crushing of the locomotive to proceed uniformly through both the unoccupied and occupied areas of the locomotive.

The crash energy management design approach results in varying longitudinal strength, with high strength in the occupied areas and lower strength in the unoccupied areas. This approach attempts to distribute the structural crushing throughout the locomotive to the unoccupied areas to preserve the occupant volumes and to control and limit the decelerations of the locomotives. The crash energy management approach has been found to offer significant benefits.

Interior crashworthiness study evaluates the influence of interior configurations and occupant restraints on injuries resulting from occupant motions during a collision. For a sufficiently gentle train deceleration, compartmentalization (a strategy for providing a "friendly" interior) can provide sufficient occupant protection to keep widely accepted injury criteria below the threshold values applied by the automotive industry. If installed properly and used, the combination of lapbelts and shoulder restraints can reduce the likelihood of fatality due to deceleration to near-certain survival for even the most severe collision conditions considered.

The value of a **crash energy management design is not in the energy absorbed**—only a few percent of the kinetic energy of a collision can be absorbed in a reasonable crush distance. **The real safety benefit comes from allowing the occupied spaces to decelerate more slowly, while decreasing the likelihood that occupied spaces will fail in an uncontrolled fashion.** If the occupied spaces are initially decelerated more slowly, people will be pinned to an interior surface of the trainset with less force resulting in fewer and less severe injuries. Once pinned against an interior surface, occupants can sustain much higher subsequent decelerations without serious injuries resulting. Also, since unoccupied space is intentionally sacrificed, less occupied space will be crushed during the collision.

Crash Energy Management design involves a system of inter-related safety features, in addition to controlled crushable space, that could include:

- o design techniques to keep the trainset in-line and on the track for as long as possible during the initial impact;
- o interior design eliminating sharp corners and padding surfaces likely to be struck by people with shock absorbing material;
- o attachment of interior fittings and seats with sufficient strength not to fail causing additional injuries; and
- o a crash refuge for the vulnerable crew members in the cab.

To help maintain survivable volumes, particularly during collisions at higher closing speeds, minimum standards for the following structural design parameters would be needed:

- o anti-buckling to keep the train in-line and on the track;
- o end structures and anti-climbers to prevent override;
- o corner posts to deflect glancing collisions;
- o rollover strength; and
- o a crash refuge in the control cab.

To limit decelerations of crew members and flying objects striking the crew, standards would be necessary for the following general design parameters under the dynamic conditions created by the collision scenario:

- o limits on the maximum and average deceleration of the crew in the control cab for the first 250 milliseconds after impact (assuming the crew anticipates the collision and places themselves in the crash refuge);
- o minimum longitudinal/lateral/vertical seat attachment strength; and
- o minimum longitudinal/lateral/vertical fitting attachment.

Achieving the second item requires careful design to create a differential in structural strength between seating areas ("occupied volume") and certain other areas that would be allowed to fail before the occupied volume. By contrast, maintaining uniform rigidity throughout the trainset would result in unacceptably high initial accelerations of the crew compartment and possibly make the accident non-survivable.

The Federal Railroad Administration encourages railroads and manufacturers to develop locomotives incorporating crash energy management systems to provide additional protection to the crew in the event of a collision. The following is a concept for discussion:

> Locomotives should be designed with a crash energy management system to dissipate kinetic energy during a collision. The crash energy management system should cause a controlled deformation and collapse of the unoccupied volumes (crushable volumes) to absorb collision energy and to reduce the decelerations acting on the crew resulting from dynamic forces transmitted to occupied volume (cab).
>
> Locomotives should be designed to crush and absorb energy in a controlled manner by "zones" when subjected to end loads in collisions that exceed the static load capability of the structure. The zones—as shown in Figure D.1—shall be as follows, from the highest to the lowest priority:
>
> Zone A: usually occupied area of the locomotive, i.e. the cab;
>
> Zone B: occasionally occupied areas of the locomotive such as passageways and toilets;
>
> Zone C: unoccupied space; and
>
> Zone D: space occupied by large, solid mass, relatively uncrushable equipment.
>
> The locomotive should be designed with energy crush zones for types B and C which are 100 percent stronger than that for type A, ahead of the occupied control cab in the direction of travel.

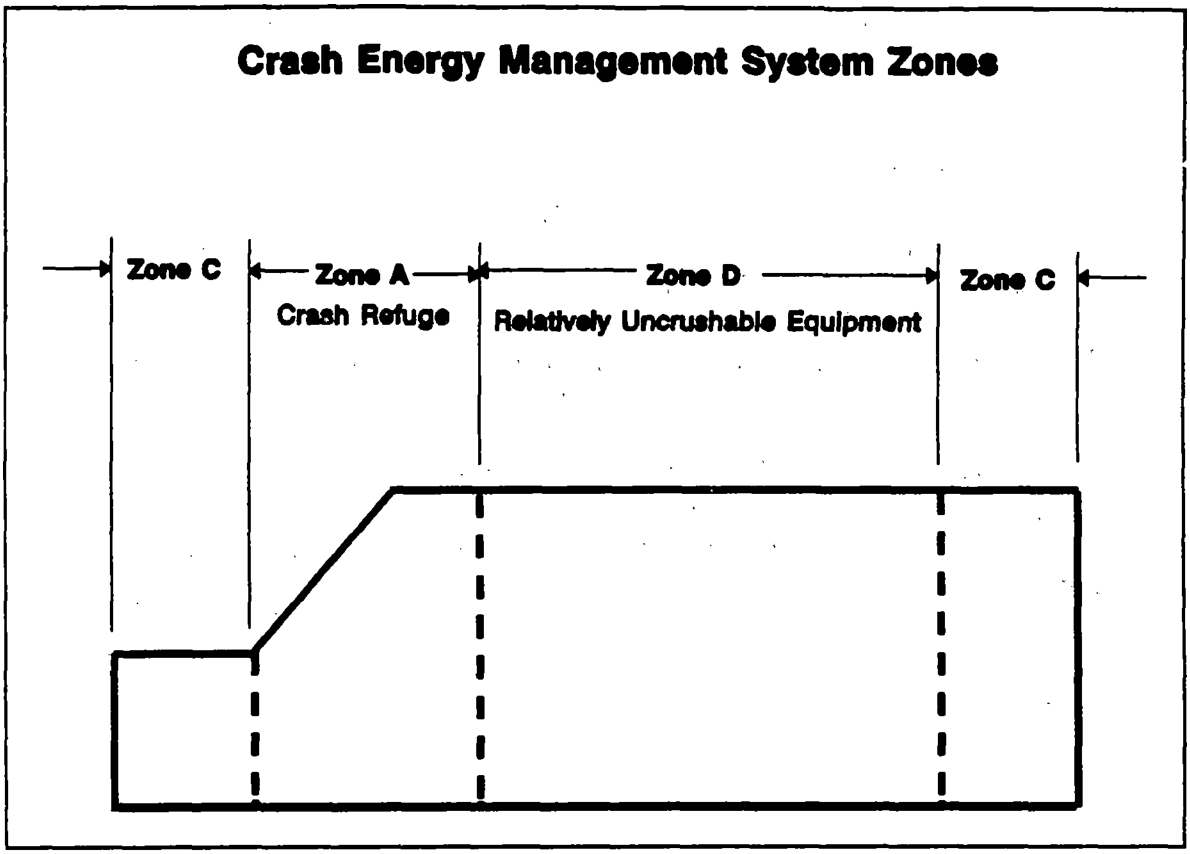


Figure D.1

The greater the crush distance that can intentionally be designed into the locomotive before reaching the cab occupied volume, the more survivable a collision will be. Since the control cab is necessarily near the leading surface of the locomotive, little crush distance is available to protect the crew in the cab. As a result, the decelerations of the crew can be large; and a special crash refuge (see Appendix L for Crash Refuge Guidelines) is needed to increase survivability of collisions with a closing speed of greater than 30 mph.

The combination of the crash energy management system and the crash refuge should be designed to limit the maximum deceleration of the crew in the control cab to 24g for the first 250 milliseconds after impact (assuming the crew anticipates the collision and moves to the crash refuge) for the maximum revenue operating speed. Limiting crew deceleration is based on automobile crashworthiness research and levels occupants are likely to survive. The 250 milliseconds duration was selected as the time required for people to make their initial impact with an interior surface and be pinned by inertia against that surface. After this time, the peak deceleration can be greatly increased without causing extensive injuries.

The crushable volumes should be designed to be structurally weaker than the occupied cab. During a collision or derailment, the crushable volumes should start to deform and eventually collapse in a controlled fashion to dissipate energy before any structural damage occurs to the cab volume. The crushable volumes of the locomotive should have a static end yield strength of no more than 80 percent of the actual static end strength of the cab volume. The crash energy management system should start to function at a static end load of no more than 90 percent of the actual static end strength of the cab volume.

The cab of the locomotive should be designed and constructed in a manner to prevent telescoping of the crushed, unoccupied structure into the occupied volume of the cab.

An analysis based on a collision scenario with a specified collision closing speed should be performed to verify that the locomotive crash energy management system meets these guidelines. Assumptions made as part of the analysis to calculate how the kinetic energy of the collision is dissipated should be fully justified. The analysis must clearly show that the crushable volumes of the locomotive crush before collapse of the cab volume starts and that the deceleration of crew in the occupied cab is limited to the recommended levels.

APPENDIX E

LOCOMOTIVE END STRUCTURE AND ROLLOVER STRENGTH CONCEPTS

The general requirements for locomotive crashworthiness include:

- o the locomotive should maintain an envelope or minimum volume of survivability for the crew which resists extreme structural deformation and separation of main structural members;

- o the locomotive should protect against penetration of the occupied compartments;

- o the locomotive should protect against occupants being ejected from the cab; and

- o the locomotive should protect the occupants from secondary impacts with the interior of the cab.

End structures are the forward and rear vertical sections of the locomotive frame. While the end structure tends to define the forward and rear end surfaces of the locomotive, they need not define a single vertical plane. The end structures play a large role in providing a survivable volume for the crew and in preventing penetration of the cab. The Federal Railroad Administration (FRA) recommends consideration of unitized end structures. A unitized end structure takes advantage of the structural strengths of its component members to maximize the protection provided to the crew. The following is provided as a concept for consideration:

> The forward end structure of the locomotive should include full height corner posts, a full height center post and collision posts that extend to the top of the short hood. A conceptual implementation of such a forward end structure design with minimum ultimate strength recommendations is given in Figure E.1. A crushable short hood could be placed ahead of the end structure. The collision posts could be placed at the leading surface of the short hood and be pushed back as the short hood collapses or they could be at the rear of the crushable short hood. The members of the forward end structure should be tied together with 1/2-inch steel plate with 25,000 psi yield strength or equivalent.
>
> The rear end structure of the locomotive should include full height corner posts and full height collision posts. A conceptual implementation of such a rear end structure design with minimum ultimate strength recommendations is given in Figure E.2.

Chapter 3 of this report discusses the expected loads experienced by a locomotive during a rollover accident scenario, and the resulting need for locomotive cabs to be designed and built with a structure that resists the loss of survivable volume due to rollover. A concept for consideration is provided as follows:

Locomotives should be able to withstand a uniformly applied load equal to 2g acting on the mass of the locomotive without failure of the cab side structure or the cab roof structure (local deformation of the side sheathing or roof sheathing in the cab area is permitted).

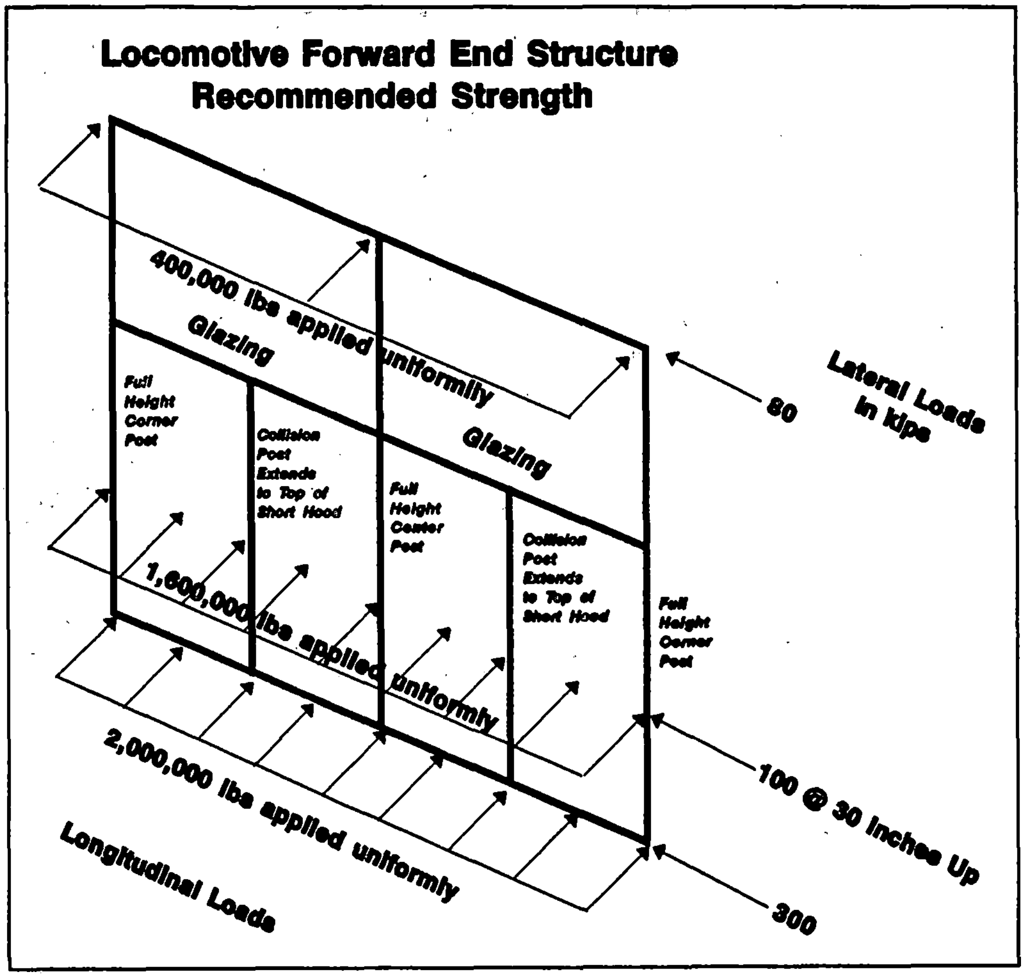


Figure E.1

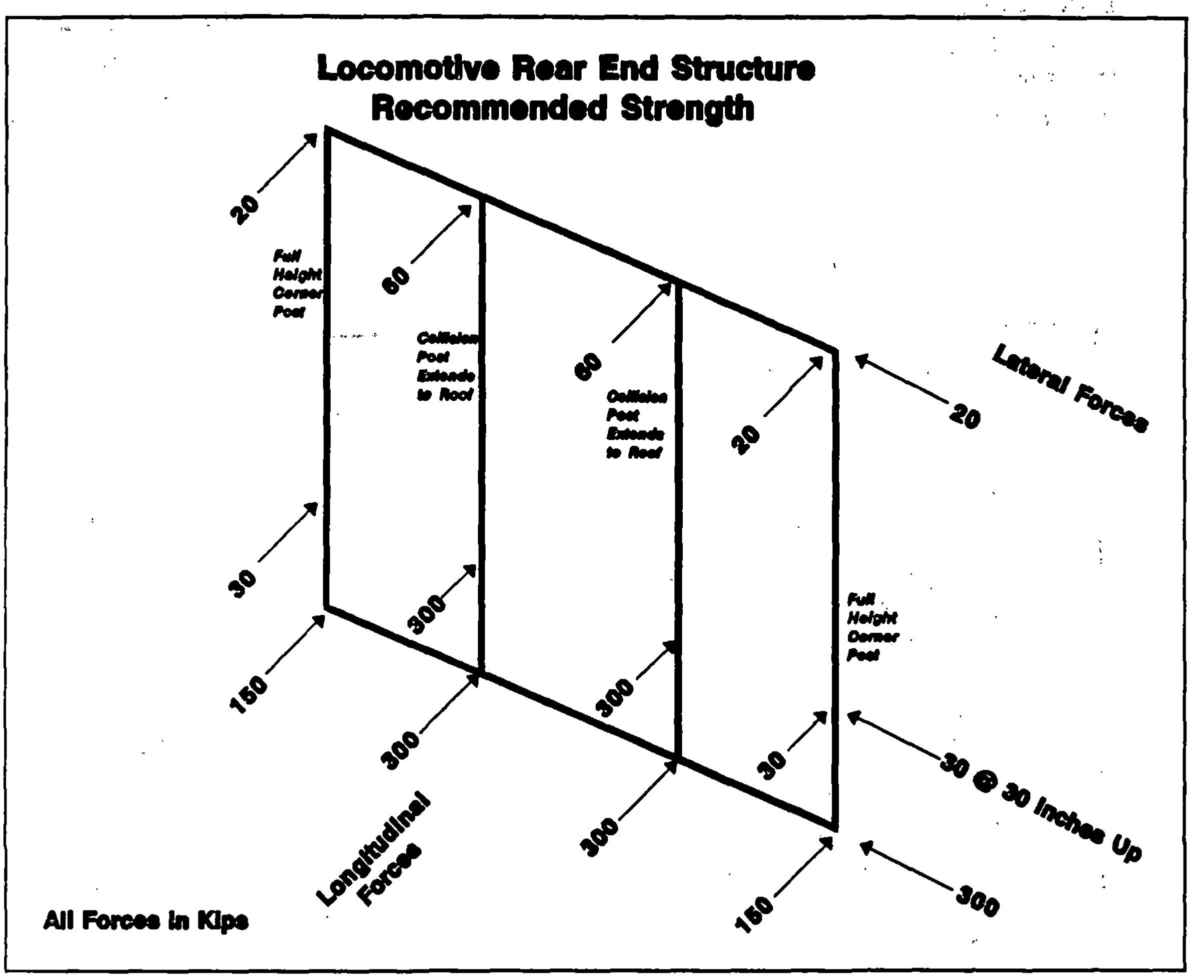

Locomotive Rear End Structure
Recommended Strength
20
Full Height Corner Post
60
Collision Post Extends to Roof
60
Collision Post Extends to Roof
20
20
Lateral Forces
30
300
150
300
300
Full Height Corner Post
30
30 @ 30 Inches Up
300
Longitudinal Forces
150
300
All Forces in Kips

Figure E.2

APPENDIX F

LOCOMOTIVE CRASH REFUGE DESIGN CONCEPT

The general requirements for locomotive crashworthiness include:

- o the locomotive should maintain an envelope or minimum volume of survivability for the crew which resists extreme structural deformation and separation of main structural members;
- o the locomotive should protect against penetration of the occupied compartments;
- o the locomotive should protect against occupants being ejected from the cab; and
- o the locomotive should protect the occupants from secondary impacts with the interior of the cab.

A crash energy management system and the structural strength of a locomotive alone are adequate to provide these four essential protections up to collision speeds of approximately 30 mph. To provide these four essential protections during higher speed collisions or derailments, a crash refuge for the crew is necessary. A crash refuge is a small volume of high structural strength that provides restraints or otherwise protects occupants from secondary impacts to which the crew can quickly retreat when a collision is imminent.

To give locomotive designers maximum flexibility to implement crash refuge designs, the Federal Railroad Administration (FRA) provides only very broad guidelines. The crash refuge should not be totally enclosed. Crews indicated that they would be very reluctant to use such a refuge.

The refuge should provide additional structural protection and should connect occupants to the vehicle in some manner as quickly as possible. Additional structural protection can be provided by making the entire cab structure very strong (as Amtrak has chosen to do for their new high speed trainset) or by providing a small reinforced area within the cab such as a trench in the cab floor (see Figure F.1 for a conceptual example).

If the strong cab approach is taken, protection against secondary impact should be provided by seat belts or by rotating the seat so that the occupant can ride down the collision with the back of the crew member to the oncoming vehicle or obstruction. The seats and seat supports should be designed to withstand the shock of the collision. Seat belts are not necessary to provide the basic protection against secondary impact with the rotating seat concept, even though there is likely to be some recoil action of the impact as the locomotive comes to rest. However, a seat belt would minimize the risk of injury from this event.

If the trench or some similar approach to provide a crash refuge is taken, the interior of the refuge should be padded with shock absorbing material. A concept depicting an individual properly positioned in a trench type crash refuge is given in Figure F.2. Whatever type crash refuge is selected, the crew member should be able to correctly position themselves in it with only a few seconds notice before impact.

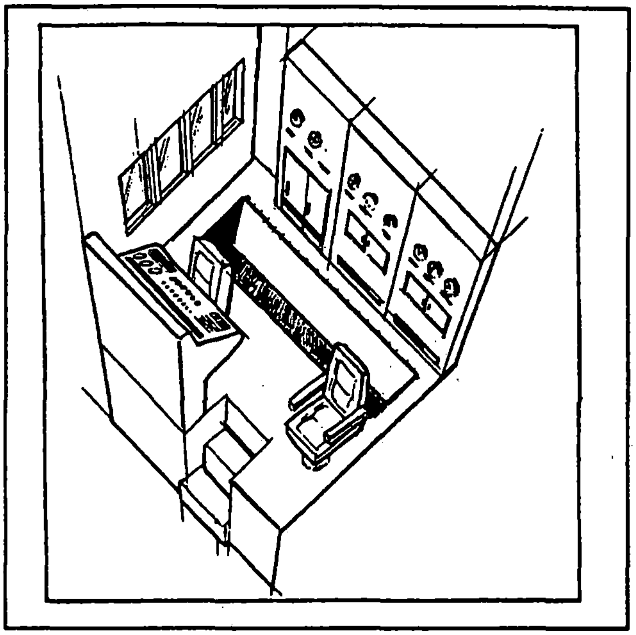


Figure F.1 Illustration of the Trench Crash Refuge Concept

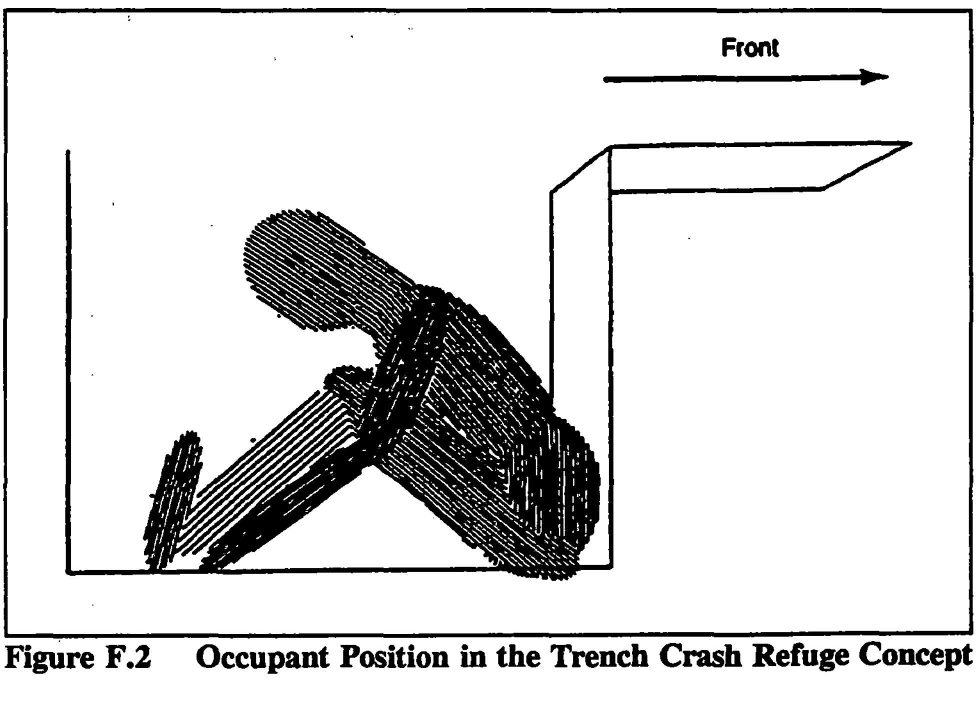


Figure F.2 Occupant Position in the Trench Crash Refuge Concept

APPENDIX G

GLAZING DESIGN

These proposed guidelines apply to new or rebuilt equipment to be placed in service at speeds greater than 79 mph.

Bullet Impact Requirements

Exterior glazing shall stop without spall or bullet penetration a single impact of a 9-mm, 147-grain bullet traveling at an impact velocity of 900 ft/second with no spall or bullet penetration.

Large Object Impact Requirements

- o End facing glazing shall stop without spall or object penetration the impact of a 12-pound solid steel sphere travelling at the maximum speed at which the equipment will operate at an angle equal to the angle between the glazing surface as installed and the direction of travel.

- o Side facing glazing shall stop without spall or object penetration the impact of a 12-pound solid steel sphere travelling at 15 mph at an angle of 90 degrees to the surface of the glazing.

Small Object Impact Requirements

Side facing glazing shall stop without spall or object penetration the impact of a granite ballast stone—with major and minor axes no greater than 10 percent different in length—weighing no less than .5 pounds travelling at 75 mph impacting at a 90 degree angle to the glazing surface.

Glazing Frame Requirements

- o Glazing frames shall hold glazing in place against all forces that do not cause glazing penetration.

- o Glazing and frame shall resist the forces due to air pressure differences caused by trains passing with the minimum separation for two adjacent tracks while traveling in opposite directions each traveling at maximum speed.

Interior Glazing Requirement

Interior equipment glazing shall meet the minimum requirements of AS1 type laminated Glass as Defined in American National Standard "Safety Code for Glazing Materials for Glazing Motor Vehicles Operating on Land Highways", ANSI Standard Z26.1-1966.

Certification and Marking Requirements

- Only glazing certified by the manufacturer to meet the requirements of this specification shall be installed on high speed equipment.
- Each individual glazing panel certified to meet the requirements of this specification shall be marked to indicate:
  - "FRA TYPE IHS" if exterior, end facing;
  - "FRA TYPE IIHS" if exterior, side facing;
  - "FRA INTERIOR" if interior;
  - the manufacturer of the material; and
  - the type or brand identification of the material.

Testing Requirements

- Each manufacturer of glazing for high speed rail equipment shall have the glazing certification tests performed by an independent testing laboratory.
- Certification tests shall be performed at a minimum of once every 3 years or when changes in glazing design or manufacturing processes are made.
- Certification tests shall be developed and performed that demonstrate the glazing meets all the parametric requirements of this specification.
- A .001-inch aluminum witness plate, placed 12 inches from glazing surface shall be used to determine if the glazing spalled. The witness plate shall not be marked after any test.

APPENDIX H

CAB SURVEY INSTRUCTIONS TO FRA INSPECTORS

Each region will be expected to inspect and perform a test in the cabs of not less than 20 Class 1 railroad locomotives while in road service and 10 locomotive cabs while in yard service. Each regional specialist shall attempt to have tested and inspected randomly selected designated locomotives of those railroads which have generated complaints involving the locomotive cab environment. Locomotives will be tested while going through tunnels in those regions where such service is performed. The locomotives shall be tested while they are in service. The testing which will be performed while riding trains will take not less than 6 hours. This will permit the inspector to perform a noise test which will be reported to the FRA Industrial Hygienists, RRS-12, in the normal manner.

The road freight locomotives inspected and tested must be rated at 3,000 horsepower or higher, which could include the ED GP-40, SD-40, SD-50, SD-60, and GE U-30-B, U-30C and DASH 8 series. The locomotives used in yard service may be of a lesser horsepower.

The attached form titled "Locomotive Cab Environmental Survey" is to be used and the items answered as applicable. Each Regional Specialist will tabulate the results for that Region prior to being submitted to Headquarters. The inspector is not to request the train crew to open cab windows in order to meet the test requirements. Noise levels should be measured in closed, air conditioned cabs.

The inspectors shall inspect the sanitary facilities on board locomotives. This inspection shall record the following information/data:

- The type of facility by manufacturer's name and installation date.
- The location of the facility on the locomotive.
- The general condition of the toilet and surrounding area, and whether is it clean, comfortably proportioned and adequately equipped.
- Description of the odors being emitted from the toilet facility while in use. Type and quantity of chemicals being used and maintenance actions required.
- Determine whether the toilet:
  - is adequately vented to the inside or outside of the cab to release odors,
  - has forced air circulation, and
  - is heated and/or air conditioned
- Are the odors from the toilet area reaching the crew members in the cab? Are odors a nuisance or nauseating?

- o Does the railroad's maintenance program for maintaining the toilet facilities include the time cycle for draining effluent, cleaning, sanitizing, and replenishing materials? Is the program followed?

The inspectors are also to report on the following items that may have a bearing on safety and working conditions in locomotive cabs:

- o Determine and carefully record the operating mode of the locomotive when observations or measurements are made. Operating modes include: power mode (give throttle position), braking mode, at idle, and at rest.

- o Determine the temperature at various locations in the cab each 15 minutes under normal train operating conditions. Also, report ambient temperature.

- o Describe heating arrangement in the cab. Include a description of type, location, and capability of each unit.

- o If the locomotive cab is air-conditioned, the following information must be provided:

  - the name and type of air conditioning system, temperature control system, or stand-alone unit,

  - whether the system is adequate, noisy, frequently out of service, etc., and

  - an outline of the railroad maintenance program.

- o Describe the noise generated by the heating and air conditioning system and whether it is conducive to stress even though within FRA standards.

- o Is the exhaust from air operated brake valves and devices released in or out of cab? If within the cab, measure the sound level.

- o Describe the type of seats provided for the crew members and if they provide sufficient support for 12 hours on duty. Are the seats susceptible to failure from force applied to the back rest? Are the cushions properly secured in position? Are adjustments to facilitate each user easy and safe to operate?

- o Are sun visors provided and maintained to protect against bright sunlight that could impede vision?

- Are cab fixtures, operating valves, cabinet door handles free of pointed corners and sharp edges that could cause injuries? Are the cab lights working properly, and is the bulb shielded?

- Are the cabinet doors in the cab secured and closed, while the locomotive is in service?

- Do the cab doors open and close with minimal effort?

- Are cab floors and passageways inspected for unsafe conditions, such as broken floor covering or obstructions? Are fire extinguishers provided, and are they secured? Are proper containers for the torpedoes and fusees provided?

- Report the number of cab seats and whether provisions are made for storing crew belongings.

- Report the type of drinking water provided, and whether refrigerated water is used. Report the water cooler type, method of securement, general condition and railroad maintenance program.

- Carefully inspect the cab glazing for damage, particularly spall chips.

Department of Transportation
Federal Railroad Administration

LOCOMOTIVE CAB ENVIRONMENTAL SURVEY

Motive Power & Equipment
Public Law 102-365 Sect. 10

1. Inspector's Name:	2. Inspector's I.D. No.	3. Region:	4. Date of Inspection:	5. Locomotive Owner's Full Corporate Name:	6. Location or Trip of Inspection:

7. Locomotive Manufacturer:	8. Model Number & Built Date:	9. Locomotive Number:	10. Locomotive Service: (Circle) Road Switching Yard Out of Service	11. Locomotive Power: Diesel LNG Electric Other	12 Locomotive Position: Lead Trailing

Cab Equipment

Equipment	Type/Manufacturer	Capacity/Size	Condition	Maintenance Program	Cleanliness/Odors
Heater:	13.	14.	15.	16.	17.
Air Conditioner:	18.	19.	20.	21.	22.
Toilet:	23.	24.	25.	26.	27.
Water Cooler:	28.	29.	30.	31.	32.
Food Storage:	33.	34.	35.	36.	37.
Seats:	38.	39.	40.	41.	42.
Sun Visors:	43.	44.	45.	46.	47.

Glazing Condition

Glazing Location	Type?	Clean?	Cracked?	Spalled?	Describe Other Damage or Condition:
Side Glazing	48.	49.	50.	51.	52.
Front/Rear Glazing	53.	54.	55.	56.	57.

Noise Measurements

Operating Mode: (Circle) Powered: Throttle Position ____ Braking Idling At Rest

Time	Location of Measurement	Train Speed	Measured Value	Source of Noise?	Annoyance Level?
58.	59.	60.	61.	62.	63.
64.	65.	66.	67.	68.	69.
70	71.	72.	73.	74.	75.
76.	77.	78.	79.	80.	81.
82.	83.	84.	85.	86.	87.
88.	89.	90.	91.	92.	93.

Temperature Measurements

Operating Mode: (Circle) Powered: Throttle Position ____ Braking Idling At Rest

Time	Location of Measurement	Measured Value	Outside Temperature	Comfort Level
94.	95.	96.	97.	98.
99.	100.	101.	102.	103
104.	105.	106.	107.	108
109.	110.	111.	112.	113
114.	115.	116.	117.	118
119.	120.	121.	122	123.

Fumes/Odors

Location of Fume/Odor	Locomotive Operating Conditions	Describe Fume/Odor	Effect of Fume/Odor on Crew
124.	125.	126.	127.
128.	129.	130.	131.
132.	133.	134.	135.
136.	137.	138.	139.

Other Cab Interior Features

~~140. Type Ventilation of Toilet~~ Area:	141. General Cab Interior Cleanliness:
142. Condition of Cab Floor:	143. General Impression of Quality of Cab Interior Maintenance:
144. Condition of Passageways:	145. Location of Brake Valve Exhaust
146. How Do Cab Environmental Factors Appear to Affect the Ability of the Crew to Safely Operate the Train?:	Locomotive?

Figure H.1

APPENDIX I

SUMMARY OF CAB SURVEY RESULTS

LOCOMOTIVE CAB ENVIRONMENTAL SURVEY RATING DEFINITIONS

5 = <u>EXCELLENT</u>

- Notations from inspection (excellent or very good).
- Cab equipped with forced air conditioning system in which the temperature can be maintained at desired level.
- No fumes, evidence of fumes or odors.
- All air brake valves vent outside of cab.
- Venting for toilet area is forced air.
- Maintained and controlled temperature.

4 = <u>GOOD</u>

- Notations from inspection (good).
- No fumes, evidence of fumes or odors.
- All air brake valves vented outside of cab.
- Forced air toilet venting.
- Cab temperature of 61°F to 79°F (constant).

3 = <u>ACCEPTABLE</u>

- Notations from inspection (acceptable, fair, or average).
- Slight fumes or odors, but no apparent effect to crew.
- All air brake valves vented in control stand, but not loud.
- Draft toilet venting, but not defective or inadequate.
- Cab temperature of 61°F to 79°F (variable).

2 = <u>POOR</u>

- Notations from inspection (poor).
- Fumes or odors present with mild effects to crew.
- All air brake valves vented in control stand and loud.
- Draft toilet venting, but not defective or inadequate.
- Cab temperature of 50°F to 60°F or 80°F to 90°F.

1 = <u>UNACCEPTABLE</u>

- Notations from inspection (very bad, very dirty, or unusable).
- Fumes or strong odors from toilet are present.
- All air brake valves vented in control stand and loud.
- Draft toilet venting, but not defective or inadequate.
- Temperatures of below 50°F or over 90°F.
- No water cooler or food storage (not applicable on switch locomotive).

WINTER TESTS

REGIONS 1 - 8

LOCO #	FRA REG	MANUF	MODEL	YEAR BUILT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOLER	FOOD STOR	SEAT COND	VISOR COND	GLAZE COND	TEMP LEVEL	FUMES	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEAN	CAB MAINT	AIR VAL EXHST	AVG
CR6844	2	EMD	SD60	1989	RD/TRL	4		4		4	4		4	4	5	3	4	4	4	4	4	4.00
CR6062	2	GE	C40-8W	1990	RD/LD	3		1		3	3	3	4	4	5	3	4	4	4	4	4	3.50
NW7130	2	EMD	GP60	1991	RD/LD	4				2	4		4	4	5		4	4	3	3	4	3.73
NW7144	2	EMD	GP60	1991	RD/TRL	4					4		4	4	5		4	4	3	3	4	3.90
NW6632	2	EMD	SD60	1986	RD/LD	4				4	4		4	2	5		4	4	4	4	4	3.91
NW7109	2	EMD	GP60	1991	RD/LD	4				1	4		4		5		4	4	3	3	4	3.60
NW6627	2	EMD	SD60	1986	RD/TRL	4				2	4		4		5		4	4	4	4	4	3.90
NW8732	2	GE	DASH 8	1992	RD/LD	4				2	4		4		5		4	4	4	4	4	3.90
NW8644	2	GE	39C-8	1986	RD/LD	4				1	4		4	3	5		4	4	3	3	4	3.55
NW7139	2	EMD	GP60	1991	RD/TRL	4				1	4		4	5	5		4	4	4	3	4	3.82
CR6854	2	EMD	SD60	1989	RD/LD	4		2	4	4	4	4	3	4	3	3	4	4	3	4	2	3.47
CR6286	2	EMD	C36-7	1967	RD/LD	4		2	4	4	4	3	4	3	5		4	4	3	1	1	3.29
NW8504	2	GE	C36-7	1981	RD/TRL	4				1	4		4		5		4	4	3	3	3	3.50
NW3327	2	EMD	SD40-2	1979	RD/LD	4				1	4		4	5	5		3	4	3	3	3	3.55
NW1647	2	EMD	SD40-2	1974	RD/TRL	4				4	4		4	4	5		4	4	3	3	3	3.82
CR8103	2	EMD	GP38-2	1973	RD/LD	4		4		4	4	4	4	4	5	3	4	4	4	4	4	4.00
CR6767	2	EMD	SD50	1984	RD/TRL	4		4		4	4	4	4	4	5	3	4	4	4	4	4	4.00
CR6439	2	EMD	SD40-2	1977	RD/LD	4		4		4	4	4	4	4	5	3	4	4	4	4	4	4.00
ATK270	2	EMD	F40PH	1977	RD/LD	4		4		4	4	4	3	4	5	4	4	4	4	4	4	4.00
CR7889	2	EMD	GP38	1971	SW/TRL	4		4		4	4	4	3	4	5	4	4	4	4	4	3	3.93
CR9417	2	EMD	SW100	1973	SW/TRL	4				4	4	4	4	4	5		4	4	4	4	4	4.08
CR8100	2	EMD	GP38-2	1973	SW/LD	4		4		4	4	4	3	3	5	3	4	4	4	4	4	3.86
SOU2840	2	EMD	GP38A	1971	SW/LD	4		4	4	4	4		4	4	5	3	4	4	4	4	4	4.00
NW2810	2	EMD	GP38	1970	RD/TRL	4				1	4		4	4	5		4	4	3	3	3	3.55
SOU2393	2	EMD	MP15	1979	SW/LD	4			4	4	4		4	4	5			4	4	4	4	4.09
SOU2364	2	EMD	MP15	1977	SW/LD	4			4	4	4		4	4	5		4	4	4	4	4	4.08
SOU2426	2	EMD	MP15	1982	SW/LD	4			4	4	4		4	4	5		4	4	4	4	4	4.08
CR7890	2	EMD	GP38	1971	SW/TRL	3		3		3	3	3	4	4	5	3	4	4	4	4	4	3.64
CR7739	2	EMD	GP38	1969	SW/LD	4		3		3	3	1	3	4	5	3	4	4	4	4	4	3.50
ATK348	2	EMD	F40PH	1980	RD/LD	4		4		4	4	4	4	4	5	3	4	4	4	4	3	3.93
ATK407	2	EMD	F40PH	1988	RD/TRL	4		4		4	4	4	4	4	5	3	4	4	4	4	4	4.00
ATK203	2	EMD	F40PH	1976	RD/TRL	4		2		4	4	4	4	4	5	3	4	4	4	4	4	3.86
SOU6555	3	EMD	SD60	1985	RD/LD	4		2	4	4	4		4	4	5	3	2	3	2	2	1	3.14
SOU6571	3	EMD	SD60	1985	RD/LD	4		4		4	4		4	4	2	1	3	3	2	2	4	3.15
SOU4608	3	EMD	GP59	1986	RD/LD	4		2	4	4	4		4	3	5	1	3	4	4	4	4	3.57
CSX7609	3	GE	C40-8	1993	RD/LD	4		2	4	4	4	4	4	4	5	3	4	4	4	4	4	3.87
CSX7721	3	GE	CW40-8	1991	RD/LD	4		4		4	4	4	4	4	5	1	1	3	3	2	4	3.36
NS8714	3	GE	D8-40C	1992	RD/LD	4		2	4	4	4	4	4	4	5	1	4	4	2	2	4	3.47
ATK822	3	GE	DASH 8	1993	RD/LD	4	4	4	4	4	4	4	4	4	5	4	5	4	4	4	4	4.13
IC3101	3	EMD	GP40R	'65/r'87	RD/LD	4		2	4	4	4		2	4	1	1	4	3	1	2	1	2.64
IC3137	3	EMD	GP40	1966	RD/LD	4		2	4	4	4	4	4	4	5	1	4	4	2	2	1	3.27
IC3126	3	EMD	GP40	'69/r'88	RD/LD	4		4	4	4	4		2	2	1	1	2	3	1	2	1	2.50
ATK219	3	EMD	F40PH	1976	RD/LD	4	4	4		4	4	4	4	2	5	1	4	4	4	1	1	3.33
ATK310	3	EMD	F40PH	1976	RD/LD	4		4	4	4	4	4	4	4	5	1	4	4	4	4	4	3.87

Table I-1: Winter Tests

WINTER TESTS

REGIONS 1 - 8

LOCO #	FRA REG	MANUF	MODEL	YEAR BUILT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOLER	FOOD STOR	SEAT COND	VISOR COND	GLAZE COND	TEMP LEVEL	FUMES	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEAN	CAB MAINT	AIR VAL EXHST	AVG
NS5125	3	EMD	GP38-2	1974	SW/LD	4		2	4		4		3	2	5	1	4	4	2	3	4	3.23
CSX6127	3	EMD	GP40-2	1975	RD/LD	4		4	4	4	4	4	4	4	5	3	4	4	4	4	4	4.00
CSX8101	3	EMD	SD40-2	1980	RD/LD	4		2	4	4	4	4	4	2	5	3	4	4	2	2	4	3.47
FEC403	3	EMD	GP40	1971	RD/LD	4	4	4	1		4	4	4	4	5	3	4	4	4	4	4	3.80
CSX8098	3	EMD	SD40-2	1980	RD/LD	4		4		4	4	4	1	3	5		4	4	4	4	4	3.77
CSX6214	3	EMD	GP40-2	1978	RD/LD	4		4	4	4	4	4	4	4	5	3	4	4	4	4	4	4.00
NW6146	3	EMD	SD40-2	1978	RD/LD	4		4	4	4	4		3	4	5	1	2	4	2	2	4	3.36
CSX7757	3	GE	DASH 8	1991	RD/LD	4		4	4		4	4	4	4	5	3	4	4	4	4	3	3.93
SOU3264	3	EMD	SD40-2	1978	RD/LD	4		1	4	4	4		3	3	5	1	2	4	2	2	1	2.86
SOU3303	3	EMD	SD40-2	1979	RD/LD	4		4	4	4	4		4	4	2	1	2	4	2	1	4	3.14
SOU9685	5	EMD	SD60	1990	RD/LD	4	1	4	4	4	4	4	4	3	5	3	4	4	4	4	4	3.75
SSW9707	5	EMD	GP60	1990	RD/TRL	4	1	4	1		4	4	4	3	5	1	4	4	4	4	4	3.40
UP2438	5	GE	C30-7	1978	RD/LD	4		4	4	4	4	4	4	2	5	3	3	3	4	4	4	3.73
UP3421	5	EMD	SD40-2	1978	RD/LD	4		4	1	1	4	4	4	3	5	3	4	4	4	4	4	3.53
UP3635	5	EMD	SD40-2	1979	RD/TRL	4		4	4		4	4	4	4	5	3	4	4	4	4	4	4.00
UP3678	5	EMD	SD40-2	1980	RD/TRL	4		2	3		4	4	4	4	5	4	4	4	3	2	3	3.57
UP3570	5	EMD	SD40-2	1979	RD/TRL	4		1	1		4	4	4	4	5	3	4	4	3	4	4	3.50
UP3514	5	EMD	SD40-2	1979	RD/LD	4		2	1	1	4	4	4	4	5	3	4	3	3	3	4	3.27
SP9342	5	EMD	SD45-2	1974	RD/LD	4	4	4	4		4	4	4	4	5	1	4	4	4	4	4	3.87
SSW9661	5	EMD	GP60	1989	RD/LD	4	1	4	1	1	4	4	4	4	5	3	4	4	4	4	4	3.44
SP7493	5	EMD	SD45	1984	RD/LD	4		1	4		3	3	4	4	5	3	4	4	4	4	4	3.64
SP7244	5	EMD	GP40-2	1984	RD/LD	4	1	2	4		3	4	4	3	5	3	4	4	4	4	4	3.53
KCS685	5	EMD	SD40-2	1978	RD/TRL	4		4	4		4		4	3	5	3	4	4	3	4	4	3.85
KCS680	5	EMD	SD40-2	1978	RD/LD	4		4	4	4	4		4	3	5	3	4	4	4	4	4	3.93
KCS656	5	EMD	SD40-2	1972	RD/TRL	4		4	4		4		4	4	5	4	4	4	4	4	4	4.08
KCS632	5	EMD	SD40	1971	RD/LD	4		4	4		4		4	2	5	1	4	4	4	3	4	3.62
UP2173	5	EMD	GP38-2	1980	TRL/LD	4		3	3		4	2	3	3	5	4	4	4	3	3	3	3.43
KCS4357	5	EMD	SW150	1972	SW/LD	4				4	4		4	4	5	1	4	4	4	4	4	3.83
ATSF2769	5	EMD	GP30	1983	RD/LD	4	4	4	4		4	4	4	4	5		4	4	4	4	4	4.07
ATSF2754	5	EMD	GP30	1982	RD/LD	4	4	3	4		4	4	4	4	5	1	4	4	4	3	4	3.73
ATSF2880	5	EMD	GP35	1983	YD/TRL	4	4	3	4		4	4	2	3	5	1	2	3	3	3	4	3.27
SP2700	5	EMD	MP15	1975	YD/TRL	4			4		4		4	2	5		4	4	4	4	4	3.91
SP2660	5	EMD	SW150	1972	YD/TRL	4					4	2	3	3	5		4	4	4	4	4	3.73
SP2498	5	EMD	SW150	1968	YD/LD	4			1		4		3	3	5		3	2	2	3	4	3.09
BN2324	5	EMD	GP38-2	1976	RD/TRL	4		4	4		4	2	4	1	5	4	4	4	4	4	4	3.71
ATSF2911	5	EMD	GP35	1982	RD/LD	4	4	4	4		4	4	4	3	5	1	4	4	4	4	4	3.80
ATSF3435	5	EMD	GP39-2	1987	RD/LD	4	4	4	4		4	4	4	4	5	1	1	4	4	4	4	3.67
SP2709	5	EMD	MP15A	1975	SW/LD	4					4	2	4	4	5		4	4	3	3	4	3.73
SP2706	5	EMD	SW150	1975	YD/LD	4					4	4	4	4	5		4	4	2	2	3	3.64
ATSF507	7	GE	D8-32B	1991	RD/LD	4	4	4	4	4	4	4	4	3	5	4	4	4	4	4	4	4.00
ATK505	7	GE	D8-32B	1991	RD/TRL	4	4	4	4	4	4	4	3	4	5	4	4	4	4	4	4	4.00
UP9001	7	GE	C-36-7	1985	RD/LD	4		3	3	3	4	4	4	2	5	3	3	4	3	3	4	3.47
SP7459	7	EMD	SD45-2	1982	RD/LD	4		3	4	4	4	4	1	4	5	3	4	4	3	3	4	3.60
SP8236	7	EMD	SD40-2	1980	RD/LD	4	4	3	4	4	4	4	4	4	5	4	4	4	3	4	4	3.94
UP1590	7	EMD	GP50-1	1977	SW/LD	4		3	4	4	4		3	3	5	4	4	4	4	4	2	3.71

Table I-1: Winter Tests (con't)

WINTER TESTS

REGIONS 1 - 8

LOCO #	FRA REG	MANUF	MODEL	YEAR BUILT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOLER	FOOD STOR	SEAT COND	VISOR COND	GLAZE COND	TEMP LEVEL	FUMES	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEAN	CAB MAINT	AIR VAL EXHST	AVG
SP8351	7	EMD	SD40	1974	RD/LD	4	4	4	4	4	4	4	4	4	5	3	3	3	3	3	3	3.69
SP8315	7	EMD	SD40-2	1978	RD/TRL	4	4	1	2		4	4	2	4	2	3	3	2	1	1	4	2.73
GATX7378	7	EMD	SD40-2	1975	RD/TRL	4		1			3	3	3	4	2	1	3	3	3	3	3	2.77
UP3613	7	EMD	SD40-2	1979	RD/TRL	4		2			4	3	4	3	2	2	3	2	3	3	4	3.00
ATK294	7	EMD	F40PH	1977	RD/LD	4	4	4	4	4	4	4	4	4	5	2	4	4	4	4	4	3.94
ATK291	7	EMD	F40PH	1978	RD/TRL	4	4	4	4	4	4	4	3	3	1	2	4	4	3	3	4	3.44
ATK351	7	EMD	F40PH	1980	RD/LD	4	4	4	4	4	4	4	4	3	5	2	4	4	4	4	4	3.88
ATK295	7	EMD	F40PH	1977	RD/TRL	4	4	4	4	4	4	4	4	4	5	2	4	4	4	4	4	3.94
ATK250	7	EMD	F40PH	1976	RD/LD	4	4	4	4		4	4	4	4	5	2	4	4	4	4	3	3.87
SP1537	7	EMD	SD-7	1953	SW/LD	4			2		4	4	4	2	5		4	4	4	4	4	3.46
SP1504	7	EMD	SD-7	1979	SW/LD	4			3	4	4	3	2	3	5		4	4	3	3	4	3.54
ATSF2296	7	EMD	GP-9	1980	SW/LD	3	3	2	4	4	4	2	4	4	5	3	4	2	3	3	4	3.38
ATSF2260	7	EMD	GP-9	1978	SW/LD	4	4	2	2	2	4	4	4	4	1		4	4	4	4	3	3.33
UP1595	7	EMD	GP-15-	1977	SW/LD	3		3	3	3	3	3	4	4	5	3	4	4	4	4	4	3.60
SP1531	7	EMD	SD-7	1950	SW/LD	4		1	3	3	4		4	4	5		4	4	4	4	3	3.62
SP1508	7	EMD	SD-7	1953	SW/TRL	3			3	3	3	3	3	3	5		3	3	3	3	3	3.15
ATSF3671	7	EMD	GP39-2	1977	SW/LD	4	4	4	4	4	4	4	3	2	5	2	3	4	4	3	4	3.63
ATSF2894	7	EMD	GP35	1984	SW/LD	3	3	3	3	3	3	3	4	3	5	3	4	3	3	3	3	3.25
ATK517	7	GE	D8-32	1991	RD/TRL	4	4	3	4	4	4	4	4	2	5	3	4	4	5	4	4	3.88
ATK525	7	GE	DASH 8	1990	RD/LD	4	4	4	4	4	4	4	4	4	5	3	4	4	4	4	4	4.00
ATSF119	7	EMD	GP60M	1990	RD/TRL	4		2	4	4	4	4	3	4	5	3	4	4	3	3	4	3.67
UP6037	7	EMD	SD60	1986	RD/LD	4		4	4	4	4	3	4	4	5	3	4	4	4	4	4	3.93
SP7505	7	EMD	SD45-2	1985	RD/LD	4		3	4	4	4	4	4	4	5	3	4	4	4	4	4	3.93
UP9242	7	GE	C40-8	1988	RD/TRL	4		3	3	4	4	4	4	3	1	3	4	3	3	4	4	3.40
ATK516	8	GE	D8-32B	1991	RD/LD	4	4	3	4	4	4	4	4	4	5	5	4	4	4	4	4	4.06
ATK519	8	GE	D8-32B	1991	RD/TRL	4	4	5		4	5	4	4	5	2	5	4	5	4	4		4.21
SSW9653	8	EMD	GP60	1989	RD/TRL	4		1	4	4	2	4	4	4	1	3	4	4	2	2	4	3.13
SP9748	8	EMD	GP60	1991	RD/LD	4		1	1	1	4	4	4	2	1	3	4	4	4	3	1	2.73
BN7119	8	EMD	GP40-2	1976	RD/LD	4		3	3	3	3	2	2	2	5	4	4	4	3	3	3	3.20
BN6364	8	EMD	SD40-2	1972	RD/TRL	4		1	4	4	4	4	3	2	1	3	4	4	3	3	4	3.20
BN6313	8	EMD	SD40	1971	RD/LD	4		3	4	4	4	4	3	2	1	2	4	4	2	3	1	3.00
BN6804	8	EMD	SD40-2	1973	RD/LD	4		3	4	4	4	2	3	2	1	3	4	2	3	3	3	3.00
BN7826	8	EMD	SD40-2	1974	RD/TRL	3			2	2	4		4	2	2		3	3	2	2	3	2.67
SP7362	8	EMD	SD40-2	1984	RD/TRL	2		2			2	3	4	3	2	3	4	4	4	2	4	3.00
SP7803	8	EMD	SD40-2	1980	RD/LD	3		1	1	1	3		2	2	5	3	4	4	1	1	5	2.57
SP8567	8	EMD	SD40-2	1979	RD/LD	4		4	4	4	4	4	4	2	5	3	4	4	3	2	4	3.67
SSW6869	8	EMD	SD40-2	1989	RD/TRL	4		4	4	4	4	4	3	4	5	3	4	4	4	3	4	3.87
SP7486	8	EMD	SD45-2	1983	RD/TRL	4		2	4	4	4	4	3	3	2	3	4	4	4	3	4	3.47
SP8517	8	EMD	SD40-2	1978	RD/LD	4		4	4	4	1	4	4	2	5	3	4	3	3	3	3	3.40
BN7069	8	EMD	SD40-2		RD/TRL	4		4	4	4	3	4	3	2	1		4	4	3	3		3.31
BN7041	8	EMD	SD40-2	1978	RD/LD	4		4	4	4	4		4	3	5	3	4	4	4	4	4	3.93
BN7801	8	EMD	SD40-2	1977	RD/LD	4		4	4	4	4	2	4	2	2	3	4	4	4	4	4	3.53
BN8071	8	EMD	SD40-2	1979	RD/LD	4		4	4	4	4	4	4	2	5	3	4	4	4	4	2	3.73
BN6828	8	EMD	GP40-2	1978	RD/LD	4		2	4	4	4	3	3	3	5	3	4	4	2	2	1	3.20
ATK317	8	EMD	GP40P	1979	RD/LD	4		4	4	4	4	4	4	2	5	1	2	4	4	4	1	3.40

Table I-1: Winter Tests (con't)

WINTER TESTS

REGIONS 1 - 8

LOCO #	FRA REG	MANUF	MODEL	YEAR BUILT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOLER	FOOD STOR	SEAT COND	VISOR COND	GLAZE COND	TEMP LEVEL	FUMES	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEAN	CAB MAINT	AIR VAL EXHST	AVG
ATK361	8	EMD	F40PH	1981	RD/TRL	4		4			4	4	4	3	5		4	4	4	4	4	4.00
ATK203	8	EMD	F40PH	1976	RD/LD	4		4	3	3	2	4	2	3	5	1	4	4	3	3	3	3.20
BN2871	8	EMD	GP39-2	1991	SW/LD	4		4	4	4	4	4	4	3	5	3	4	4	4	2	3	3.73
SP4440	8	EMD	SD-9	1980	SW/LD	4		4	4	4	3	2	4	4	5	3	4	4	3		1	3.50
SP2577	8	EMD	SW150	1970	SW/LD	2			4	4	4	2	2	3	5		4	4	3	3	4	3.38
SP4352	8	EMD	SD-9	1972	SW/LD	2		2	4	4	3		2	2	5	3	3	3	3	3	4	3.07
SP4344	8	EMD	SD-9	1974	SW/LD	4		1	4	4	2	3	4	3	5	3	4	4	3	3	1	3.20
BN6122	8	EMD	SSD-9	1958	SW/LD	4		2	2	3	2	4	2	3	5	3	4	2	2	2	1	2.73
UP1305	8	EMD	MP15	1974	SW/LD	4			4	4	3	2	2	4	5		3	3	2	2	4	3.23
UP1312	8	EMD	MP15	1975	SW/LD	4			4	4	2		2	4	5		4	3	2	3	4	3.42
UP1311	8	EMD	MP15	1975	SW/LD	3			3	3	3	2	2	4	5		4	4	3	2	4	3.23
BN6195	8	EMD	SD-9	1957	SW/LD	4		4	4	4	4	3	3	4	5	3	4	3	3	2	3	3.53
BN389	8	EMD	SW10	1972	SW/LD	4			4	4	2	4	2	3	5		4	4	4	4	4	3.69
GTW5714	4	EMD	GP38-2	1972	RD/LD	4		4	1	4	4	4	4	2	5	3	4	4	4	4	4	3.67
GTW6425	4	EMD	GP40-2		RD/TRL	4		4	4	4			4	3	5	3	4	4	4	4	4	3.92
GTW6204	4	EMD	GP38	1966	RD/LD	4		4	4	4	4	4	4	3	5	3	4	4	4	4	4	3.93
GTW5827	4	EMD	GP38-2	1978	RD/TRL	4		4	3	3			4	4	5	3	4	4	4	4	4	3.85
ATSF3026	4	EMD	GP20 D	1961	RD/LD	4	4	1	4	4	4	4	4	3	5	3	4	4	5	4	4	3.81
ATSF3439	4	EMD	GP39-2		RD/TRL	4	4	3	3		4	4	4	4	5	3	4	4	4	4	4	3.87
CR1687	4	EMD	GP15-1	1979	SW/LD	4		4	4	4	4	4	4	3	5	4	4	4	4	4	1	3.80
SOO6027	4	EMD	SD60	1989	SW/LD	4		4	4	4	4	4	4	4	3	4	4	4	4	4	4	3.93
SOO4418	4	EMD	GP38-2	1979	RD/TRL	4		1	4	4	4	4	4	3	2	1	4	4	4	2	1	3.07
SOO6000	4	EMD	SD60	1987	RD/LD	4		1	4	4	4	4	4	2	5	1	4	4	4	4	1	3.33
SOO777	4	EMD	SD40-2	1974	RD/TRL	4		1	4		3	4	4	3	5	1	4	4	2	3	3	3.21
SOO6047	4	EMD	SD60	1989	RD/LD	4		1	4	4	4	4	4	3	5	1	4	4	4	4	1	3.40
UP1394	4	EMD	MP15A	1980	YD/LD	4				4	4	3	4	4	5		4	4	4	4	4	4.00
CNW5534	4	EMD	GP40	1965	RD/LD	4		4	2		4	2	4	3	5		3	4	4	4	3	3.54
CNW5522	4	EMD	GP40	1965	RD/LD	4		4	4		3	2	2	3	5	1	3	4	4	4	3	3.00
CNW6651	4	EMD	SD38-2	1975	RD/LD	4		4		3	4	4	2	3	4	3	3	4	3	3	4	3.43
ATK287	4	EMD	F40PH	1978	RD/LD	4		4	4	4	4	4	4	3	1	1	4	4	4	4	1	3.33
ATK367	4	EMD	F40PH	1981	RD/LD	4		4	4	4	4		3	4	4	1	4	4	4	4	1	3.50
ATSF137	6	EMD	GP60M	1990	RD/TRL	4	4	1	1	2	3	4	3	3	1	1	4	4	2	2	4	2.69
BN8132	6	EMD	GP40-2	1980	RD/LD	4		3	4	4	4	4	4	2	5	3	2	2	2	2	2	3.13
BN5012	6	GE	GEC30-	1989	RD/LD	3		4	4	4	3		4	3	5	4	4	4	4	4	4	3.86
SSW9668	6	EMD	GP60	1990	RD/TRL	4	1	1	4	3	2	3	2	3	5	4	4	4	4	4	4	3.25
SSW9709	6	EMD	GP60	1990	RD/TRL	4	1	4	2	2	4	4	3	3	5	1	2	4	4	4	4	3.19
ATK240	6	EMD	F40PH	1977	RD/TRL	4		4	4	4	4	4	2	2	5	1	4	4	3	2	4	3.40
ATK204	6	EMD	F40PH	1977	RD/LD	4	4	1	4	4	4	4	2	3	5	1	4	4	4	4	3	3.44
KCS639	6	EMD	SD40-2	1972	RD/LD	4			4	1	1		4	4	2		1	4	4	4	4	3.08
BN5553	6	GE	GEC 30	1978	RD/LD	3		2	4	4	2	2	4	2	5	3	2	4	4	3	3	3.13
ATSF543	6	GE	DASH8-	1991	RD/TRL	4	4	4	4	4	4	4	1	4	5	4	4	4	4	4	4	3.88
SP9753	6	EMD	GP60	1991	RD/LD	4	4	4	4	4	3		3	4	3	3	3	3	3	3	3	3.40
SP6855	6	EMD	SD45T	1989	RD/LD	4	4	3	2	4	4		3	3	3	1	3	3	3	3	3	3.07
UP3815	6	EMD	SD40-2	1977	RD/LD	4		3		3	3		3	4	3	4	4	4	3	3	3	3.38
UP1403	6	EMD	MP15A	1976	SW/TRL	4		1	3	1	1	3	2	1	3	1	3	3	3	3	3	2.33

Table I-1: Winter Tests (con't)

WINTER TESTS

REGIONS 1 - 8

LOCO #	FRA REG	MANUF	MODEL	YEAR BUILT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOLER	FOOD STOR	SEAT COND	VISOR COND	GLAZE COND	TEMP LEVEL	FUMES	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEAN	CAB MAINT	AIR VAL EXHST	AVG
UP1404	6	EMD	MP15A	1976	SW/TRL	3		1	3	3	1	3	1	3	3	1	3	3	3	3	3	2.47
UP4249	6	EMD	SD40-2	1978	RD/TRL	4		1			3	3	2	3	3	1	3	1	3	3	3	2.54
BN5051	6	GE	C30-7	1980	RD/TRL	4		2	3		3	3	4	3	3	3	3	3	3	4	3	3.14
ATSF2300	6	EMD	GP38	1984	RD/TR	3		2	3	3	4	4	3	3	1	1	3	4	4	4	4	3.07
ATSF2332	6	EMD	GP38	1984	RD/LD	4	4	4	4		4	4	4	3		1	3	4	4	3	4	3.57
BN7069	8	EMD	SD40-2		RD/TR	3		4	4	4	3	4	3	1	1	1	4	4	3	3		3.00
CR8163	6	EMD	GP38-2	1977	RD/SW	4		4	4	4	4	4	4	5	5	4	4	4	4	5	4	4.20
BN2119	6	EMD	GP38-2	1971	YD/LD	4		4	4	4	4	4	4	3	5	5	4	4	4	5	4	4.13
ATK206	1	EMD	F40PH	1976	RD/TRL	4		4		4	4	4	4	4	5	1	4	4	4	4	4	3.86
ATK207	1	EMD	F40PH	1976	RD/LD	4		4		4	4	4	4	4	5	1	4	4	4	4	4	3.86
ATK332	1	EMD	F40PH	1980	RD/LD	4		4		4	4	4	4	4	5	1	4	4	4	4	4	3.86
FEC405	3	EMD	GP40	1971	RD/LD	4	4	4	2		4	4	4	4	5	4	4	4	4	2	4	3.80
CSX6705	3	EMD	GP40		SW/LD	4		4	4	4	4		3	4	5	1	4	4	4	4	1	3.57
CSX1914	3	GE	U-18B	1973	RD/LD	4		2			4		4	3	5	1	4	4	2	2	4	3.25
UP3523	3	EMD	SD40-2	1979	RD/LD	4		4	4	4	4	4	4	3	5	1	4	4	4	4	4	3.80
FEC651	3	EMD	GP9	1954	RD/TRL	4		1	2		4	4	4	3	1	1	4	4	4	4	3	3.07
IC1433	3	EMD	SW14	1980	SW/LD	4			4	4	4		2	4	5		4	4	1	2	1	3.25
CSX2556	3	EMD	GP38-2	1972	SW/LD	4				4	4	4	4	3	5		1	1	1	1	1	2.75
CSX2507	3	EMD	GP38-2		SW/LD	4				4	4	4	4	3	5		4	4	4	4	4	4.00
IC1467	3	EMD	SW14	1981	SW/LD	4			4	4	4		4	2	5		4	3	2	2	1	3.25
CG5224	3	EMD	GP38-2	1977	RD/LD	4		1	4	4	4		4	3	1		4	4	2	2	1	2.92
SOU5117	3	EMD	GP38-2	1974	RD/LD	4		4	4	4	4		4	2	5		3	3	2	2	1	3.23
SOU2788	3	EMD	GP38-2	1970	RD/LD	4			4	4	4		4	4	5		4	4	4	2	4	3.92
SOU5082	3	EMD	GP38-2	1973	YD/LD	4		3	4	4	4		2	3	2		4	4	2	2	4	3.23
SOU2320	3	EMD	SW150	1968	YD/LD	4			4	4	4	4	2	4	5		4	4	4		1	3.67
						3.90	3.52	3.07	3.54	3.56	3.73	3.64	3.52	3.31	4.37	2.48	3.71	3.78	3.40	3.32	3.38	

Legend: 1/Unacceptable, 2/Poor, 3/Acceptable, 4/Good, 5/Excellent

Table I-1: Winter Tests (con't)

SUMMER TESTS

REGIONS 3, 5 & 7

LOCO #	RE	BUILD	MODEL	YR BLT	TYPE/ USE	HEAT COND	A/C COND	TOILET COND	WATER COOL	FOOD STOR	SEAT COND	VISO COND	GLAZ COND	TEMP LEVEL	FUMES ODORS	TOILET VENT	PASSAGE COND	FLOOR COND	CAB CLEA	CAB MAIN	AIR VALV EXHAUST	AVG.
UP3934	5	EMD	SD40-2	1979	road/lead	4		3	3	1	4	3	3	1	5	2	4	4	4	3	4	3.20
UP6115	5	EMD	SD60-M	1989	road/lead	4		3	3	3	3	3	4	1	5		4	4	4	4	2	3.36
SSW9657	5	EMD	GP60	1989	road/trial	4		4	3		3	3	3	2	5	3	4	4	4	4	4	3.57
UP2443	5	GE	C-30-7	1979	road/trail	4		4	3	3	3	3	3	2	5	3	4	4	4	4	4	3.53
SP9781	5	EMD	GP60	1993	road/lead	5	5	4	4	4	4	4	5	4	5		4	4	4	4	4	4.27
SP9733	5	EMD	GP60	1991	road/lead	5	5	2	4	4	4	4	4	5	5	3	4	4	4	4	4	4.06
MP2167	5	EMD	GP38-2	1980	yard/lead	4		2	4	4	4	1	2	2	2	3	4	4	3	3	3	3.00
MP2197	5	EMD	GP38-2	1980	road/lead	4		1	4	1	4	4	4	1	5	3	4	4	3	3	2	3.13
ATK249	5	EMD	F40PH	1977	road/lead	4	1	4	4		3	3	4	2	5	3	3	3	4	4	3	3.33
SP7848	5	GE	R-30-7	1984	road/trail	4		3	4	4	4	4	4	1	5	3	4	4	4	4	2	3.60
CSX2542	3	EMD	GP38-2	1973	road/lead	4		3	2	2	3	3	4	2	4	3	3	3	2	2	2	2.80
CSX6923	3	EMD	GP40-2	1980	road/lead	4		3	2	2	3	3	4	2	4	3	3	3	2	2	2	2.80
CSX8317	3	EMD	SD40-2	1970	road/lead	4		3	2	2	3	3	4	1	4	3	3	3	2	2	2	2.73
FEC415	3	EMD	GP40-2	1972	road/lead	4	3	3	3	3	3	3	4	3	4	3	3	3	3	3	3	3.19
CSX6901	3	EMD	GP40-2	1980	road/lead	4		3	2	2	3	3	4	1	4	3	3	3	2	2	2	2.73
SOU7022	3	EMD	GP50	1980	road/lead	4		3	3	3	3	3	4	2	4	3	3	3	3	3	2	3.07
SOU7044	3	EMD	GP50	1980	road/lead	4		3	3	3	3	3	4	2	4	3	3	3	3	3	2	3.07
SOU3291	3	EMD	SD40-2	1978	road/lead	4		3	3	3	3	3	4	2	4	3	3	3	3	3	2	3.07
SOU2740	3	EMD	GP38	1969	road/lead	4		3	3	3	3	3	4	2	4	3	3	3	3	3	2	3.07
SOU1624	3	EMD	SD40	1971	road/lead	4		3	3	3	3	3	4	4	4	3	3	3	3	3	2	3.20
ATK507	7	GE	DASH 8	1991	road/lead	4	4	4	4	4	4	4	4	5	5	3	4	4	5	5	3	4.13
SP8148	7	GE	DASH 9	1994	road/trail	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	3	4.75
SP8149	7	GE	DASH 9	1994	road/lead	5	4	3	4	4	4	4	4	2	5	3	3	3	3	3	3	3.56
SP8036	7	GE	B39-8	1987	road/trail		3	1	4	4	4	1	3	1	1	1	4	4	4	4	3	2.80
ATSF8140	7	GE	C-30-7	1981	road/trail			3	1	4	4	3	2	1	5	3	4	4	4	3	3	3.14
SP9679	7	EMD	GP60	1990	road/lead		1	1	3	3	4	2	4	1	5	3	3	3	3	3	3	2.80
SP8008	7	GE	B-39-8	1987	road/lead		3	1	4	4	3	3	2	1	5	3	4	3	4	4	3	3.13
SP8334	7	EMD	SD40-2	1979	road/trail		1	2	4	4	3	3	1	1	1	3	4	4	3	3	3	2.67
SP8363	7	EMD	SD40 T	1978	road/lead		1	3	3	3	3	3	3	2	5	3	4	4	2	4	3	3.07
SP6787	7	EMD	SD45 T	1982	road/lead			1	4	4	4	3	3	1	1	1	1	4	4	4	3	2.71
						4.17	3.00	2.80	3.27	3.18	3.47	3.1	3.57	2.07	4.17	2.86	3.47	3.57	3.37	3.37	2.77	3.24

Legend: 1/Unacceptable, 2/Poor, 3/Acceptable, 4/Good, 5/Excellent

Table I-2: Summer Tests

APPENDIX J

HEAT EFFECTS ON HUMANS

HEAT EFFECTS ON HUMANS: REACTIONS OF THE BODY TO HOT ENVIRONMENTS[1]

The body produces heat and must dissipate it. As in cold environments, two primary means exist to control the energy flow:

- o blood distribution; and
- o metabolic rate.

In hot environments, the body must dissipate heat instead of preventing, as in cold weather, heat loss.

Blood is redistributed to allow heat transfer to the skin. For this, the skin vessels are dilated and the superficial veins are fully opened, actions directly contrary to the ones taken in the cold. This may bring about a fourfold increase in blood flow above the resting level, increasing the conductance of the tissue. Accordingly, energy loss through convection, conduction, and radiation (which all follow the temperature differential between skin and environment) is facilitated.

If heat transfer is still not sufficient, sweat glands are activated and the evaporation of the produced sweat cools the skin (note: The energy needed to evaporate water is approximately 2,440 J cm^{-3}). Recruitment of sweat glands from different areas of the body differs among individuals. Some persons have few sweat glands, while most have at least 2 million sweat glands in the skin. Hence, large differences in the ability to sweat exist among individuals. The activity of each sweat gland is cyclic. The overall amount of sweat developed and evaporated depends very much on clothing, environment, work requirements, and on the individual's acclimatization.

If heat transfer by blood distribution and sweat evaporation is insufficient, muscular activities must be reduced to lower the amount of energy generated through metabolic process. In fact, this is the final and necessary action of the body if otherwise the core temperatures would exceed tolerable limits. If the body has to choose between unacceptable overheating and continuing to perform physical work, the choice will be in favor of core temperature maintenance, which means reduction or cessation of work activities.

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[1] Advances in Human Factors/Ergonomics, Book 4, Engineering Physiology: Physiologic Bases of Human Factors/Ergonomics by K.H.E. Kroemer, H.J. Kroemer, and K.E. Kroemer-Elbert of the Ergonomics Research Institute, Inc. in Blacksburg, VA 24060

Indices of Heat Strain

There are several signs of excessive heat strain on the body. The first one is the sweat rate. Above the so-called insensible perspiration (in the neighborhood of about 50 cm^3 hr^{-1}) sweat production will increase depending on the heat that must be dissipated. In strenuous exercises and hot climates, several liters of sweat may be produced in 1 hour. However, on the average, during working time usually not more than about 1 liter per hour is produced, but sweat losses up to 12 liters in 24 hours have been reported under extreme conditions. Sweat begins to drip off the skin when the sweat generation has reached about one-third of the maximal evaporative capacity. Of course, sweat running down the skin contributes very little to heat transfer.

Increases in the circulatory activities signal heat strain. Cardiac output must be increased, which is mostly brought about by a higher heart rate. This may be associated with a reduction in systolic blood pressure. Another sign of heat strain is a rise in core temperature, which must be counteracted before the temperature exceeds the sustainable limit.

The water balance within the body provides another sign of heat strain. Dehydration indicated by the loss of only 1 to 2 percent of body weight can critically affect the ability of the body to control its functions. Hence, the fluid level must be maintained, which is best accomplished by frequently drinking small amounts of water. Sweat contains different salts, particularly NaCl, in smaller concentrations than in the blood. Hence, sweating, which extracts water from plasma, augments the relative salt content of the blood. Normally, it is not necessary to add salt to the water drunk since in western diets the salt in the food is more than sufficient to resupply the salt lost with the sweat.

Water supply to the body comes from fluids drunk, water contained in food, and water chemically liberated during oxidation of nutrients. Daily water losses are approximately:

- from gastrointestinal tract (0.2 liters);
- from respiratory tract (0.4 liters);
- through skin (0.5 liters); and
- from kidneys (1.5 liters).

Obviously, these figures can change considerably when a person performs work in a hot environment.

The least important reactions to heavy exercise in excessive heat are sensations of discomfort, and perhaps skin eruptions ("prickly heat") associated with sweating. Also as a function of sweating, so-called "heat cramps" may develop, which are muscle spasms related to local lack of salt. They may occur after quickly drinking large amounts of fluid.

APPENDIX K

SANITARY FACILITY PRACTICES

There are several sources of information that address acceptable practices for sanitary facilities. Some useful sources are listed below which will help the railroad industry develop/implement industry-wide guidance on providing locomotive acceptable sanitary facilities. In addition, various industrial associations have established, through industry-wide sanitation committees, practice codes related to the particular industry.

- Occupational Safety and Health Administration, 29 CFR 1910.141, Sanitation.
- Occupational Safety and Health Administration, 29 CFR 1910.142, Temporary Labor Camps.
- Food and Drug Administration, 21 CFR 1250, Interstate Conveyance Sanitation.
- American National Standards Institute, American National Standard Minimum Requirement for Sanitation in Places of Employment Z.41-1968.
- U.S. Public Health Service, Handbook On Sanitation of Railroad Servicing Areas.
- American Foundrymen's Association, Code of Recommended Practices for Industrial Housekeeping and Sanitation.
- National Safety Council, Industrial Sanitation and Personnel Facilities, Accident Prevention Manual for Industrial Operations.
- Association of Food Industry Sanitarians and National Cancer Association, Sanitation for the Food Preservation Industries.
- National Institute for the Food Service Industry, Applied Food Service Sanitation.
- Various state regulations of Departments of Labor and Divisions of Industrial Hygiene.

APPENDIX L

CAB HUMAN FACTORS DESIGN

INTRODUCTION

In the event of an impending accident, the locomotive engineer cannot even attempt to redirect his vehicle to avoid or mitigate the effects of an impact, as operators of other vehicles can. Because, unlike many operators of other large transportation vehicles and craft, the locomotive engineer can only operate his vehicle in a forward or reverse direction; he cannot move left or right, or up and down.

Thus, the engineer's work area and operating controls should be designed as a tradeoff between operator vigilance, workload, security, and safety.

Since engineers may spend as many as 12 hours on a locomotive, they have an interest in how its cab is designed. Also, engineers in different parts of the country are going to have different needs and desires. The employing railroad has to spend more than $2.0 million to purchase a new locomotive. These different interests and needs add up to ensure that locomotives for different railroads will have a different look and feel.

Besides the design issues to overcome with this arrangement, locomotive engineers may be reluctant to use this arrangement. A plan should be developed for addressing this normal resistance and helping engineers make the transition to a new arrangement.

CONTROLS AND DISPLAY RELATIONSHIPS

Controls are what the human operator uses to change the state of the machine he or she is operating. Displays are those gauges that the operator uses to monitor the state or change of state of the machine. Thus, controls and displays work in unison to provide the operator with the tools he or she needs to operate a machine.

Because of this human interconnection, displays are usually located above controls, in the same way that eyes are above hands and feet. Good design also has displays located as close as possible to the controls that affect them. If this is not possible, then the arrangement of displays should be similar to that of the controls.

When laying out the engineer's workspace, the designer should keep safety as a top priority. The design should minimize potential safety hazards through good understanding of the tasks to be performed, and proper location of instruments and their housings.

Instrument panel design usually begins by determining the observer's position and then arranging the instruments accordingly. In locomotive cab design, just the opposite occurs. The instruments are located first and then the engineer's seat is positioned. One manufacturer follows this approach because of a concern for creating a crashworthiness envelope to protect the engineer.

However, this latter method tends to force the engineer to adapt to the locomotive rather than adapting the locomotive to the engineer. As an example, consider the body contortions an engineer had to make in using the traditional cab stand versus that required with the workstation arrangement. Yet, it is clear that the industry is taking steps to make the engineer the priority.

Work area design must also address ingress and egress. An engineer should be able to get into and out of a properly adjusted chair without any adjustments. Particularly important is that normal egress should lead to or go through the crash protection envelope. Care should be taken that this pathway is not obstructed by controls nor conflicts with other crew or people in the cab.

In the arrangement of instrument panels one wonders which comes first, the controls or displays? Generally, designers arrange the displays and then the associated controls. However, given the relatively large physical size of locomotive controls and the typically smaller displays arranging the controls is a higher priority. But, like any design function, there will be several iterations of control display arrangements before the "best" compromise arrangement is achieved.

When planning the arrangement of the instrument panels and the engineer's seat, there should be sufficient clearance between the instruments and the seat to allow easy ingress and egress by engineers. Design clearance should be based on the 95th percentile of locomotive engineers for the particular railroad. National standards should not be used as they may suggest too wide a spread and may be skewed to the low side.

SAE Standard J898, Control Locations for Off-road Work Machines, October 1987 outlines the zones of comfort and reach for hands and feet relative to the Seat Index Point (SIP). The outer limit of the zone of comfort from the SIP is 22 inches for hands, while the outer limit for the zone of reach 33.5 inches. In the vertical plane the outer limit of the zone of comfort referenced from the SIP is from 3.94 inches below to 16.75 inches above for hands, while the outer limit for the zone of reach is from 9.84 inches below to 39.17 inches above.

All main controls, including their full range of motions, should be within the zones of comfort with auxiliary controls placed within the larger zones of reach.

Edges should be rounded, protective coverings used on levers, pinch points eliminated, shatterproof glass used, switches recessed, and displays/controls well labeled.

CONTROLS

There are many controls located in a locomotive cab. In this discussion, the controls are grouped into three basic categories: internal, external, and combined depending upon (a) where the engineer might be focusing his attention, and (b) the stimulus for using the control.

The combined category exists because it is not known whether an engineer would be using the controls because of a stimulus inside the cab or outside the cab.

There are only four or five primary controls in a locomotive, depending upon the specific configuration being used. These are the reverser, throttle, dynamic brake, train brake, and independent brake. While these controls are all separate on the traditional cab stand, in workstation arrangements the throttle and dynamic brake are often combined into one control.

When new controls are introduced, designers also should consider that behavior patterns might change. For example, one engineer has reported that he tends to watch gauges more when using a continuous throttle. This tendency might be exacerbated if the cab speedometer is digital rather than analog.

There are two different opinions regarding the direction workstation throttle and brake controls should be moved to increase speed and braking. Both sides seem to agree that the throttle control lever should go in one direction and the brake levers in the opposite direction. The question is which way should they move.

On one hand, some feel that the throttle should be pulled forward so that an unconscious engineer slumping forward over the work station would tend to remove power and apply the brakes (Kingsley, 1980). It has also been stated that a track perturbation could cause an engineer to push the control forward if his hand were on the control at the time of the unexpected impulse. If this occurred with this control arrangement, he would be slowing the train not causing it to accelerate.

On the other hand, for most hand braking situations, brakes are applied by pulling the controls toward the operator. Examples are motorcycle or bicycle brakes, hand-operated parking brakes on an automobile, or even the reigns on a horse.

When specifying a control, one must first consider the intended function of the control. There are four basic types of functions. Bailey (1989) defines these as:

- o Activation: a binary two-position control, usually either on or off. A room light switch is an example;
- o Discrete Setting: a control requiring three or more discrete settings. The locomotive throttle is an example;
- o Quantitative settings: a control requiring continuous setting (i.e., infinitely variable through the range). The locomotive dynamic brake control is an example; and

- o Continuous control: a control requiring constant adjustment. A sailboat's rudder is an example.

He also states that foot controls should be considered when moderate to large forces (greater than 20 to 30 pounds) are required or the hands are overburdened with other tasks. Each foot should not have more than two controls assigned to it, and these should only require fore and aft or ankle flexion movement.

Bailey further states that the force, speed, accuracy, and range of body movements required to operate a control should never exceed the capability limits of the least capable user. In fact, these performance requirements should be considerably less than the abilities of the least capable user. In addition, control surface should be designed to prevent the finger, hand or foot from slipping.

Another consideration in the design of controls is the amount of resistive force a control will provide. With too little resistive force, a control may be inadvertently actuated. Too much force and the operator may quickly become exhausted or injured from operating the control.

In some instances, the feel of a control may be carried over into newer designs of the same control. This may be desirable from a perspective of consistency. However, the designer must be aware that there may be time when such consistency should be avoided. This is particularly true if the newer design operates in a different direction, has a different location, is operated by a different part of the body (hand versus whole arm, knee versus foot, arm versus leg), or has a different range of motion.

Given the dual nature of the controls in the combined branch, they should have the highest priority in their placement. The motion controls should be placed directly in front of the engineer with the brake module on the right and the reverser and throttle on the left. The radio hand controls should be placed on the left hand side to allow an engineer to operate the locomotive motion controls with his right hand while still using the radio with his left hand. This arrangement could be especially helpful when moving cars in and out of a consist. These controls should be located within the zone of comfort for hands.

Controls for the sanders, whistle, horn, headlights, radio and microphone, should be located at least within the zone of reach and preferably within the zone of comfort, if possible.

Controls should be arranged to minimize engineers changing their position solely to operate a control. Position all controls so that, in manipulating them, operators do not appreciably move their nominal eye reference and possibly miss seeing important events occurring outside or on the principal internal display (Woodson 1992).

Controls should be arranged according to the order they are expected to be used. Tracing the sequence of control use will help identify poor arrangements. Note though that the brake module containing the controls for the train and independent brake should be positioned for one hand operation when moving in either direction. The location will tend to favor operation by the right hand because American locomotive engineers are seated on the right side. Controls should operate according to generally accepted control motion expectations.

Controls should be consistent with normal limb motions. This means that where arm motions are needed they should be forward and back, not sideways. Compare the workstation arrangement of the primary controls versus the cab stand arrangement.

Controls that have a similar function or purpose should be grouped together. Several methods can be used to reinforce the grouping such as location; shape, size, and color coding; mode of operation coding, and labeling. Care should be taken when dimensional coding is used to ensure that all engineers will be able to operate the controls and not activate another control inadvertently. This is especially important in cold northern climates when engineers can be expected to wear bulky clothes and winter gloves. Typically hand controls should have as a minimum 50 mm clearance between the control and any other control or adjacent surface (Kingsley 1980).

Given the principle of control motion expectancy, pushing the throttle lever forward and the brake levers back may be easier to learn and get accustomed to than having the levers move in the opposite direction.

ELECTRO-MECHANICAL DISPLAYS

Displays are essential for monitoring both the state of the train and the state of the locomotives. They are the only means an engineer has of knowing what is going on with the train and its various systems. As stated earlier, engineers must be able to read the displays at a glance. Specifically, instrument panel layout should facilitate both rapid identification of system states (in particular, failures), and rapid identification of which system is referred to by each display (Kingsley, 1980).

The lighting conditions under which gauges are read can vary widely. Reading gauges may also be affected by an engineer's visual distance and angle to the gauges, visual acuity, color acuity, and other factors. Since the primary visual task of the engineer is outside the cab, then it is expedient that the most important internal displays be viewed without excessive eye movement from the nominal exterior line of sight.

The most important internal displays are the speedometer and the air brake gauges.

Reliability of Display Readings

The basic factor in the reliability of reading an instrument dial is the physical width (measured as an angle of view) of the subjective scale divisions (Ivergard, 1989). The subjective scale divisions are the smallest step necessary to interpolate. There should be zero, two, or five subjective scale divisions for every marked interval. The length of a scale can be determined from the formula:

$$D = 14.4 L$$

Where:

D = Reading distance;
L = Length of scale; and
D and L have the same units.

If the standard scale cannot be obtained from the formula, a correction factor may be used that leads to the modified formula:

$$D \times (i \times n) = 14.4 L$$

Where: i = number of subjective scale divisions into which each marking interval is to be interpolated; and

n = the number of marking intervals.

When a display is adjustable by means of an associated control, the control should be located as close as possible to the display. However, since there may be directional relationships, care must be taken to position the control relative to the display so the operator knows exactly how the control should be moved so that the display element will move in the desired direction. Controls placed below their respective displays are less confusing than those that are placed to the right or left of the displays.

AUDITORY DEVICES

There are two types of alarm systems currently found on locomotives. One is a vigilance system and the other is a consist monitoring system.

The vigilance-monitoring system is intended to monitor the vigilance of the engineer. It provides an audio and visual cue to the engineer. If the engineer fails to respond to the cues in a timely manner, an automatic brake application is made.

This system has evolved from a foot-operated deadman's switch to an elaborate system that is tied into the primary locomotive controls. Engineers are no longer forced to maintain constant pressure on a foot switch, nor are they motivated to short circuit the switch and, thereby defeat its intended safety function as they have in the past.

Today's systems monitor the engineers' use of controls. Engineers now have the freedom to change positions while still maintaining vigilance without impairing safety. The modern system is connected to a manual reset button, the throttle, all braking systems, the radio, horn, and bell (Heron, 1988). In some cases, even window panes are part of the system.

Both visual and auditory signals are emitted if none of these controls is used within a certain time period. In some cases, this time period varies inversely with speed; as train speed increases the signalling interval decreases, and vice versa. Such a situation could cause a problem in low-speed operation that has little control activity. An engineer could be incapacitated and might not be detected for quite some time.

Another alarm system monitors locomotive operating conditions. Usually this system will have both visual and auditory alarms. Visual alarms could be shown on a warning advisory panel located on the left side of the engineer through a series of indicator lights.

Both the vigilance and the locomotive monitoring system have visual and auditory components. Each system also requires an acknowledgement from the engineer.

An alarm can be of two types, a response-based model or a stimulus-based model (Stanton, 1994). In the response model, a stimulus causes an alarm state in the individual. While in the stimulus model, an alarm exists in the environment (i.e., external to the himself) and its presence has some effect on the operator.

This latter type is the type needed and found in locomotives. An alarm is sounded whenever predetermined conditions are exceeded. The responses of all operators to the same alarm should be virtually the same for all operators. Otherwise, initiation of corrective action could be delayed depending on what specific stimulus might cause each operator to become alarmed.

An alarm is a messenger that provides a means of signalling state changes and a means of attracting attention.

An alarm can be visual, auditory, or both. In locomotive cabs both types are used. Audio is used to get the engineers to focus on the displays and the nature of the alarm. Visual alarms then indicate which system or component has exceeded its threshold.

Auditory signals should be used when: the information is short, simple and time critical; the visual workload is already high; the information is critical and warrants a redundant signal; a warning or cue for further action is needed; usual practice creates an expectation; and voice communication is required.

Visual signals should be placed to maximize the engineer's visual acuity. This optimal area is a cone extending from the engineer's line-of-sight to an area 15 degrees below the line measured from the center of the pupil of the eye.

The warning advisory panel may show alarms for any consist locomotive for any of these conditions. Additional displays that indicate which locomotive is experiencing a problem should be associated with this warning. The displays for these conditions should be grouped in a logical manner that is quickly evident by looking at the warning panel. This panel should also contain an alarm for the End of Train Unit (EOT). Lastly, a lamp test function should be built into the display panel.

When a monitored condition occurs, the appropriate warning display flashes and an audio alarm is presented to the engineer. An acknowledger control is used to silence the auditory alarm and stop the display from flashing. If the situation is corrected, the panel indictor light goes out. If the situation is not corrected within a certain time period, the audio signal resumes and the panel display begins flashing again.

Non-speech signals should be in the 200 to 5,000 Hz range, and ideally in the 500 to 3,000 Hz range. Loudness of sounds used should be consistent with the ambient sound level, but not so loud that they startle or disrupt the proper response.

The purpose of the auditory display in each of the above systems is to get the engineer's attention. It should naturally direct the engineer's attention to the source of further information about the problem. For the vigilance system, the engineer's attention should be directed towards the outside. Consequently, the audio alarm and visual alert should be near the windshield. For the engine monitoring system, the warning sound should come from somewhere near the warning advisory panel.

Avoid the use of sounds that could be confused with operational or malfunction noises (e.g., air brake releases, pump operations, sand discharges, etc.) Limit the selection of advisory sounds to no more than four to ensure proper identification.

Two different tones should be used; the first for the vigilance system should have a sound that is indicative of urgency. If an engineer has fallen asleep, this sound should wake him up. The warning advisory panel sound should be easily distinguishable from the vigilance system tone. It should be less urgent, and indicated by lower frequency, lower volume, or slower pulse rate.

DIALOG DESIGN

This section discusses human factors issues associated with how the operator will interact with a computer-based interface for train control. Computer-based interfaces offer the designer new flexibility in creating displays and controls for exercising train control and monitoring status of the locomotive. In place of mechanical gauges, the designer may create displays that show the same information in similar formats to that found in analog mechanical gauges or in new ways that depend upon the creativity and knowledge of the designer. Likewise, mechanical controls that were previously implemented with levers, rotary buttons and switches can now be executed using keyboards, touch screens and other innovative devices. These issues related to electronic controls and displays mediated by computers are discussed in the following two sections. The current section addresses how the user-interface may affect the engineer.

The success with which the engineer can control the train via these input devices and gather information to stay alert to the status of the train depends in part upon how the designer conceives the interaction between the engineer and the rest of the system. Management of this interaction is referred to as the interface style or dialog design.

The implementation of computer-based controls and displays in the locomotive cab is a relatively recent development. There is very little published research documenting the use of this technology in the railroad environment. The documentation that does exist tends to be anecdotal (Brown, 1994) and does not address the nature of the interaction and how automation might be designed into the cab. The Association of American Railroads (AAR) specifications for the operating display (AAR Locomotive System Integration Architecture Specification M591, 1993 and ATCS Specification 320, 1993) concerns itself primarily with the location of the various displays on the screen, the precision of the information to be displayed, color, labeling and the range of values that the information should take. Although not explicitly stated, the interface presented in the specification uses a menu-based approach with function keys for interacting with the operating display.

Several issues will affect the nature of the interface that is selected for the railroad operating environment. A key consideration that will affect this choice is the environment in which the equipment must operate. The locomotive cab is a harsher environment than that found in the typical office. The hardware must be able to withstand extremes of temperature, vibration, dirt, and must be readable under exposure to bright light as well as nighttime conditions.

Two other considerations in the choice of the interface are the characteristics of the users and the tasks to be performed. For example, how computer literate is the potential user population? Many of the engineers who will operate this new interface were comfortable with the analog displays and controls found on older locomotives with the AAR control stand. Some of these engineers may find it difficult to adapt to a new interface if it differs radically from the old interfaces with which they were comfortable. How these issues are addressed will circumscribe the type of interface that will be effective in the locomotive cab.

Dialog Design

There are four types of interaction styles that can be used alone or in some combination with each other. These include menu selection, command language, form fill-in, and direct manipulation.

> **Menu selection** systems give the user a list of items from which they select the one most appropriate to their task.

Command language systems require the user to learn a set of commands with a specific syntax. They use these commands to initiate tasks.

Form fill-in systems are useful in situations where data entry is important. Users enter data in a series of fields by moving a cursor among the fields and typing in the appropriate information. In this system, the user must understand the labels associated with each field and be aware of the permissible values.

Direct manipulation systems create a visual representation of the tasks that can be executed. These objects can be directly manipulated by the user using pointing devices like a mouse or a touchscreen.

The following chart shows the Advantages and Disadvantages from Four Interactions Styles (Adapted from Shneiderman, 1992)

Interaction Style

Advantages	Disadvantages
Menu selection	
shortens learning	imposes danger of many menus
reduces keystrokes	may slow frequent users
structures decision making	consumes screen space
permits use of dialog-management tools	requires rapid display rate
allows easy support of error handling	
Command language	
flexible	poor error handling
appeals to "power" users	requires substantial training and
supports user initiative	memorization
convenient for creating user-defined macros	
Direct manipulation	
presents task concepts visually	may be hard to program
easy to learn	may require graphics display and
easy to retain	pointing devices
allows errors to be avoided	
encourages exploration	
permits high subjective satisfaction	
Form fill-in	
simplifies data entry	consumes screen space
requires modest training	
makes assistance convenient	
permits use of form-management tools	

In deciding what type of interaction style to choose for the locomotive cab, a variety of factors need to be considered. These include: minimizing head-down time, hardware that can withstand the environment conditions found in the locomotive cab, and effects on workload. Currently, it is important for the engineer to direct his attention out the window to monitor track signals, look for trespassers and motorists, and determine location on the track, relative to the final destination. The interaction style selected must be one which minimizes the amount of time monitoring information displays and initiating actions in response to changing conditions. Form fill-in and command languages require more typing and thus more head-down time. Both of these interaction styles also increase memory load on the engineer by requiring him to know what command to enter or how information should be typed into a field. Menu and direct manipulation systems enable the engineer to select actions and respond to changes in system status relatively quickly. Both of these interaction styles also demand less of the engineer's short-term memory.

It should be emphasized that the menus and direct manipulation are not mutually exclusive interaction styles. Direct manipulation can include menus. For example, a menu of response alternatives may be presented textually or graphically or in some combination. Direct manipulation differs from menu systems in how the item is selected. In menu systems, function keys or keys on the keyboard activate the item to be selected. In direct manipulation, a pointing device (i.e., finger or mouse) activates the item to be selected.

The interaction style currently recommended for use by the AAR (Locomotive System Integration Architecture Specification M591, 1993 and ATCS Specification 320, 1993) is a function key menu-based interface. Specifically, it adopts a soft function key approach.

According to Mayhew (1992), this interface has the following advantages: it tends to be self-explanatory, requires little human memory, is easy to use, is flexible, and has low typing requirements. Soft function keys accommodate greater functionality than hardwired function keys, but increase complexity and use more screen space. One of the advantages of soft function keys, the ability to quickly and easily add functions, can become a liability as the increasing functionality increases the complexity of the system. As the systems grows in complexity, it becomes more difficult to learn and use.

The interaction style can be thought of as a metaphor for how the user-interface works. For example, the Apple Macintosh computer uses a desktop metaphor to represent how the system works. To open a file located in a specific directory, the user selects a folder containing documents. Selecting one of these documents opens the file. The construction of the user-interface represents a road map for how the system works. The effectiveness of the user-interface depends upon how well the representation of the system, say a menu system, matches the engineer's way of thinking. According to Norman (1991), the layout of the system should engage the way the user conceptualizes the operation of the system. Menu systems frequently hide the organization and structure of the system. Matching the representation of the system to the way the operator processes information makes it easier to learn. Learning is facilitated when new information can be assimilated into an existing framework.

For menu systems as well as other types of user-interfaces, usability depends upon how it is organized. As a system grows in complexity, the importance of good organization increases.

Good organization is a function of the amount of information displayed and the formatting of that information.

Since the AAR specification uses a menu-based user-interface, particular attention is paid to human factors considerations in the design and evaluation of this type of interface. However, the same information processes that affect performance using menus also influence performance in other types of user-interfaces. These processes include searching for information, encoding and decoding the meaning of response alternatives, assessing and choosing from the response alternatives, and making a response.

Evaluation Guidelines

Since the AAR specification proposes use of a soft function key menu interface, the following guidelines specifically addressing this type of interface are offered: Brown, 1989; Mayhew, 1992; and Smith and Mosier, 1986. Optimizing a soft key function menu interface, designers need to consider a number of issues: labeling, spatial layout, and consistency.

Response Time Performance

The time taken by the system to respond to the engineer's commands may affect performance in a number of ways. Short-term memory is limited by how long information remains in memory, generally 15-30 seconds. Short-term memory is also highly susceptible to interruptions, resulting in loss of information. When response time is too slow, engineers who are engaged in complex information processing activities may forget pertinent information, contributing to operator error or delays in completing the task. Response times that are too short can also contribute to operator error when users try to work too quickly (Shneiderman, 1992). Without sufficient time, users may fail to properly plan their course of action and will make performance errors.

Guidance & Feedback

Alarm design. When errors occur, the system should tell the user what happened and how to correct it. The system should also notify the engineer when changes in the system require some corrective action. Alarms or alerting signals serve this purpose by attracting the engineer's attention and indicating the state of the system. A number of issues need to be considered in the design of alarms.

The locomotive is a complex environment with the engineer's attention divided between viewing out the window and monitoring displays and controls inside the locomotive cab. Currently, the engineer's primary attention is directed out the window, with secondary concern for the visual displays in the cab. The system should not overload the user with too many alarms that may distract the engineer from looking out the window.

The use of auditory and visual alarms should be considered both alone and in combination. Visual alarms are advantageous when the engineer can selectively attend to the alarm. They can indicate more precisely the nature of the problem and possibly what actions are necessary. Visual alarms using text can be understood more quickly than speech signals and rely less heavily on short-term memory. They are also advantageous as the ambient noise levels rises.

Auditory alarms are preferable under the following conditions (Sanders and McCormick, 1993):

- o the message is short and simple;
- o the message will not be referred to later;
- o the visual channel is overburdened;
- o the message deals with events in time;
- o continuously changing information is presented; and
- o vision is limited.

An alarm conveys varying degrees of warning or danger (Stanton, 1994). For example, a low fuel warning is less urgent than a brake failure warning. Alarm design should convey the urgency of the warning so that the engineer can allocate his attention appropriately, particularly if multiple warnings are present. The perceived urgency of an auditory warning can be varied by changing speed, number of repeating units, and speed of the signal (Edworthy, 1994 in Stanton, 1994). The perceived urgency of the visual warnings can be varied by changing the color and flash rate of the signal (Sanders and McCormick, 1994).

Engineer should be able to control the alarms by acknowledging or turning off non-critical alarms. Where alarms are presented by both visual and auditory methods, engineers should be permitted to turn off the auditory alarm, without erasing the visual message that accompanies the auditory signal (Smith and Mosier, 1986).

Another method of granting the engineer control over alarms is to provide a mechanism for modifying the conditions that activate alarms (Smith and Mosier, 1986). False alarms that occur too frequently can result in the engineer ignoring the alarm altogether. Except where functional, procedural or legal requirements preclude user control, allowing the engineer to define when alarms activate may reduce the likelihood of alarms being ignored. For systems that allow the engineer to define alarm boundary conditions, the system should show the status of those settings when requested.

Feedback and User Guidance (Smith & Mosier, 1986)

Feedback gives the engineer information about the condition of the system and the steps necessary to affect the system (Williges, Williges, and Elkerton, in Salvendy, 1987). As a general rule, feedback should provide some indication of the system status to users at all times and occur close in time to a related event. Three system states should be considered

(Norman, 1991): (1) when the system is waiting for the user to initiate an action; (2) when the user has selected a response, but not implemented it, and (3) when the user implements the selection. Feedback should clearly distinguish between the system that is waiting for the user to initiate an action and a delay in the response to an action initiated by the user.

When the results of user action are contingent upon different operation modes, clearly indicate the currently selected mode.

Every input or response selection by the user should consistently produce perceptible response output from the system.

When errors occur, feedback should clearly indicate the corrective action to take. The following guidelines address the formatting and content of error messages (Shneiderman, 1992; Smith and Mosier, 1986; Williges, Williges, and Elkerton, 1987).

Error Messages

Error messages should be specific (task oriented), concise as possible, and written from the user's perspective. Use language that the engineer will understand.

The visual format and placement as well as the grammatical form, terms and abbreviations should be consistent throughout the system.

Use the active voice and a positive tone to tell the user what needs to be done.

Consider multiple levels of messages where users may desire more detailed levels of information or where more than one error was made.

Display the error message after the user completes a response to minimize disruption of the user's task performance and thought processes.

Display error messages within 2-4 seconds following the response for which the error is detected.

AUTOMATIC SYSTEMS

This section discusses the use of automatic systems in the locomotive cab and how it may affect the engineer. Automatic systems are defined as those systems which, through the use of machines, electronic devices, and computers, are able to perform tasks previously completed by engineers. The goals of implementing automatic systems are reviewed, and the human factors considerations that need to be considered as automatic systems are incorporated in the locomotive cab are explored.

New command, control and communications technology is being considered for improving railroad operations. These systems are referred to by several names: Advance Train Control System (ATCS), Positive Train Control (PTC) and Positive Train Separation (PTS). The goal of these systems is to improve train operations through the following processes (FRA report to Congress, 1994):

- ensure positive train control;
- maintain flexible blocks;
- enhance train management;
- improve accuracy in train communications;
- maintain constant communication; and
- provide information to the locomotive engineer.

These new systems may change how the engineer interacts with the controls and displays as well as the tasks the engineer performs. For example, positive train control operations could override the engineer's controls by braking the train to enforce speed restriction or avoid collisions and obstructions. Digital radio will enable the dispatcher to send movement authorities directly to an on-board computer in the locomotive cab and display this information directly. Eliminating the need to hear and record this information transmitted by voice radio will eliminate a source of human errors due to hearing or transcription. (Note: Automatic over-rides should be used only as "a last resort.")

However, incorporation of automatic systems carries risks as well as benefits. If not properly done, automatic systems in the locomotive cab can reduce safety by decreasing situational awareness or increasing the operator workload. The success with which use of automatic systems may improve safety and productivity depends upon how it is implemented.

The use of automatic systems in train control is currently under development. No systems are in actual operation. The only Federal Government-sponsored study evaluating ATCS found this new system to improve train control when compared to conventional train control systems (Keuhn, 1992). However, this study only evaluated the use of one type of automatic system in the locomotive cab. The use of predictor displays was established as an effective tool to aid in train control. However, this study evaluated only one aspect of automatic systems. Other issues that need to be considered as automatic systems are developed for train control include the type of errors made, the impact on situation awareness and workload, and the use of additional automatic systems to manage information.

Principles of human-centered automation

The human factors principles listed below (Billingsley, 1991) are driven by a user-centered approach to automation in which the computer is subordinate to the engineer. A user-centered approach supports the engineer's need for information. This approach contrasts with a technology-driven approach in which the engineer is subordinate to the machine.

Evaluating the effectiveness of automated systems in the locomotive cab will require looking at a variety of issues. Currently there are few specific guidelines. A thorough evaluation will require measuring usability, suitability and acceptance by locomotive engineers. The following principles are offered based upon research in the aviation industry (Billings, 1991).

- The engineer must be in command. Because the engineer is responsible for the safe operation of the locomotive, he or she must have the ability to control those operations;
- To command effectively, the engineer must have an active role in controlling the train. This means engaging in relevant activities so that situational awareness is retained. In order to remain aware the engineer must know what the automated system has accomplished;
- Automated systems must be predictable. The engineer must be able to predict how the locomotive will be affected by the automation to know how to use it and it must behave in a consistent manner to know when a failure occurs; and
- Each element of the system must have knowledge of the others' intent. Automated systems must monitor the human operator. This sort of knowledge will decrease errors and aid recovery should mistakes occur.

The following guidelines for automation of control tasks and information management support the principles listed above (Billingsley, 1991).

Information management guidelines

All displays should contribute to and maintain situational awareness.

Less information is generally better than more information, if it is the right information for a particular circumstance. While it is important to keep the engineer situationally aware, it is important to avoid giving too much information. Too much information makes it more difficult to attend to the most important information. The information that is available should be coded to emphasize its relative importance. Good formatting will help the engineer to more quickly find the relevant information.

Displays that have multiple modes should clearly indicate what mode is active.

ELECTRONIC (COMPUTER-GENERATED) DISPLAYS

This section discusses the use of electronic, computer-generated displays in the locomotive cab. Current use of electronic displays is found in cabs that adopted the North American Comfort Cab design as well as more recent designs. In this design, computer-generated displays share space on the workstation with analog electro-mechanical displays. In the future, information presented on electro-mechanical displays may be entirely generated on electronic computer-generated displays.

The locomotive cab is a harsh environment for electronic displays to operate. The displays must withstand high and low ambient temperature, vibration and electromagnetic interference. The engineer needs to view the display under varying light levels that range from bright to very dim. Glare from direct and indirect sunlight may interfere with the engineer's ability to see the display. Because of the need for excellent visibility, large windows are present, but allow sunlight into the cab and contribute to the problem of glare. In addition to glare and ambient lighting conditions, the designer must consider the following factors: color, contrast, viewing angle, image quality and size.

The two types of display screens currently manufactured, cathode ray tubes (CRTs) and flat panel displays cannot meet all the environmental and visual requirements for a locomotive cab (Karbowski, Ben-Yaacov, and David Blass, 1991). For designers, the choice of an appropriate hardware platform depends upon the relative importance of various environmental and visual requirements. Karbowski, Ben-Yaacov, and David Blass (1991) favor the flat panel display over the CRT because they are more rugged and compact, and can better withstand the range of temperature, humidity, shock and vibration found in the locomotive cab.

This section explains the human factor concerns for displaying the computer-generated information that the engineer will use for train control. The design of computer-generated displays is a complex topic and is the subject of extensive research. Several authors have surveyed the literature and developed guidelines useful for design and evaluation of computer-generated displays (Smith and Mosier, 1986; Mayhew, 1992; Sanders and McCormick, 1994; Helander, 1994; Shneiderman, 1992; Galitz, 1993). The guidelines presented come from these sources. The material is divided into three areas; general issues, hardware issues, and software issues.

Although the locomotive cab is more spacious than an aircraft cockpit or a motor vehicle, the designer is faced with the same human constraints that limit the amount of usable space within the cab to display information. Just as the engineer is limited in how far he or she can reach a particular control by the length of his or her arms and legs, so too is the ability to see displays limited by the engineer's visual system. The size and area of the central and peripheral vision limit how far the engineer can and the accuracy with information will be seen (Sanders and McCormick, 1994). Current recommendations (NASA-STD-300, 1994) suggest a nominal viewing distance of 20 inches (510 mm) and all areas of the display be viewable from within 30° of the horizontal axis centered on the screen.

Text based information (Typography)

In presenting text on electronic displays, legibility, readability, and comprehensibility are key issues that need to be addressed in evaluating its usability. Legibility refers to the rapid identification of individual characters while readability refers to the ability to recognize the form of a word or group of words. The following recommendations address the issues of legibility, readability and comprehensibility.

Character height. Readability is affected by its size. The optimal height of characters will vary with distance of the viewer from the display. The following chart shows recommended heights for different luminance conditions, which is one set of recommended heights of alphanumeric characters at 28 inch viewing distance. (Adapted from Sanders and McCormick, 1994, p. 107.)

Height of numerals and letters*

	Low luminance (down to 0.03 fL)	**High Luminance (1.0 fL and above)**
Critical use, position variable	0.20-0.30 in (5.1-7.6 mm)	0.12-0.20 in (3.0-5.1 mm)
Critical use, position fixed	0.15-0.30 in (3.8-7.5 mm)	0.10-0.20 in (2.5-5.1 mm)
Noncritical use	0.05-0.20 (1.27-5.1 mm)	0.05-0.20 (1.72-5.1 mm)

* For other viewing distances (D), in inches, multiply the values by D/28.

APPENDIX M

CAB SEAT DESIGN

CAB SEAT DESIGN CONCEPT

Features and Adjustments	Folding armrests, variable back tilt, sloping seat pan, fore-aft adjustment, variable height, swivel
Seat Pan Size	16 to 18 inch effective length for any position of the seat back
Seat Pan Width	17 inches minimum at back, 20 inches minimum at front
Seat Pan Slope	1° to 3° from horizontal, front edge higher
Cushion Thickness	3 inches minimum for pan and back
Back Height	21 to 25 inches
Back Width	16 inches minimum at hips, 21 inches minimum at shoulders
Armrest Height	7 to 8 inches from top of uncompressed seat to top of armrest
Armrest Width	4 inches minimum
Armrest Length	13 inches minimum
Armrest Padding	½ inch minimum inside and top
General Armrest	Adjustment to lower elbow end to tilt 115° from horizontal, armrests parallel to seat pan and 19 to 22 inches between inside edges
Seat Covering	Should not cause sliding or be easily torn or cracked, must permit breathing and water vapor exchange
Fore-aft Adjustment	Minimum of 4 inches fore and aft of center
Swivel	At least 180° rotation from forward to rear facing, rotation towards center of cab
Seat Height	No more than 16 inches at lowest position and at least 19 inches at top position (measured at top of front edge), adjustment steps no larger that 1 inch
Seat Back Tilt	From 95° to 115° from vertical in steps no larger than 5°

Note: The table provided above represents a compilation of numerous seat design guidelines garnered from several engineering design references.

The previous table provides the fundamental design characteristics; however, additional seating features are beneficial. Adjustable lumbar support that extends across to the pelvic bone crests is widely recommended. This provides support and corrects posture. Moderate contouring of the seat cushion for the buttocks and the seat back for spinal curves evens pressure and provides support. It can also be a subtle deterrent to slouching because body contours will not match the seat contours in an improper posture. Lateral support on seat back or a curved seat back to supplement side sway support addresses an engineer's concern and reduces abdominal muscle effort. A continuous balance seatpan, armrest controls, or other means to relieve the lumbar stress that occurs when bending forward will address a large residual seating problem. Additional backward motion of the seat or other adjustment that makes room to permit standing operation would add to possible operating position options lost in the shift to consoles.

There is some variety in the seat adjustment mechanisms in use. The ideal seat adjustment mechanism is easy to use, reliable, and wear resistant. The harshness of the locomotive operations may make office type mechanism designs unsuitable. A survey of current designs for ease of use, reliability, and wear resistance is needed to identify suitability of current designs, develop criteria to evaluate new designs, and determine where further design work is most needed.

The workspace in which the seat is placed has considerable impact on the user's perception of the seat. Non-seat characteristics can have a direct or indirect impact on the seated position or use of the seat. These need to be considered along with the seat characteristics to determine seating comfort.

Non-seat factors that need to be considered include:

- leg room;
- knee room;
- availability of footrests;
- clearance from sidewall;
- vibration levels;
- ease of entry and exit;
- clearance when swiveling;
- visibility; and
- reach-to-control distance.

The use of a deadman pedal as a vigilance device also has a bad impact on the seated position and is questionable in value to indicate awareness.

Leg and knee room and footrests have comfort and health implications. Little leg and/or knee room forces immobility; the resulting discomfort can be endured for a short time, but not for long periods typical of an engineer's shift. Health aspects come into play from the lack of muscular movement. Cramps are a common result with the potential to develop phlebitis which can lead to clot formation.

Locomotive Crashworthiness and Cab Working Conditions, 1996, US DOT, FRA - 04-
Locomotives/Propulsion Systems