TRANSIT COOPERATIVE RESEARCH PROGRAM

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TCRP Report 15

Procurement Specification Guidelines for Mass Transit Vehicle Window Glazing

Transportation Research Board
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Procurement Specification Guidelines for Mass Transit Vehicle Window Glazing

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The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academy of Sciences, acting through the Transportation Research Board (TRB), and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

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The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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FOREWORD

By Staff
Transportation Research Board

This report will be of interest to transit maintenance and procurement specialists concerned with purchasing windows and window systems. The report provides detailed guidelines for the development of specifications for the procurement of durable and vandal-resistant bus and rail vehicle passenger-side windows and window systems. The guidelines provide information on the different types of window systems and materials; their strengths, weaknesses, special features, and costs; and other information. Several relatively new materials are discussed including sacrificial plies, peel-ply protective films, anti-spall films for glass, and aerospace coating and transparency technologies. The guidelines also include specific tests and acceptance criteria that can be used to assess durability, as well as recommend practices for ensuring that the procured window glazing system is easily replaced, and that repair and refurbishment are considered up-front during the initial specification-development process. Finally, the guidelines include short, lessons-learned discussions for each type of specification requirement.

Transit agencies expend considerable resources procuring and maintaining bus and rail vehicle passenger-side windows. Plastic and glass are the two predominant materials used for these windows. Increasingly, both materials have become subject to costly damage caused by vandal etching. In addition, glazings are subject to potential damage from cleaning chemicals, mechanical wash brushes, and harmful environmental conditions such as ultraviolet sunlight. Compounding these problems, most current window designs make it difficult to replace damaged glazing in an efficient and cost-effective manner. As a result, there is a need in the transit industry for more reliable passenger-side window glazing.

Under TCRP Project C-4, research was undertaken by the University of Dayton Research Institute to (1) compile information on current and emerging window glazing technologies with potential applicability to the transit industry and (2) develop guidelines to assist transit agencies in the preparation of procurement specifications for transit vehicle passenger-side window glazing.

To achieve the project objectives, the researchers conducted extensive surveys of domestic and foreign transit systems to obtain information on transit window-related issues, including vandalism and durability. In addition, the researchers surveyed window-system and material manufacturers and suppliers serving transit and other industries; transit bus and rail vehicle manufacturers; and relevant research organizations to obtain information on existing and emerging technologies that result in longer lasting, more durable transit glazing systems. Based on the information collected, the procurement specification guidelines included in this report were prepared.

An unpublished companion report, prepared under this project and entitled *Enhancement of Vehicle Window Glazing for Vandal Resistance and Durability—Final Report*, provides the details of the various surveys completed during the research effort. The report also contains a historical overview of graffiti and vandalism and discusses prevention

approaches to the problem. Special attention is focused on the need for a cooperative integrated team approach—which includes operators, security, and maintenance personnel—with a zero-tolerance approach to controlling vandalism.

A summary of the companion report has been published as TCRP *Research Results Digest No. 9*, Responding to Vandalism of Transit Bus and Rail Vehicle Passenger Windows. In addition, the companion document is available on a loan basis through the TCRP, 2101 Constitution Avenue, N.W. Washington, D.C. 20418.

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ACKNOWLEDGMENTS

The following guidelines and recommendations were formulated by the Aerospace Mechanics Division of the University of Dayton Research Institute (UDRI), Dayton, Ohio. This work is sponsored by the Transportation Research Board under Transit Cooperative Research Program Project C-4.

The effort resulting in this document was conducted from a period of October 1994 through December 1995. UDRI project supervision was provided by Mr. Blaine S. West, Head, Aerospace Mechanics Division; and Mr. Gregory J. Stenger, Leader, Structures Group. Messrs. Daniel R. Bowman, Research Engineer, and Thomas J. Whitney, Associate Research Engineer, were the Principal Investigators, and significant technical contributions were made by Mr. Marc A. Huelsman, Assistant Research Engineer.

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CHAPTER **1**

SCOPE

1.1 BACKGROUND AND PROBLEM DEFINITION

Transparency systems (windows) in public transportation vehicles are an integral part of the transit system. In addition to the windows' obvious function—to provide a view of surroundings—there are a number of additional benefits/features of windows. Window quality (cleanliness, optical clarity, tint, size, placement) affects the transit rider's opinion of overall system quality. In addition the rider tends to feel safer and less confined in a bright, well-lit, clean environment, both while on the vehicle and prior to boarding. Window tint and interior vehicle lighting are very important for all modes of transit to create a bright, well-lit environment. Other window performance parameters such as durability and impact resistance affect life-cycle cost, safety, and transit system liability.

The very first windows used on transit vehicles had two requirements, to shield the passenger from the environment and to be transparent. Historically, window specifications have included material and cross section. In past years, important window design parameters included only luminous transmittance (which controls visibility through the windows), solar transmittance (which controls heat transfer through the windows), and impact resistance. However, over the years, transparency specifications have become increasingly complex with many diverse requirements. With the advent of engineering plastics, specifically polycarbonate and acrylic, many additional design parameters have become important. These include flammability and smoke generation, abrasion resistance, scratch resistance, weathering resistance/durability, chemical resistance, and vandal resistance.

Durability (how long something performs) has become critically important with the increasing use of plastics and with the advent of window vandalism in the form of carving, etching, scratching, and scribing. This form of vandalism has become a high priority problem only in the past 3 years for most transit authorities. Unlike spray painting and marker graffiti, window scratching and etching cause permanent damage and cannot be cleaned up with solvent or paint. Etching and scratching can compromise the structural integrity of glass windows, thereby reducing their resistance to impact and increasing the potential for litigation.

Window vandalism has grown to considerable proportions. MTA New York City Transit reports that to maintain unetched windows in their transit vehicles, they would need to spend $60-$70 million per year (Lloyd Tyler, Senior Director of Projects and Operations, New York City Transit, MTA, personal communication, July 17, 1995). Nationally, graffiti and vandalism have grown to such proportions that remedial costs were over $7 billion in 1994 with $1 billion of that total resulting from glass etching.[1] The survey conducted by Bowman et al.[2] indicates that cost of vandalism for mass transit is increasing by 11 percent per year, which means that it is doubling every 6.5 years. To combat the problem of vandalism and to increase durability, a number of approaches are available, including material solutions. To implement material solutions, the transit agencies must have access to new materials, new technologies, and a tool (in this case a procurement specification) to procure these materials and technologies.

The rise of window vandalism to epic proportions has caused many transit authorities to rethink window issues. Whereas the window used to last the life of the vehicle or was changed-out only on that rare occasion when it was chipped or broken, it has now become a consumable item, requiring frequent change-outs, considerable maintenance resources, and the logistics of maintaining an inventory of spares. Vandalism resistance and quick change-out of the windows are becoming high priorities to transit authorities with vandalism problems. They are also investigating window refurbishment and special window treatments (liners, sacrificial plies, etc.) to combat vandalism and reduce maintenance cost.

There are essentially three ways to attack the vandalism problem: repair or refurbishment, material solutions to the problem (i.e., materials or material systems that provide resistance to vandalism), and prevention. Prevention includes police/security, maintenance, and operator involvement, as well as transit authority policies, punishment, legislation, surveillance, and other technologies. Service life and maintenance issues are a function of the procured system and the operating environment. Strategies to improve service life and reduce maintenance problems have implications for new procurements in terms of specifications for durable, repairable/refurbishable, relatively trouble-free, vandal-resistant technologies. This document provides recommendations for both format and content of transit window procurement specifications. Information is provided that can be used by specification writers to standardize format and enhance content.

The specification for the transparency is the document that defines the transparency. A well-written specification helps to ensure that the delivered product meets the transit authority's expectations for both quality and performance. A specification represents an agreement between the buyer and the seller that defines the requirements the product in question must meet. It is essential that the requirements be clearly defined and that a methodology for determining compliance with the requirements be defined. When test methods and the interpretation of resulting test data are not clearly defined, serious misunderstandings may occur.

1.2 PURPOSE

This specification establishes the format and content of window-glazing system technical specifications produced by and for the mass transit industry. The purpose is to establish recommended uniform practices for specification preparation, to ensure the inclusion of essential requirements, and to aid in the use and analysis of specification content.

This document does not address every possible issue and situation regarding the procurement, manufacture, or use of transit windows; all users of this document are responsible for ensuring that the final specifications created with this guideline meet the needs of their agencies in a safe and economical manner.

1.3 EXECUTIVE SUMMARY

The objective of this document is to provide the transit industry with guidelines in the development of window and window system specifications. A standardized format is recommended. The use of this format has many advantages, including the potential for more commonality between specifications for different agencies. Transit industry acceptance of a more standardized format should reduce the vendor costs associated with having to produce a myriad of different specifications and requirements.

The standardized format has provisions for all of the different components of a specification. Users of this guideline may select requirements and other information from the standard format. In addition, guidance is given regarding what certain requirements should be and how they should be evaluated. These recommendations cover different types of window systems and window materials.

This document focuses on passenger windows, but the recommended format could easily be used for all transit windows.

This specification guideline is the product of Transit Cooperative Research Program Project C-4, entitled "Enhancement of Vehicle Window Glazing for Vandal Resistance and Durability." In that project the researchers surveyed a number of major domestic and foreign transit authorities to obtain information on transit window-related issues, including vandalism and durability. The researchers also surveyed window manufacturers from transit and other industries, as well as transit vehicle manufacturers and various research organizations. As part of the survey of the transit authorities, the researchers asked for copies of current window procurement specifications and used this information to assess current procurement practices and to provide a foundation for this document.

These guidelines are based on the results of the surveys described above, as well as on contact with transit personnel, window system suppliers, and window material suppliers. They include information to allow a transit entity to specify and test for durability and to specify repairability, refurbishment, and maintenance features. In addition, the guidelines include short lessons-learned discussions for each type of requirement. Also included are sections that describe each of the different types of transparency systems, their strengths, weaknesses, special features, and so forth.

Durability is a function of the window-glazing material and the environment in which the window is placed, including the natural environment (moisture, temperature, and sunlight) and the imposed operating environment (cleaning chemicals and substances, solvents associated with painting and paint overspray, greases and oils, pollution, maintenance damage from impact or abrasion, and intentional damage from vandalism). The guidelines include specific tests and acceptance criteria that can be used to assess durability.

The guidelines include information regarding recommended practices for ensuring that the procured window-glazing system is easily replaced, and that repair and refurbishment are considered up front instead of as an afterthought. Also, since the transparency is a consumable item (it has a finite service life, like brakes) and must be changed-out on occasion, quick change-out of the transparency is a very desirable feature. If the transparency can be refurbished out of the frame, it is advantageous to have a quick change-out to keep maintenance costs low and to reduce the vehicle's time out of service. The same is true for systems that have a sacrificial ply or peel-ply. The faster the ply can be removed and replaced, the better.

REFERENCES

1. Beswick, J., *National Crime and Graffiti Prevention News*, Vol. 1, No. 4, p. 1.
2. Bowman, D. R., T. J. Whitney, and M. A. Huelsman, "Enhancement of Vehicle Window Glazing for Vandal Resistance and Durability," TRCP Project C-4, unpublished final report, Transportation Research Board, Washington, DC (December 1995).

CHAPTER **2**

RELEVANT ISSUES

2.1 SPECIFICATION DEVELOPMENT PROCESS

This section includes a brief discussion on the specification development process. The who, how, what, and when of specification development are discussed.

The specification writer may be a transit system employee, a consultant, or a vehicle manufacturer. Regardless of who actually writes the specification, the specification development process needs to involve various individuals/ groups, including individuals from engineering, maintenance, procurement, management, public relations, safety, and security. An integrated team may include representatives from vehicle design, human factors/ergonomics, transparencies, structures, strengths, materials, manufacturing, and other disciplines.

In practical terms the specification development process is the documentation of requirements. These requirements include material and geometry, durability, performance, quality control and verification, and other contractual issues, such as marking, packaging, shipping, delivery, quantities, terms, and scheduling conditions. Some of these requirements are "boilerplate" in nature. The specification writer should use the boilerplate provided in these guidelines and choose specific requirements as dictated by the situation.

The customer is the ultimate source of requirements, but the final customer—the transit rider—does not provide all requirements. The requirements of the transit rider tend to be general and related to issues of perception, such as (1) optical quality of the window, (2) light/heat transmitted by the window, (3) window size and placement, (4) ease of use/durability of opening mechanisms, and (5) safety, among others. In addition to customer-generated requirements, there are legislated requirements. Specific requirements, developed by the transit authority or its consultants, address such issues as impact resistance, flammability, maintainability, and costs. These specific requirements, as a whole, must satisfy the system's general requirements.

The development of a specification is the first logical activity after a program is defined. The program may be an entire new vehicle, a vehicle upgrade, or merely a window system upgrade.

Adding requirements to a transparency design that is mature and complete can be expensive, but the procurement specification should be a living document and should be changed to improve the product and lower the cost.

The specification writer must consider the economics. Typically, the more detailed a specification is, the more expensive the product will be. Although at the same time, the more detailed a specification is, the more likely the product will perform as desired. A balance must be achieved between detail and cost. In general, the specification writer should develop the simplest specification that meets the transit authority's needs.

2.2 TRANSIT MAINTENANCE AND ENGINEERING ISSUES

Transit authorities need window systems that are easily procured and maintained. A key issue is quick change-out of windows. With many pressing issues facing the transit maintenance staff, including few spare vehicles and significant work time required to keep vehicles fueled and operating, little time remains to face special issues like window maintenance and change-out. Vandalism and graffiti problems with transit windows have become a high priority for most transit authorities only in the past few years. Before, windows were changed only when they "wore out." Many window designs were not conducive to maintenance and quick change-out. For instance curved window panes may be aesthetically pleasing, but they have a number of inherent disadvantages, including increased cost and limited available sources for procurement. Flat windows, on the other hand, can be procured from many sources, are less expensive, and can be changed relatively easily from one window material system to another. Most transit and maintenance personnel surveyed during the project indicated that they would not procure new vehicles with curved windows.

Los Angeles County Metropolitan Transportation Authority would like change-out times of 3 to 5 minutes for the window panes in buses. Typical change-out times for most vehicles, including railcars with the rubber gasket "zip-strip" edge designs, are one-half hour or more. Significant maintenance time results when a number of windows require changing in one night to maintain a "zero tolerance/no vehicle in service with graffiti" standard.

Of the three window types currently available, fixed windows are most attractive from a maintenance standpoint.

They have fewer moving parts and, hence, fewer potential in-service failures; however, passengers cannot open fixed windows when the air conditioning system fails. It should be noted that most rail systems, including subways, have fixed windows and rely solely on the vehicle's air conditioning system for passenger comfort.

The second type of window system, the slider, has received many complaints from maintenance personnel and riders alike due to the high failure rate of the latches and the difficulty of maintaining the windows. The slider has the sole advantage of allowing the rider to open the window. Allowing passengers to open windows also has a disadvantage. Opened windows often result in inefficient or ineffectual air conditioning or heating.

The third type of window is the transom window. This window has a large fixed portion with a small transom at the top. The transom opens inward and is supported by two gascharged cylinders. This system is more complex than a simple fixed window but less prone to failure than a slider window.

Some preventive/remedial products are available for maintenance use and engineering approval, although most are directed toward paint and markers. The overall aim of anti-graffiti products is to reduce replacement costs by prevention or by easier cleanup. Prevention and cleanup products cover a wide range of solutions, including graffiti removers, protective coatings, sacrificial plies and peel-plies, capture and security technology, graffiti-resistant building components, and lasers and alternative blasting media.

Technical bulletins or briefings can make maintenance personnel aware of practices that reduce window durability. One example is the use of strong solvents (such as toluene, MEK, or some graffiti-removal solutions) to clean windows. Maintenance and engineering personnel should be aware that solvents, chemicals, and cleaners may cause damage to plastic windows, coatings, and liners. Many graffiti-removal agents include strong solvents. There are more than 200 graffiti-removal solvents with a myriad of chemical compositions. Although glass is impervious to most chemicals, plastics and coatings are not. Testing graffiti-removal solutions, eliminating those that attack the windows, and keeping an approved materials list are recommended because maintenance personnel and graffiti-removal personnel will use whatever is available to expedite removal and maintain a zero tolerance condition.

Another practice that may increase the durability of windows is changing the vehicle washer brushes to softer brushes at the window level (a practice currently in use). Softer brushes may decrease window damage, and changing to noncontacting washers eliminates brush washer damage to the windows. Unfortunately, transit authorities have reported that noncontacting washers do not get the vehicles clean. Another possibility is the use of hollow brushes that have water pumped through the brush body. These brushes are used to wash buses in Houston.

2.3 RECOMMENDATIONS FOR FUTURE PROCUREMENTS

Recommendations for future procurements are fairly simple. Procure flat windows. For new procurements, specify window systems that allow very fast change-out—5 minutes or less is desirable. To achieve quick change-out, window systems may require items, such as dry seals on the outboard side of the window and a clamped interior frame, that can be removed easily after removal of a number of specialty-head quarter-turn fasteners. For new procurements, specify window systems that provide for the inclusion of sacrificial ply protection (peel-ply protection typically does not require any special provisions since it does not require its own frame). Procure the least complex window system possible. Fixed windows are the least complex. Transom windows are more complex, and slider windows are the most complex and troublesome. Window frames should be clear anodized aluminum or stainless steel. Black anodized aluminum has proven to be a target for carvers because the black anodizing provides high contrast when vandals carve through it to the aluminum.

Future procurements (such as the addition of sacrificial plies or peel-plies) to replace current window systems or to update window systems need to be undertaken and sufficient stocks and spares must be procured to accomplish zero tolerance. New/updated systems can be added to the vehicles on a "preferred spares" status (when a window is removed from service, it is replaced with the new "preferred spare"); or vehicle, partial-fleet, or whole-fleet change-outs can be undertaken. Obviously, assignments and schedules of maintenance personnel are important to accomplish change-out programs. Once new systems are in service, particular attention is needed to maintain unetched windows. If a vehicle-by-vehicle or zone-by-zone change-out plan is undertaken, these vehicles or zones must be monitored, and damaged windows must be replaced.

Another recommendation for future procurements is the development of simplified vehicle maintenance manuals, which include "blowup" part schematics with an illustrated parts breakdown and parts list. These manuals can be very useful for maintenance functions. Procurement specifications can be written so that these manuals also list approved cleaners, solvents, and graffiti-removal substances for the window system. An alternative to such manuals is the development of this type of information by the transit engineering department.

2.4 DURABILITY

Durability of consumable systems or subsystem components of ground transportation vehicles influences operating costs and fleet operational readiness. Window glazings have become or are becoming consumable components of a vehicle transparency system. (In addition, window glazings are a highly visible component of a transportation system and

affect the consumer's/rider's perception of the transportation system with regard to cleanliness, safety, trust, and respect.) The durability of a window system is a function of the environment in which it is placed and of the material system. The environment the window must endure is composed of not only the natural environment (which would include moisture, temperature, and sunlight) but also the imposed operating environment (which would include cleaning chemicals and substances, the effects of vehicle washing, solvents associated with painting and paint overspray, greases and oils, pollution, maintenance damage from impact or abrasion, and intentional damage from vandalism).

CHAPTER **3**

COURSES OF ACTION

Three different approaches can be used to increase transparency durability: (1) identification/development of alternative systems, (2) development of repair techniques for the current system, and (3) changes in the environment to which the window is subjected.

Alternative systems that are applicable to window glazings and that have been or are being developed include material change (such as changing from glass to plastic or viceversa), coatings on glass or plastic substrates (polysilicates/ polysiloxanes, polyurethanes, etc.), polymer liners on glass or plastic substrates, sacrificial plastic surface plies that are not bonded to the window glazing, and thin tempered glass plies that are laminated to acrylic or polycarbonate. A summary of new materials identified in the survey performed in the project is included in Table 1. It should be noted that this summary represents the best information available to the researchers at the time that this report was written. The information is not intended to endorse any products or manufacturers, and any omissions were inadvertent.

Tables 2 and 3 contain cost comparison data for different transparency materials that are used for bus and rail, respectively. Included are data for some of the specialty materials, such as sacrificial plies and peel-plies, as well as anti-spall plies. These cost data are provided so that comprehensive comparisons can be made among the different materials. Window manufacturers and window framers were surveyed to obtain these estimated costs. Frame costs, labor costs for installation and change-out, and seal costs are not included. Quantities purchased, curvature, and other special geometry requirements can significantly affect costs. To evaluate the cost of a transparency system to the transit authority, a lifecycle cost analysis should be undertaken. This analysis should include initial cost, replacement cost (material plus labor), and change-out frequency. There is a direct relationship between change-out intervals and the recurrence of vandalism. For more information on this relationship, see Bowman et al.[2] Also, the cost of a transparency system may not be the only measure used when choosing new or alternative systems. Transit authority management may mandate that no window with graffiti shall be in service (zero tolerance). This choice may be made to improve the perception of transit quality and may require significant initial investment. The payoffs for this type of decision are improved system quality (which has an intangible cost benefit) and long-term reduction in change-outs of vandalized windows (which will eventually result in cost savings).

Three basic materials are generally considered for glazing applications: glass, acrylic, and polycarbonate. Table 4 includes a qualitative comparison of these window materials. Glass is the best material for abrasion, chemical, pollution, and weathering resistance and optical clarity; but it is heavier and more difficult to fabricate and machine than acrylic and polycarbonate. Plastics commonly used for transparencies are cast acrylic and polycarbonate. These materials are not nearly as resistant to weathering, chemical attack, or abrasion as glass, but are lighter, more impact resistant, and easier and cheaper to form into complex shapes and curvatures than glass. Acrylic and polycarbonate require coatings to obtain better abrasion, chemical, and ultraviolet resistance. There is the potential for new types of plastics, such as the Simula 2003 material (see Table 1) that would not need to be coated to provide resistance to chemical attack and abrasion. Acrylic has slightly better optical clarity than polycarbonate, while polycarbonate is much tougher than acrylic. Breakage and safety also must be considered for window applications. Acrylic may be precluded from applications with strict flammability and smoke generation requirements. In general, glass is the cheapest material while polycarbonate is the most expensive. Different ideas, opinions, applications, and requirements in the transit industry result in the use of all three materials.

3.1 CURRENT SYSTEMS

3.1.1 Glass

Glass is a very strong, stable, durable material that is reasonably resistant to abrasion and is very resistant to chemical attack, pollution, and weathering. The drawbacks of glass are its brittle nature and its density. To reduce problems associated with its brittle nature, glass is often strengthened, or two plies of glass are laminated together with polyvinyl butyryl (PVB). Strengthening and lamination increase impact resistance and provide protection against laceration.

The only glass material that is commercially available for transit use is float glass. Float glass is available in clear float, which has a slight greenish tint, and with a variety of special tints and coatings. Tints are used to change the glass color and/or to reduce both visible and infrared light (heat) transmission. Available coatings include metals and metal oxides that are vacuum deposited. Coatings are also used to reduce both visible and infrared light transmission. Since the coat-

TABLE 1 Summary of new transparency materials applicable to transit

Company	Sacrificial Ply	Peel-Ply	Anti-spall Ply	Coatings	Specialty Materials	Availability
3M		x				Now
Advanced Glass Systems					Noviflex® Attack Resistant Interlayer for Glass Laminates	Now
DuPont			Spallshield ®			Now
Diamonex				Diamond Like Carbon (DLC)		Now
GE Plastics					Nu-View® Polycarbonate Laminate Lexan® MR 10—1 year Warranty Hardcoated Polycarbonate	Now 1996
Graffiti Removal, Inc.		Vandal Shield®				Now
Lucilex	x					Now
Laird Plastics				x		Near Future
Llamas Plastics				Aerocoat #105 Silicone Hardcoat		Now
NORDAM				Hard Coatings		Now
PPG				Aegis Polyurethane®		1996
SDC				Silvue® 200 ARC Silvue® 211 ARC Abrasion Resistant Coatings		Now
Sierracin/Sylmar			Polycarbonate			Now
				Various Polysiloxane and Polyurethane coatings/liners FX 216BB (polyurethane/siloxane) FX 302 (rain repellent)		Now Fall 1995
					Thin-Glass-Clad Acrylic and Polycarbonate	1996
Simula					SIM 2003 Polyurethane Hard Plastic	
Texstar				Hard and Soft Coatings		Now
Transit Care	Glass Guard®					Now
Triton Systems				Silicate Coating		?

ings are vacuum deposited, coated glass is more expensive than tinted glass. However, coated glass can be tailored so that visible light transmission is maximized while maintaining low infrared light transmission and, thus, low heat loadings. Vacuum-deposited coatings would generally be used only in glass laminates, with the coating on one of the glass surfaces that is buried inside the laminate, thus protecting the coating from damage.

Glass is available in annealed, chemically tempered, and thermally tempered conditions. Annealed glass has the lowest strength of the glasses and when it breaks, it breaks into fairly large, jagged pieces. Therefore, annealed glass is used only in laminates for transit applications.

Chemically tempered glass (often referred to as Z-glass) is glass that is strengthened using an ion exchange process. The resulting glass has a compressive residual stress at the glass surface, which increases the resistance of the glass to fracture. The depth of this residual compressive stress is defined by the "case depth," which is usually only 0.001 to 0.002 in. deep for chemically tempered glass. The magnitude of the residual compressive stress is often as high as 50,000 psi. Scratches that penetrate this case depth can cause failure of the glass. This type of glass is sometimes used in laminates for transit applications.

Thermally tempered glass is glass that is strengthened by heat treatment. Relatively rapid cooling of the exterior surfaces of the glass results in residual compressive stresses at the glass surfaces. The case depth for thermally tempered glass is about 20 percent of the glass thickness. Thus, thermally tempered glass is fairly resistant to scratches and other minor surface damage. The amount of temper is defined by the magnitude of the residual compressive stress at the surface of the glass. Fully tempered glass has residual surface compressive stresses that exceed 13,000 psi and are often as high as 25,000 to 30,000 psi. Fully tempered glass breaks into very small pieces when fractured. For transit applications thermally tempered glass is used to reduce the likelihood of lacerations whenever single-ply glass is required.

The term *safety glass* is often used. There are three types of safety glass. The first is laminated glass (usually two sheets of annealed glass with a PVB underlayer). Injury as a result of human impact with the window glass is reduced by the compliance of the laminate and the adherence of the glass to the interlayer material. The second is single-ply tempered glass, which breaks into very small fragments when fractured. The third is glass with wire mesh embedded within the glass. This third type is not used in transit vehicles.

3.1.2 Acrylic

Acrylic, technically known as polymethyl methacrylate, is one of the earliest transparent plastics. It is second to glass for both optical clarity (light transmission and haze) and

TABLE 2 Rough estimates of window cost for buses (glazing only)

Material	Thickness	Estimated Cost for 24-In. x 36-In. Window
Laminated Glass (Clear), AS 2	7/32 in.	$15.60 ($2.60/ft^2)
Laminated Glass (Tinted), AS 3	7/32 in.	$17.40 ($2.90/ft^2)
Laminated Glass (Clear), AS 1	1/4 in.	$18.00 ($3.00/ft^2)
Laminated Glass (Tinted), AS 3	1/4 in.	$21.00 ($3.50/ft^2)
Monolithic Tempered Glass (Clear), AS 2	3/16 in.	$10.50 ($1.75/ft^2)
Monolithic Tempered Glass (Tinted), AS 3	3/16 in.	$12.60 ($2.10/ft^2)
Monolithic Tempered Glass (Clear), AS 2	1/4 in.	$11.04 ($1.84/ft^2)
Monolithic Tempered Glass (Tinted), AS 3	1/4 in.	$13.74 ($2.29/ft^2)
Coated Acrylic (Clear), AS 4	1/4 in.	$58
Coated Acrylic (Tinted), AS 5	1/4 in.	$65
Coated Acrylic (Clear), AS 4	1/2 in.	$115
Coated Acrylic (Tinted), AS 5	1/2 in.	$235
Coated Polycarbonate (Clear), AS 4	1/4 in.	$45
Coated Polycarbonate (Tinted), AS 5	1/4 in.	$50
Coated Polycarbonate (Clear), AS 4	1/2 (0.46) in.	$100
Coated Polycarbonate (Tinted), AS 5	1/2 (0.46) in.	$110
Anti-spall Ply[a]	0.037 in.	$42–$60 ($7–$10/ft^2)
Peel-Ply[b]	0.006 in.	$9 ($1.50/ft^2)
Acrylic Sacrificial Ply (Window Only)	1/8 in.	$7–$8
Acrylic Sacrificial Ply (Initial Installation Kit—Window and Framing)[c]	1/8 in	$55

Note: Cost is based on a 100-unit purchase; freight is not included.

[a]Additional cost of adding an anti-spall ply to a glass window, including labor.

[b]Additional cost of adding a peel-ply to a glass window; does not include labor to install ply.

[c]Does not include labor to install frame.

durability. Although not nearly as hard as glass, uncoated acrylic is often used for many window applications, including architectural and aircraft windows. Because of the severely abrasive environment to which transit windows are subjected, acrylic windows are usually coated with some type of hardcoat (polysiloxane coatings are the most common). Acrylic has reasonably good impact properties and is not as brittle as glass. Usually, it fractures in large pieces, which may be jagged but are not nearly as sharp as glass. Acrylic is combustible and typically will not pass vertical burn tests. It is usually tested in horizontal burn tests.

3.1.3 Polycarbonate

Polycarbonate is a very ductile tough transparent plastic. It is used where impact resistance is important. Polycarbonate is susceptible to abrasion and is not resistant to weathering or chemical attack. Polycarbonate must be coated to provide a reasonable service life. Polycarbonate is selfextinguishing and will pass vertical burn tests, flammability tests, and smoke tests.

3.2 ALTERNATIVE AVAILABLE AND EMERGING TECHNOLOGIES

3.2.1 Sacrificial Plies and Films

Sacrificial surface plies and films (peel-plies) are alternative systems that can increase window durability. The sacrificial plies are held in place with an add-on frame around the window perimeter or with double-sided tape. When this sacrificial ply is damaged, it is simply removed and replaced with another ply. This product is also being specified in new procurements and has been incorporated into the frame design by at least one manufacturer.

Peel-ply products, which consist of a sacrificial plastic film, are applied directly to the interior of the window. This film protects the substrate from damage and is removed and replaced with another film when it becomes damaged. The film adheres to the glass, prevents easy penetration of the glass, and provides spall protection.

Neither sacrificial ply nor peel-ply products require replacement of the more expensive actual window, and repair can be accomplished without removing the window.

TABLE 3 Rough estimates of window cost for rail (glazing only)

Material	Thickness	Estimated Cost for 24-In. x 36-In. Window
Laminated Glass (Clear)	1/4 in.	$30–$72 ($5–$12/ft^2)
Laminated Glass (Clear), FRA-II	3/8 in.	$70.44 ($11.74/ft^2)
Laminated Glass (Tinted), FRA-II	3/8 in.	$76.44 ($12.74/ft^2)
Laminated Glass (Clear), FRA-I	9/16 in.	$75.90 ($12.65/ft^2)
Laminated Glass (Tinted), FRA-I	9/16 in.	$81.90 ($13.65/ft^2)
Monolithic Tempered Glass	Not Applicable to Rail	Not Applicable to Rail
Coated Acrylic	Not Applicable to Rail	Not Applicable to Rail
Coated Polycarbonate (Clear), FRA-II	1/2 (0.46) in.	$100
Coated Polycarbonate (Tinted), FRA-II	1/2 (0.46) in.	$110
Anti-spall Ply[a]	0.037 in.	$42–$60 ($7–$10/ft^2)
Peel-Ply[b]	0.006 in.	$9 ($1.50/ft^2)
Polycarbonate Sacrificial Ply (Window Only)	1/8 in.	$11–$12
Polycarbonate Sacrificial Ply (Initial Installation Kit—Window and Framing)[c]	1/8 in	$60

Note: Cost is based on a 100-unit purchase, freight is not included

[a]Additional cost of adding an anti-spall ply to a glass window, including labor.

[b]Additional cost of adding a peel-ply to a glass window; does not include labor to install ply.

[c]Does not include labor to install frame.

In some cases, it may make sense to use sacrificial plies and peel-ply films only in certain locations on transit vehicles. For instance, in Dayton, Ohio, Miami Valley Regional Transit Authority buses rarely have etching except on one or two windows at the back of the bus. A popular place for graffiti is behind the rear exit structure because this structure shields the vandal from the operator's view. For certain transit systems, only the rear windows may require special treatment. This approach has already been tried by some transit agencies that also use different seats in the back of the vehicles because the backseats tend to get the most vandalism damage.

3.2.2 Anti-Spall Technologies

Anti-spall films have been developed specifically to combat "smash-and-grab" robberies, car-jackings, and hurri-

TABLE 4 Qualitative comparison of current window materials

Material	Application	Durability	Impact Resistance	Resistance to Flame and Smoke	Machinability/ Formability[a]	Density	Cost
Laminated Glass	All Vehicles	Excellent	Good	Excellent	Fair	0.08–0 09 lb/in	Low to Moderate
Monolithic Tempered Glass	All Vehicles Except Intercity and Commuter Rail[b]	Excellent	Fair	Excellent	Fair	0.091 lb/in	Low
Coated Acrylic	Bus	Fair	Fair	Fair	Excellent	0 043 lb/in	Moderate to High
Coated Polycarbonate	All Vehicles	Fair	Excellent	Good	Excellent	0 043 lb/in.	Moderate to High

[a]In terms of resistance to weathering, abrasion, chemicals, etc.

[b]Does not meet mandated ballistic and large object impact requirements for intercity and commuter rail.

[c]Does not meet mandated flammability and smoke emission requirements for intercity and commuter rail.

canes. Research in recent years has studied alternative window materials for automobiles. Side window head impact resistance is one issue that is being evaluated. For protection against car-jacking, glass/plastic laminates, plastics, and glass windows with an anti-spall film have been evaluated. The reason to use anti-spall products is mostly to reduce the possibility of liability resulting from flying (spalled) glass. While some agencies are very concerned about the liability of glass spall, others are not.

Thin polycarbonate plies have also been recommended for spall ply protection. Polycarbonate has the advantage of providing both spall protection and sacrificial ply protection. The polycarbonate would need to be coated with abrasionresistant coatings, such as some of those discussed below, that would not affect impact performance. Also, impact testing would need to be conducted to evaluate spall protection and to ensure that the sacrificial ply would not pull out of the frame and allow the whole panel to come into the vehicle. The attachment frames may need to be redesigned to prevent the panel from pulling out of the frame during impact.

3.2.3 Coating and Aerospace Transparency Technologies

A number of technologies developed for the aerospace transparency industry apply to transit system windows. For example, polyurethane coatings and liners have been developed that provide remarkable improvements in the durability of plastic transparencies. These new materials are significantly more resistant to scratching, scuffing, abrasion, chemical attack, and weathering than uncoated plastics. Polyurethane liners, which may be 0.010 to 0.030 in. thick, have self-healing properties, meaning that gouges, imprints, and abrasion damage disappear with time and/or with the application of heat. Early flight test results of these types of coatings are encouraging. How well they would last in the transit environment (which includes vehicle washers and graffitiremoval solvents) is not known.

In addition to being potential candidates for exterior coatings on acrylic and polycarbonate windows for transit, advanced coatings also have the potential for use on sacrificial plies, especially polycarbonate sacrificial plies.

Several companies, including Sierracin/Sylmar and PPG Industries, are evaluating an aircraft acrylic side window clad with a very thin (0.03 in.) chemically tempered glass ply. This glass is unique because it does not shatter on impact but tends to be damaged only at the impact site. The underlayer adhesive system prevents the glass from spalling. This type of system would prevent crazing of acrylic or polycarbonate windows (because the glass would protect the plastic from the environment) and would substantially increase durability of the exterior surface in terms of resistance to abrasion and weathering. Cost would be a significant issue, however. The average cost for a new aircraft cabin window (which is approximately 14 in. by 20 in.) is $90. The cost for a glass-clad cabin window is currently reported to be $200. The average cost for an acrylic transit window is about $400. The additional cost for adding a thin glass ply to the exterior is unknown.

Several emerging technologies include diamond-like-carbon (DLC) coatings and ion beam surface modifications of plastics. Both technologies have very attractive properties—excellent abrasion resistance, chemical resistance, thermal resistance, and durability—for transit applications. A substantial body of testing has been conducted on DLC-coated polycarbonate. For example, Diamonex of Allentown, Pennsylvania, has a DLC coating which has been used in a number of domestic applications. DLC coatings were used on laser scanner glass windows for bar code scanners in grocery stores. The use of DLC increased the service life of the windows from weeks to years. The cost of these types of new systems has not been established.

3.3 REPAIR TECHNOLOGIES

Repair technologies applicable to window glazings which have been or are being evaluated include polishing, removing material, stripping and recoating, filling cracks and gouges with polymers, and replacing the surface ply. Attractive repair/refurbishment techniques are those that are inexpensive and fast. Best would be a repair technique that does not require window removal, is quick (5–15 minutes per window), is easily implemented, and is not messy. Unfortunately, such a system has not yet been developed for the transit industry. The best current alternative is to remove the windows and send them to a contractor for refurbishment. This system requires the transit authority to maintain a stock of spare glazings, new or refurbished. Transparencies that are removed from service are either thrown away or sent out for refurbishment. When returned, they are placed back into the window inventory.

Various transit agencies are currently investigating or using both repair and refurbishment techniques for existing windows and alternative window materials and systems. The technology exists for complete refurbishment of glass windows, but the windows must be removed from the vehicle and shipped to a company that can grind and polish the surface(s). Discussions with transit authorities and various industries indicate that compared with new glass replacement, this approach is not economically feasible.

To date, it appears that only acrylic windows can be refurbished economically. The acrylic windows are removed from service, sent to a refurbishment/repair facility, ground and polished or machined, recoated as needed, and sent back to the transit authority. The logistics issues related to refurbishment include record keeping, storage, and shipping. Competition from the refurbishment industry has resulted in a significant reduction in the cost of new acrylic transparencies. This narrowing of the margin between new and refurbished

window costs has reduced the attractiveness of refurbishment to some agencies.

There are differences between grinding/polishing techniques and machining techniques for refurbishment of acrylic windows. Grinding/polishing techniques require skill and experience to ensure that the window is not overheated when the surface is ground/polished. Overheating can ruin the window or reduce its service life. Machining techniques, such as diamond milling, actually cut off material, do not overheat the window, and result in a potentially smoother surface and longer service life. The service life of uncoated aircraft windows has been related to surface finish. The smoother the surface finish, the longer the service life (assuming the acrylic has not been damaged by too much heat during refurbishment). It should be noted that not all coatings have equivalent performance. The overall performance of a refurbished window is dependent on the coating.

3.4 PREVENTION SOLUTIONS

For prevention solutions, changing the environment to which the window is subjected is limited to the education of maintenance personnel concerning practices that are detrimental to window service life and, more importantly, the prevention of vandalism, which is discussed extensively by Bowman et al.[2] A brief summary of the findings reported by Bowman et al. is included below.

Preliminary findings show that one system that works to control vandalism is an integrated team approach to zero tolerance. Zero tolerance means "no vehicle in service with graffiti." The integrated team includes drivers and security and maintenance personnel and may be extended to include even the passengers. This zero tolerance approach should be a structured proactive cooperative effort. Many of the following solutions work best when practiced so that all of the team members work together. Practices of this zero tolerance team may include anti-graffiti education; immediate reporting of problems; immediate response to problems; routine and random uniform and undercover patrols; video surveillance; rewards and bounties; truancy sweeps; documentation of incidents; interagency sharing of tag documentation and tagger files; prosecution of all vandals (treatment of all vandalism as a crime); punishment, including arrest and detainment, as well as vandal and parental monetary fines and responsibility for damages; and immediate cleanup/repair of vandalism/damage (within 24 hours). Customer respect is an important issue. A clean, neat, comfortable system will foster customer respect, even from some customers who typically respect nothing. Also, teamwork produces pride in the system for all of the team members. When team members are proud of the system, they tend to take a personal interest in and responsibility for the system.

CHAPTER **4**

SPECIFICATION FORMAT

4.1 SECTIONAL ARRANGEMENT

The recommended format for transit window system specifications is based on MIL-STD-961D. This format has been used in the past by various government agencies and transit authorities.

Each specification shall contain six sections and appendixes, as required, ordered and entitled as follows:

Scope
Applicable Documents
Requirements
Quality Assurance Provisions
Preparation for Delivery
Notes
Appendixes

Subject matter shall be kept within the limits of each section so that the same kinds of requirements or information will always appear in the same section of each specification.

If no information pertains to a section, the following statement shall appear below the section heading: "This section is not applicable to the specification."

4.2 REVISIONS

A revision of a specification is a reissue of a complete specification and shall be prepared, issued, and identified in the same manner as the specification that it supersedes, except that the identification number shall be followed by an appropriate revision letter. Letters shall be assigned in alphabetical order for each succeeding revision. Revision Letter A shall be assigned to the first revision. A brief description of the revision and pages affected shall be indicated on Page 3 of the specification. The date of the last revision shall be indicated on the cover page of the specification. A suggested format for the revision page is provided in Figure 1.

REVISION CONTROL. This document is subject to revision control. Subsequent revisions, if required, shall be implemented by revising the affected page and the following revision index. Each revision shall be approved by the manager of the section that developed the original specification and other management as appropriate.

Original Issue Date: _____

Date Revised	Revision Letter	Description of Revision	Pages Affected	Approved

Figure 1. Example of recommended revision page.

CHAPTER 5

SPECIFICATION REQUIREMENTS

5.1 SCOPE

A statement of the scope shall consist of a clear, concise abstract of the coverage of the specification and may include, where necessary, information on the use of the item. This brief statement shall be sufficiently complete and comprehensive to describe generally the subject covered by the specification in terms that may be easily interpreted by those familiar with applicable terminology and trade practices. The scope should amplify the title, state the function of the specification, and note any materials, products, or services to be excluded.

References to companion or related specifications may be included as a footnote in the scope. The title and designation of such specifications shall be included in the Applicable Documents section (5.2).

Include in this section any caveats or disclaimers on safety hazards for test methods described other than by reference. A standard caveat, based on one used by the American Society of Testing and Materials (ASTM), reads as follows:

> The test methods described in this specification may involve hazardous materials, operations, and equipment. This specification does not address all of the safety problems associated with implementation of the methods. It is the responsibility of the contractor to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

5.2 APPLICABLE DOCUMENTS

This section shall contain a listing of all documents referenced in the specification. The listing shall be by number and title of the referenced document with the documents grouped by organization in alphabetical order and with the specifications in numerical order. Listing of documents shall be grouped by government and nongovernment types. Government documents include military or other organization specifications, standards, drawings, and other publications. Nongovernment documents include standards, practices, and specifications from technical societies, technical associations, and individual transit authorities. The following statement should be included:

> In case of discrepancy between referenced documents and the specification, the specification shall govern except in cases of obvious error. When a document is referenced, the latest revision of the document shall be used.

Note that whenever possible, nonmilitary documents should be referenced instead of military documents. This choice has several reasons. First, many of the Military Standards are no longer being supported by the government and are essentially disappearing. Second, certification to Military Standards tends to be more expensive than certification to nonmilitary standards, such as ASTM, International Standards Organization, American National Standards Institute (ANSI), Society of Automotive Engineers (SAE), among others. In some cases, there are no acceptable alternatives to military documents.

A list of applicable documents that may be referenced and the format for presentation follows.

The latest revision of the following documents form part of the specification to the extent specified herein:

Military Specifications

MIL-STD-12D	Abbreviations for Use on Drawings, Specifications, Standards and in Technical Documents
MIL-P-391D	Plastic Sheets, Rods and Tubing, Rigid Cast, Methacrylate (Multi-application)
MIL-STD-785B	Reliability Program for Systems and Equipment Development and Production
MIL-STD-961D	Department of Defense Standard Practice for Defense Specifications
MIL-P-5425D	Plastic Sheet, Acrylic, Heat Resistant
MIL-P-8184E	Plastic Sheet, Acrylic, Modified
MIL-P-25690B	Plastic, Sheets, and Formed Parts Modified Acrylic Base Monolithic, Crack Propagation Resistant
MIL-G-25871B	Glass, Laminated, Aircraft Glazing
MIL-P-46144C	Plastic Sheet, Polycarbonate
MIL-P-83310	Plastic Sheet, Polycarbonate, Transparent

Other Specifications and Documents

NFPA 130	Standard for Fixed Guideway Transit Systems
NFPA 258-T	Smoke Generated by Solid Materials
ANSI Y14	American National Standard Engineering Drawings and Related Documentation Practices
ANSI Z1.4	Sampling Procedure and Tables for Inspection by Attributes
ANSI/SAE Z26.1	American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways—Safety Code
ASTM B 117	Test Method for Salt Spray (Fog) Testing
ASTM C 162	Terminology of Glass and Glass Products
ASTM C 542	Specification for Lock-Strip Gaskets
ASTM C 1036	Specification for Flat Glass
ASTM C 1048	Specification for Heat-Treated Flat Glass—Kind HS, Kind F Coated and Uncoated Glass
ASTM D 395	Test Methods for Rubber Property—Compression Set
ASTM D 412	Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers—Tension
ASTM D 471	Test Method for Rubber Property—Effect of Liquids
ASTM D 543	Test Method for Resistance of Plastics to Chemical Reagents
ASTM D 573	Test Method for Rubber—Deterioration in an Air Oven
ASTM D 635	Test Method for Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position
ASTM D 673	Test Method for Mar Resistance of Plastics
ASTM D 756	Practice for Determination of Weight and Shape Changes of Plastics Under Accelerated Service Conditions
ASTM D 1003	Test Method for Haze and Luminous Transmittance of Transparent Plastics
ASTM D 1044	Test Method for Resistance of Transparent Plastics to Surface Abrasion
ASTM D 1149	Test Method for Rubber Deterioration—Surface Ozone Cracking in a Chamber
ASTM D 1435	Practice for Outdoor Weathering of Plastics
ASTM D 1499	Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Plastics
ASTM D 1925	Test Method for Yellowness Index of Plastics
ASTM D 2240	Test Method for Rubber Property-Durometer Hardness
ASTM D 2565	Practice for Operating Xenon Arc-Type Light Exposure Apparatus With and Without Water for Exposure of Plastics
ASTM D 2843	Test Method for Density of Smoke from the Burning or Decomposition of Plastics
ASTM D 3002	Practice for Evaluation of Coatings for Plastics
ASTM D 3359	Test Methods for Measuring Adhesion by Tape Test
ASTM D 3801	Method for Measuring the Comparative Extinguishing Characteristics of Solid Plastics in a Vertical Position
ASTM D 4329	Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Plastics
ASTM D 4364	Practice for Performing Accelerated Outdoor Weathering of Plastics Using Concentrated Natural Sunlight
ASTM D 4585	Practice for Testing the Water Resistance of Coatings Using Controlled Condensation
ASTM D 4802	Specification of Poly (Methyl Methacrylate) Acrylic Plastic Sheet
ASTM D 5272	Practice for Outdoor Exposure Testing of Photodegradable Plastics
ASTM E 162	Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source
ASTM E 424	Test Methods for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials
ASTM E 662	Test Method for Specific Optical Density of Smoke Generated by Solid Materials
ASTM E 1478	Practice for Visual Color Evaluation of Transparent Sheet Materials
ASTM F 735	Test Method for Abrasion Resistance of Transparent Plastics and Coatings Using the Oscillating Sand Method
ASTM F 791	Practice for Stress Crazing for Transparent Plastics
ASTM G 7	Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
ASTM G 23	Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type)

	With and Without Water for Exposure of Nonmetallic Materials
ASTM G 26	Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials
ASTM G 53	Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials
ASTM G 90	Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
SAE J673	Automotive Safety Glazing, SAE Recommended Practice
SAE J1050	Describing and Measuring the Driver's Field of View

5.3 REQUIREMENTS

This section shall contain the essential requirements and descriptions that apply to the subject covered by the specification. Requirements may contain but are not limited to the following subsections.

5.3.1 General Requirements

General requirements include mandated requirements, as well as technical documentation requirements, but may be expanded to include other pertinent requirements that are not specifically covered in this document.

5.3.1.1 Mandated Requirements

5.3.1.1.1 Federal Regulations

Transit passenger glazings and windows must comply with certain federal regulations. The regulations, and the governing authorities that administer and enforce the regulations, are dependent on the mode of transportation. The party responsible (whether transit authority, manufacturer, or other) for ensuring that glazings and windows comply with the regulations is dependent on the mode of transportation and on the point in the design-manufacture-usage cycle of the vehicle.

Glazings in commuter and heavy rail must comply with regulations detailed in Title 49 of the Code of Federal Regulations (CFR), Chapter II, Part 223, "Safety Glazing Standards—Locomotives, Passenger Cars and Cabooses." This regulation is administered and enforced under the Federal Railroad Administration (FRA), Department of Transportation. This regulation defines impact and ballistic requirements for Type I (end-facing locations) and Type II (sidefacing locations) glazing material, lists glazing requirements (including the presence of at least four emergency opening windows) for new passenger cars, lists requirements for glazing replacement with certified glazing for existing passenger cars, and describes the certification process for glazing material. FRA holds the commuter or heavy rail line responsible for compliance with this regulation. **Because it is the responsibility of the rail line to operate equipment that complies with 49 CFR, Chapter II, Part 223, all procurement specifications for new equipment or glazing/window system retrofits should require compliance with 49 CFR, Chapter II, Part 223.** FRA holds the manufacturer responsible for certifying that products they provide, which are intended to comply with 49 CFR, Chapter II, Part 223, have been successfully tested in accordance with the 49 CFR, Chapter II, Part 223 test requirements. Certification includes making available, upon request, pertinent original data logs and test setup, measurement devices, and procedure documentation. **Procurement specifications should include the witnessing of appropriate tests to ensure compliance with 49 CFR, Chapter II, Part 223, for new equipment and the delivery of test documentation to ensure compliance of glazing spares.**

Glazings in bus windows must comply with regulations detailed in 49 CFR, Part 571, specifically Standard 205, "Glazing Materials," and Standard 217, "Bus Window Retention and Release." These regulations are administered and enforced under the National Highway Traffic Safety Administration (NHTSA), Department of Transportation. Standard 205 specifies requirements for glazing materials and references ANSI/SAE Z26.1 with a number of exceptions, additions, and changes. Standard 217 specifies requirements for emergency egress in terms of emergency exit size and location, force required to open emergency exit windows and doors, and retention of windows in their frame under increasing static force (push-out). NHTSA holds equipment manufacturers and vehicle manufacturers responsible for compliance with these regulations. Failure to comply, as determined by spot checks and regular inspections, may result in vehicle recall. Although these regulations do not apply to vehicle owners (such as transit agencies), it is recommended that **procurement specifications for new buses, bus overhauls, and bus window spares require compliance with 49 CFR, Chapter V, Part 571**, either by reference or by direct listing of 49 CFR, Chapter V, Part 571 requirements, to avoid costly downtime due to recall.

Standards 205 and 217 discussed above are part of the Federal Motor Vehicle Safety Standards (FMVSS) published by NHTSA. In fact, 49 CFR, Part 571 is the complete set of FMVSS. Standards are numbered identically in the CFR and the FMVSS.

Federal Motor Carrier Safety Regulations are under the jurisdiction of the Federal Highway Administration. The regulations apply to motor carriers that meet any of the following conditions: have a gross vehicle weight rating over 10,000 lbs; are involved in interstate commerce; are intrastate carriers of hazardous materials; or are school buses,

church buses, or private organization buses (a recent addition). These regulations specifically DO NOT apply to closed transit system vehicles.

The Federal Transit Administration (FTA), formerly the Urban Mass Transit Administration, is not a regulatory agency and has no safety jurisdiction, except for drug and alcohol policies and testing. However, the agency does have recommendations for safety, such as those for flammability and emergency egress. FTA does not have any recommendations specific to window glazing. The flammability recommendations apply to both bus and subway transit vehicles. These recommendations may be required under grants that are administered by FTA.

5.3.1.1.2 Pending Legislation

Public Law 103-440, dated November 2, 1994, and commonly referred to as the Rail Safety Authorization Act of 1994, amends the United States Code (USC) to provide two pieces of legislation that may affect future rail requirements. Note that the CFR is being "recodified" and made part of the USC. The sections of the USC referenced below are portions of the CFR that have been inserted into the USC.

Section 315, "Passenger Car Safety Standards," will amend 49 USC, Chapter 201, Subchapter II, to add a Section 20133, entitled "Passenger Cars." The new section requires the Secretary of Transportation to prescribe regulations establishing minimum standards for the safety of cars used by railroad carriers to transport passengers. Under consideration will be crashworthiness, safety of interior features, maintenance and inspection, emergency response and equipment, and "... any operating rules and conditions that directly affect safety not otherwise governed by regulations." Regulations may become applicable to existing cars at the Secretary's discretion. The Secretary must prescribe initial regulations, which may exempt tourist, historic, scenic, and excursion carriers, within 3 years of enactment of the Rail Safety Authorization Act of 1994 (November 1997). Final regulations are due within 5 years of enactment (November 1999). During the development of the regulations, consultation with Amtrak, public authorities, passenger organizations, and employee organizations will be permitted.

Section 219, "Railroad Trespassing and Vandalism Prevention Strategy," will amend 49 USC, Chapter 201, Subchapter II, to add a Section 20151, also entitled "Railroad Trespassing and Vandalism Prevention Strategy." This new section requires the Secretary of Transportation to "consult with affected parties" to evaluate and review current local, state, and federal laws regarding trespassing on railroad property and vandalism affecting railroad safety. The Secretary is also required to develop model prevention strategies and enforcement laws to be used for the consideration of state and local legislatures and government entities. The first such evaluation and review has been completed and model legislation is being drafted (Nancy Goldman, Trial Attorney, Federal Railroad Administration, personal communication, November 30, 1995). The model legislation, due in 1996, will address the following:

> civil or criminal penalties, or both, for vandalism of railroad equipment or property which could affect the safety of the public or of railroad employees; and ... civil or criminal penalties, or both, for trespassing on a railroad owned or leased right-of-way.

These standards are being drafted under the authority of the Federal Railroad Administration, which regulates commuter rail. **Regulations established under Section 219 will be applicable to commuter rail lines and should be consulted for appropriate requirements to be inserted in a procurement specification.** Model legislation developed under Section 219 of the Railway Safety Act may have only limited applicability to procurement specifications. How-ever, model legislation should be examined for possible application to the security measures of all modes of transit.

As authorized by the Intermodal Surface Transportation Efficiency Act of 1991, FTA will issue rules requiring states to designate a state oversight agency responsible for overseeing the safety practices of rail fixed guideway systems within the state. FTA is required to issue a rule implementing the program and may withhold federal funds (as much as 5 percent of FTA Section 9 funding) if a state fails to implement the rule. Under a notice of proposed rule making, FTA proposes to amend 49 CFR by adding a new Part 659, *Rail Fixed Guideway Systems; State Safety Oversight.* The oversight agency must develop and adopt a system safety program *standard* that (1) complies with the American Public Transit Association's *Manual for the Development of Rail Transit System Safety Program Plans,* and (2) includes an *accountability factor,* a written determination by the transit agency of the tasks essential to the safe operation of the rail fixed guideway system, and designation of transit agency officials accountable for the performance of those tasks. The oversight agency must require that the transit agency adopt and implement a system safety program plan conforming to the oversight agency's system safety program standard. Regulations established under 49 CFR 659 will be applicable to all rail lines not regulated by FRA, including all light and heavy rail, cable cars, monorails, people movers, and inclined planes that are used in the calculation of route miles for determining federal transit funding. The formal proposal and review process for the FTA oversight rules have been completed. However, the widely varying opinions of those commenting on the proposed rules indicate that significant changes may be made to the final rules. The final rules will be formally published soon. **It is recommended that the FTA oversight rules and all state regulations resulting from the rules be consulted for appropriate requi-rements to be inserted in a procurement specification.**

5.3.1.1.3 Other Regulations

It is beyond the scope of this document to address every regulation concerning windows. If other regulations not addressed (such as state or local regulations) are in effect, the transit authority should make every effort to include those regulations in their specification, especially when dealing with new contractors or out-of-state contractors who may not be familiar with all requirements. Every specification should include the following or an equivalent statement:

> Products produced per this specification shall meet all applicable federal, state, and local regulations.

5.3.1.2 Technical Documentation Requirements

If applicable, requirements for documentation shall be specified. Requirements shall specify types of documents required for design review and approval, malfunction or procurement, testing, inspection, installation, operation, maintenance, and logistic support, as appropriate. All technical documents shall meet the specific transit authority requirements.

Important technical information that the contractor may consider proprietary to the transit authority shall be quoted, in detail, in this section. Requirements for specified technical documentation (drawings, work manuals, overhaul/repair manuals, installation procedures, etc.) shall be provided. If electronic media (diskettes, magnetic tapes, etc.) are required, a format that is compatible with the specific transit authority computer systems should be used.

5.3.1.2.1 Qualification, Acceptance, and Quality Control Documentation

The contractor shall document all qualification efforts, supply a copy of that documentation to the transit authority, if requested, and maintain a copy of the documentation on file. Acceptance and quality control efforts must also be documented and maintained on file.

5.3.1.2.2 Engineering Data Package

For procurements of new or modified systems, it is recommended that the delivery of an engineering data package be included in the requirements. At a minimum, this package should include engineering drawings and technical operation manuals.

5.3.1.2.3 Drawings

Engineering drawings of windows and window/frame assemblies should include all individual parts, as well as assembly drawings. This information is critical for second-sourcing future procurements and for repair and modification efforts, both in-house efforts and vendor efforts. Minimum standards for drawings should be specified. The recommended drawing standard is the American National Standard Engineering Drawings and Related Documentation Practices, ANSI Y 14. MIL-STD-12D may be referenced for recommended abbreviations.

5.3.1.2.4 Technical Operation Manuals

Technical operation manuals should include all information that is critical for window system maintenance, including instructions for removal, disassembly, repair/refurbishment, and replacement. Also, illustrated parts breakdowns (sometimes referred to as exploded view drawings) and parts listings should be included as part of the technical operation manuals.

5.3.2 Transparency Requirements

5.3.2.1 Material Requirements

Most of the material specifications in existence do not include performance and durability testing sufficient to meet transit authority requirements. It is highly recommended that material requirements be kept as general as possible. Geometry, performance, and durability requirements should be used to ensure that the product performs as desired. It is likely that a number of materials can be used to meet the geometry, performance, and durability requirements. Requiring a specific material or a specific chemical formulation may stifle competition, result in increased cost, and preclude the use of acceptable alternative materials. In addition, requiring a specific material formulation forces the vendors to use what is in the specification and does not allow them to change to new, better, or less expensive materials that would meet all other requirements. It may be desirable to specify a general class of acceptable materials, such as glass, acrylic, or coated polycarbonate, so that the same general type of window is maintained in a vehicle or fleet.

If the agency chooses to require a specific material formulation, the description of that material should be in this section. If acceptable specifications for the material exist, it is recommended that they be cited and incorporated into the document by reference.

5.3.2.1.1 Glass

Requirement. Specification of the type of glass is optional. Applicable existing specifications include ASTM C 1036, "Standard Specification for Flat Glass," and ASTM C 1048, "Standard Specification for Heat-Treated Flat Glass." When either of these glass specifications are used, quality level q^3 should be specified. MIL-G-25871B is a specification for laminated aircraft glazing which has been referenced by various transit authorities. Definitions of terms relating to glass shall be per ASTM C 162, "Standard Definitions of Terms Relating to Glass and Glass Products."

Glass temper may be specified. Choices include annealed, chemically tempered, and thermally tempered.

Material cross section shall be specified. Choices include monolithic (single ply) or laminated (multiple plies). Ply thicknesses may be identified here and also in the geometry requirements. For laminated assemblies, the exact location of each material in the laminate must be specified. It is also important to specify which surface is the inboard and which is the outboard to ensure that the windows are fabricated, marked, and installed correctly.

The underlayer for laminated glass may be specified.

Test Method/Verification. The contractor must certify that the material meets the specification, and testing may be required.

Rationale/Discussion. If a material specification is not used, the transit authority must include sufficient performance and durability requirements to ensure that the product is satisfactory. Polyvinyl butyryl is the predominant underlayer material used for laminated glass assemblies. However, other interlayers are used in glass laminates. It is recommended that the underlayer be defined only in terms of the laminate geometry, performance, and durability requirements. Requirements for specific materials or formulations should be avoided. This is especially true for PVB, which has a number of different formulations depending on the type of glass and laminating process used by the vendor. The choice of a PVB formulation should be made by the vendors and their material suppliers, rather than be dictated by the transit authority.

5.3.2.1.2 Acrylic

Requirement. Specification of type of acrylic is optional. Applicable specifications include MIL-P-391D, MIL-P-5425D, MIL-P-8184E, MIL-P-25690B, and ASTM D 4802. Standard and low-moisture-uptake acrylic may also be specified. For cast acrylic sheet, ASTM D 4802 is recommended. This specification includes material, geometry, performance, and durability requirements. ASTM D 4802 also includes provisions for abrasion-resistant coatings. Additives such as ultraviolet (UV) light stabilizers may be specified; however, weathering test requirements should imply the necessity of such additives to the vendor.

Test Method/Verification. The contractor must certify that the material meets the specification, and testing may be required.

Rationale/Discussion. If a material specification is not used, the transit authority must include sufficient performance and durability requirements to ensure that the product is satisfactory.

5.3.2.1.3 Polycarbonate

Requirement. Specification of a type of polycarbonate is optional. Applicable existing specifications include MIL-P-83310 and MIL-P-46144C. Additives such as UV stabilizers may be specified; however, weathering test requirements should imply the necessity of such additives to the vendor.

Test Method/Verification. The contractor must certify that the material meets the specification, and testing may be required.

Rationale/Discussion. If a material specification is not used, the transit authority must include sufficient performance and durability requirements to ensure that the product is satisfactory. MIL-P-83310 has been used extensively in the past for polycarbonate aircraft transparencies. Its use for transit is not recommended because this polycarbonate is a specialty material.

5.3.2.1.4 Coatings

Requirement. Specification of coating type is optional. Type is limited to chemistry since no known material specifications exist for coatings. The predominant coating materials are polysiloxanes and polyurethanes.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. The coating will typically be specified in terms of performance and durability parameters alone, but specific materials, such as polysiloxane or urethane, may be identified. Specific manufacturers' coating formulations may be identified. One critical requirement for coatings is that they be applied after forming for curved parts. Brittle coatings, like polysiloxanes, will crack if the coating is applied before forming.

5.3.2.1.5 Specialty Materials—Sacrificial Plies and Liners, and Anti-Spall Plies

Specialty materials are all fairly recent in origin. There are no established specifications for these types of materials. They are typically described and specified in terms of geometry, performance, and durability requirements. The transit authority should be careful to include enough requirements for these materials to ensure a satisfactory product. For instance, the current industry leader in peel-ply protection has a product that has been subjected to a number of design trials and iterations to develop a viable product. This product includes three plies of a polyester material with a surface coating to increase durability in terms of abrasion resistance

and cleanability. This product also includes a water-soluble adhesive that is transparent immediately after installation. Early generations of this product required several days or more for the adhesive to cure, during which time the windows would appear cloudy and hazy. Two obvious characteristics that should be required to avoid similar problems in the future for a durable peel-ply material are (1) resistance to abrasion and normal cleaning operations and (2) transparency immediately after installation, with no haze or cloudiness. In general, these materials should meet all the requirements that the basic window material must meet, such as optical, flammability, smoke generation, abrasion, chemical, weathering, among others.

Specialty materials will typically be indicated in terms of performance and durability parameters alone, but specific materials (such as acrylic sacrificial plies) or specific products may be identified as needed. Manufacturers' products that are known to meet the agency's requirements may be referenced as possible sources.

5.3.2.1.6 Sacrificial Plies

Requirement. Specification of material is optional. Choices include polycarbonate and acrylic. ASTM C 4802 may be used as a material specification for acrylic, and MIL-P-46144C may be used for polycarbonate. Also, acceptable commercial products may be specified. Acrylic sacrificial plies need not be coated, although a coating may increase resistance to abrasion. Polycarbonate plies must be coated either by the manufacturer of the material or by the vendor. Attachment methods for sacrificial plies must be specified. Of particular importance are the specification and demonstration of change-out time, a performance requirement. Change-out time for sacrificial plies should be less than 15 minutes; 5 minutes or less is even more desirable.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. Sacrificial plies are typically fabricated from acrylic (for buses), with or without a coating, or coated polycarbonate (for rail, because of flame and smoke requirements) and are nominally 1/8 in. thick. These plies are placed on the inside of the window and provide a "sacrificial" surface that protects the more expensive main window glazing. Sacrificial plies have a number of unique attachment requirements. The three current systems for installing sacrificial plies are (1) an external channel or **Z**-shaped frame around the perimeter of the window, (2) an integral window frame that includes a recess or slot along the perimeter of the window for the sacrificial ply, and (3) two-sided tape that adhesively bonds the sacrificial ply to the main window glazing. The main advantage of sacrificial plies is that once they are vandalized, they can be replaced very quickly and at a fraction of the cost of the main windows. It is recommended that new procurements consider specifying frames that include integral provisions for sacrificial plies.

5.3.2.1.7 Sacrificial Liners (Peel-Ply Protection)

Requirement. Specification of material is optional. Specification of a coating on the material is also optional. Attachment methods for sacrificial liners need to be specified. Of particular importance is the specification and demonstration of change-out time, a performance requirement. Change-out time for sacrificial liners should be less than 15 minutes; 5 minutes or less is even more desirable.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. Sacrificial liners (peel-ply protection) are thin sheets of plastic film material that are adhesively bonded to the inside surface of the window. These plastic films typically consist of multiple plies laminated together into one film. This film resists vandalism damage and is stripped off and replaced when damaged. Currently, this product is available for protecting glass windows only, but the development of acceptable materials for use on plastic windows is anticipated.

This section or the Geometry Requirements (5.3.2.2), Performance Requirements (5.3.2.3), and Durability Requirements (5.3.2.4) sections should also include any additional requirements for the liner materials. For example, requirements for the application of a vandal-resistant sacrificial ply material to a laminated glass assembly might read as follows:

(1) Vendor shall be responsible for the application of vandal-resistant sacrificial ply material to each laminated glass assembly before packaging and shipment to the transit authority.
(2) Vandal-resistant sacrificial ply material shall be a 0.006-in.-thick 3-layer polyester lamination optically clear and distortion free. It must be applied with a water-soluble adhesive. This adhesive shall have a minimum adhesion strength of 4 psi.
(3) Vandal-resistant sacrificial ply material shall be applied to the inboard surface of the window (the side closest to the passenger) and shall be installed so that its edge is within $\frac{1}{2}$ to $\frac{5}{8}$ in. inside the edge of the laminated assembly. This requirement will allow the shield to be changed without removing the laminated assembly from the mounting gasket.
(4) After application of the vandal-resistant sacrificial ply material, there shall be no bubbles, scratches, or other distortions observable from a distance of 3 ft, and the addition of the material shall not decrease light transmission or increase haze or cloudiness.

(5) Laminates must be protected in shipping so that rubbing contact will not mark the vandal-resistant sacrificial ply material.

5.3.2.1.8 Anti-Spall Plies

Requirement. Specification of material is optional. Specification of a coating on the material is also optional.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. Anti-spall plies may be films that are laminated to the inside surface of glass windows or they may be polycarbonate plies that are laminated to the glass or that are on the inside of the glass. The function of the antispall ply is to increase the resistance of the window to penetration and to prevent glass from spalling from the inside surface of the window.

5.3.2.1.9 Marking

Requirement. Marking shall be per ANSI/SAE Z26.1. Location shall be specified. Marking shall also include transit authority's name, date of manufacture, part number, and other desired pertinent information. For windows that meet FRA requirements, the window shall include the FRA designation that applies, FRA-I or FRA-II.

Test Method/Verification. The marking requirement should be verified by inspection.

Rationale/Discussion. In some cases, the nameplate or markings may be the only means of identifying a product after delivery. Such identification is important from the standpoint of stock, replacements, and repair parts. Section 7 of ANSI/SAE Z26.1 requires that the American Standards Classification, the date of manufacture, the manufacturer, and the transit authority's name and specification number should be permanently marked on the window. Also, the window should be marked in a consistent location (e.g., the lower lefthand corner on the outside surface of the glazing) to facilitate reading the information from the inside or outside of the vehicle. This will help ensure that maintenance personnel are installing the correct window in the correct orientation (with the correct surface outboard). The markings should be placed so that they are visible before and after installation. One transit authority reported that it marks each window glazing with the transit system's name to reduce employee theft. Date of manufacture and the manufacturer's name can be useful for identifying window performance problems and for measuring durability, especially if windows from multiple manufacturers are in the vehicles and the supply system. The manufacturer's part number or some type of identification number should also be marked on each window.

5.3.2.2 Geometry Requirements

Specific geometry requirements may be addressed by incorporating or, at a minimum, referencing the appropriate engineering drawing(s). If engineering drawings are referenced or incorporated into the specification, they should include the following topics.

5.3.2.2.1 Size and Tolerances

Requirement. All physical dimensions and tolerances on the dimensions of the window should be defined (width, length, thickness, etc.). This requirement may be accomplished by referencing or incorporating engineering drawings into the specification. A recommended tolerance on overall dimensions is between $\pm \frac{1}{32}$ in. and $\pm \frac{1}{16}$ in. A recommended minimum tolerance for thickness is ±5 percent of the nominal specified dimension over 95 percent of the surface of the window with a tolerance of ±10 percent over the remainder of the surface of the window. As an alternative, a minimum and maximum window thickness may be specified.

Test Method/Verification. The size and tolerance requirements should be verified by inspection; a check fixture may be used as needed for individual parts.

Rationale/Discussion. The recommendation for tolerances is based on common transit authority practice. In some cases, transit authorities have placed the burden of obtaining correct dimensions on the supplier by specifying only that the window shall fit "a specified vehicle." In these cases, it is the supplier's responsibility to obtain engineering drawings or to inspect the vehicles. This method has been used to reduce the workload on the transit authority. In general, this practice is discouraged because of the potential for problems with tolerances and the definition of "fit." The transit authority should maintain current accurate drawings that can be used for specifying the transparency geometry. As part of new vehicle procurements, engineering drawings for all systems should be required to ensure that the transit authority has possession of drawings that can be used for the procurement of spare parts.

For new vehicle procurements, size may be defined only in a general way or by reference to other standards, such as SAE Recommended Practice J1050, which defines driver's field of view requirements. Common requirements for side windows include statements such as, "Side windows shall extend from the shoulder height of a 5th-percentile, seated, female passenger to the eye level of a 95th-percentile, standing, male passenger."

An additional geometry requirement may be needed to accommodate vehicle interior cleaning operations. In some cases, vehicles are "swept out" by placing a large vacuum cleaner/suction device over an entry door (usually the front);

a person in the vehicle uses a handheld air blower unit (leaf blower) to blow dirt and debris toward the door where they are vacuumed out. This cleaning method requires an opening at the rear of the vehicle to allow air to enter the vehicle. The size and the location of the opening should be specified. An example of a requirement for a bus follows.

> An opening in the rear of the coach shall be provided to accommodate a cyclone cleaner. An openable rear window may be used if a prop is provided so that the window cannot be accidentally closed during the cleaning operation. Minimum size of this opening shall be sixty (60) $in.^2$.

5.3.2.2.2 Contour

Requirement. Contour shall be defined by the engineering drawings.

Test Method/Verification. The contour requirement should be verified by inspection. For windows that are not flat, it is recommended that a check fixture be fabricated, and that each part be verified for contour on the check fixture.

Rationale/Discussion. For new procurements, all vehicle windows should be flat. Flat windows offer a number of distinct advantages over curved windows. Flat windows are easier to fabricate, less expensive to procure (and they can be procured from multiple sources), and easier to handle, cut, work with, and store. In addition, it is easy to change material systems or add-on specialty materials, such as sacrificial plies with flat windows. Although windows with curvature may offer some cosmetic and aesthetic advantages, they are not worth the additional problems that they create.

5.3.2.2.3 Flatness

Requirement. When an individual window is placed on a truly flat surface, such as a surface plate, the maximum bow (in inches) shall be no more than the value obtained by multiplying the smallest window dimension (in feet) by 0.03.

Test Method/Verification. The flatness requirement should be verified by inspection. Place window on surface plate or other flat surface and measure bow.

Rationale/Discussion. The recommendation for flatness is based on common transit authority practice. The transit authority may wish to replace this requirement with a requirement for the actual maximum bow for a given part. For example, for a 30-in. by 45-in. window, the actual maximum bow using the foregoing criteria would be $30/12 \times 0.03 = 0.075$ in.

5.3.2.2.4 Laminate Overlap

Requirement. The overlap of one ply over another should not exceed 1/32 in.

Test Method/Verification. Laminate overlap should be verified by measurement.

Rationale/Discussion. The recommendation for laminate overlap is based on common transit authority practice. This requirement applies only to laminates.

5.3.2.2.5 Edge Treatment

Requirement. Requirements for edge treatment include grinding, polishing, finish, sealant, and so forth. A typical requirement for glass laminates specifies that edges must be straight and perpendicular to the face surface, corners and burrs must be ground smooth, and all edges must be sealed with a polysulfide rubber or equivalent. SAE J673 may be used as a reference for edge treatment details.

Test Method/Verification. The edge treatment requirements should be verified by inspection.

Rationale/Discussion. It is important, especially with glass, that the edges be smooth and free of burrs to prevent cutting personnel during handling/installation and to prevent cutting the rubber gaskets.

5.3.2.3 Performance Requirements

5.3.2.3.1 Optical Quality

Optical quality of the window materials includes requirements for haze, distortion, inclusions, scratches, drips, runs, and other types of defects. For glass window systems, quality level q^3 of ASTM C 1036 is recommended. Note that ASTM C 1048 refers to ASTM C 1036 for glass quality requirements. ASTM C 1036 includes requirements for inclusions; knots, dirt, and stones; scratches and rubs; crush; digs; ream, strings, lines, and other linear distortion; wave; and process surface blemishes. ANSI/SAE Z26.1 includes a requirement for distortion and deviation. Defect limits should be specified.

5.3.2.3.2 Haze

Requirement. The maximum allowable haze shall be specified. In the absence of a more restrictive value, 3 percent is recommended as a maximum.

Test Method/Verification. Measurement should be in accordance with ASTM D 1003.

Rationale/Discussion. Haze is a measure of light scatter caused by the window, and haze directly affects visual acuity. The recommended maximum of 3 percent haze is based on requirements for various types of windows. With a haze of less than 3 percent, a person will be unable to detect any loss of optical quality. This requirement should not be difficult to

achieve. Use of the following statement, which has been used frequently in the past and is repeated here for completeness, is not recommended because the statement is subjective.

> All windows shall be so nearly free from haze that the window will have approximately the same clarity as a window of the same nominal thickness of plate glass when viewed against a north light.

Technically stated, the preceding statement would require a maximum haze of approximately 0.5 percent.

5.3.2.3.3 Distortion

Requirement. All windows shall meet ANSI/SAE Z26.1. Glass windows shall also meet ASTM C 1036 quality level q^3 requirements.

Test Method/Verification. Distortion shall be evaluated per ANSI/SAE Z26.1. Glass windows also require evaluation per ASTM C 1036.

Rationale/Discussion. Distortion affects optical quality. Severely distorted windows cause viewed images to "swim." Straight lines viewed through a window with distortion appear curved and may reverse in direction more than once creating **S** curves. The result is discomforting to the passenger.

5.3.2.3.4 Specks of Foreign Material and Inclusions

Requirement. Glass windows shall meet ASTM C 1036 quality level q^3 requirements.

Note the following specifications for all other windows:

- 0.015 in. or smaller—allowed without population limit to the extent that they do not constitute a severe defect, such as clustering.
- 0.015–0.03 in.—allowed up to six per square foot average over the area of the window.
- 0.03–0.08 in.—allowed up to a three per square foot average over the area of the window.
- 0.08 in. or larger—shall be cause for rejection.

There shall be no clusters or chains of bubbles or bubbles larger than 0.03 in. in diameter in the window. If present, bubbles over 0.02 in. in diameter shall have a minimum separation of 3 in. between bubbles. In a 2-in.-diameter circle on the sheet, there shall be a maximum of four bubbles in the range of 0.011 in. to 0.03 in. in diameter.

Defects occurring along the edges of the part in areas where they will be covered by the frame, seals, and so forth, shall not be cause for rejection.

Test Method/Verification. This requirement should be verified per ASTM C 1036 for glass and by inspection for other materials.

Rationale/Discussion. These defects affect window quality and passenger perception of system quality. These recommendations are based on common transit authority practice.

5.3.2.3.5 Scratches

Requirement. Glass windows shall meet ASTM C 1036 quality level q^3 requirements. For all other windows, scratches shall be cause for rejection of the material if they are visible at a distance of less than 36 in. from the window when viewed through the window using daylight (without direct sunlight) or with suitable background light.

Test Method/Verification. This requirement should be verified per ASTM C 1036 for glass and by inspection for other materials.

Rationale/Discussion. These defects affect window quality and passenger perception of system quality. These recommendations are based on common transit authority practice.

5.3.2.3.6 Drips or Runs

Requirement. The following limitations shall apply:

- 0.125 in. or smaller—allowed without population limit unless they constitute a severe defect, such as clustering.
- 0.125–0.25 in.—allowed up to four per square foot average over the area of the window, unless they constitute a severe defect, such as clustering.
- 0.25 in. or larger—shall be cause for rejection.
- Orange peel of the surface—shall be cause for rejection of the material if orange peel exceeds the standard to be established between the contractor and the engineer before manufacture of the material. An alternative requirement is that orange peel shall be cause for rejection if it causes visual impairment.

Test Method/Verification. This requirement should be verified by inspection. For the alternative orange peel requirement, look through the window at a direct light source from a distance of 12 in. If orange peel is visually distracting, reject the window.

Rationale/Discussion. Applicable only to plastic and coated windows. These recommendations are based on common transit authority practice.

5.3.2.3.7 Luminous Transmittance

Requirement. For clear windows (no tint and no solar reflective coating), the luminous transmittance should be no less than 85 percent for up to ⅛-in. thicknesses, 82 percent for ⅛- to ¼-in. thicknesses, 80 percent for ¼- to ⅜-in. thicknesses, and 78 percent for thicknesses exceeding ⅜ in. For tinted windows, minimum luminous transmission shall be specified.

Test Method/Verification. ASTM D 1003.

Rationale/Discussion. In general, it is desirable to maximize transmittance through the window in the visible part of the spectrum, between 430–690 nm. Window quality (cleanliness, optical clarity, tint, size, placement) affects the transit rider's opinion of the overall system quality. In addition, riders tend to feel safer and less confined in a bright, well-lit, clean environment, both while they are on the vehicle and prior to boarding. Window tint and interior vehicle lighting are very important for all modes of transit to create a bright, well-lit environment. Also, security personnel often want to be able to see what is happening on the inside of the vehicle from the outside. For tinted windows, it is recommended that the minimum light transmission be no less than 15 percent (which is approximately equal to the light transmission of dark sunglasses).

5.3.2.3.8 Solar Energy Transmittance

Requirement. The solar transmittance of the window should be specified.

Test Method/Verification. ASTM C 424.

Rationale/Discussion. Although it is desirable to maximize visible light transmission, it is also desirable to minimize solar energy transmitted through the windows (for subway vehicles that are not exposed to sunlight, this requirement is not applicable). Reducing solar energy transmitted through the window reduces air conditioning requirements. To accomplish these two somewhat conflicting goals, trade-offs must be made. The most common approach is to reduce solar energy transmission using tints, which may, however, result in very low visible light transmission through the windows. Another approach that has been used by the automotive industry (for forward-facing windows, which by law must transmit 70 percent of the visible spectrum) and by the architectural glass community is to use metal or metal oxide coatings on glass to reflect as much energy as possible while maintaining reasonable visible transmission. As an example, it is possible to procure glass windows with 71 percent luminous transmittance and 33 percent solar transmittance. Some transit authorities have chosen to increase air conditioning capacity instead of sacrificing visible light transmission through the windows.

5.3.2.3.9 Tint and Color

Requirement. No appreciable variation in tint or color between individual windows shall be identifiable by an individual with normal color vision when the windows are viewed against a well-lit white background.

Test Method/Verification. Test Method ASTM E 1478 may be used for a qualitative assessment of tint/color.

Rationale/Discussion. Significant variations in tint and color affect the passengers perception of system quality.

5.3.2.3.10 Impact Resistance

Requirement. The requirements for impact resistance shall be per ANSI/SAE Z26.1 for buses, which includes a variety of different impact tests; or the requirements shall be per transit authority requirement. For rail, impact requirements are given in 49 CFR, Part 223. Included are ballistic impact requirements (.22-caliber, 40-grain lead bullet at a minimum of 960 ft/sec) and large object impact (22-lb cinder block, 8 in. × 8 in. × 16 in., at a minimum of 12 ft/sec) for side-facing windows.

Test Method/Verification. ANSI/SAE Z26.1 and/or 49 CFR, Part 223 should be used.

Rationale/Discussion. Impact resistance is a passenger safety issue and a mandated requirement.

5.3.2.3.11 Strength (Pressure and Deflection)

Requirement. The side windows shall be designed to withstand pressure loadings of 35 lb/ft^2 (approximately equivalent to a 125 mph wind loading) with a safety factor of 2.5 against failure. Deflections shall be limited to 1/180 of the short span. Both negative and positive pressures shall be considered. Pressure tests shall be performed on the side windows to show conformance with the specified deflection requirement under pressure loads of 35 lb/ft^2. Under pressure loads of 70 lb/ft^2, no window glazing shall come free of its retaining frame, no glazing failure shall occur, and the retaining frame shall suffer no permanent deformation. Pressure tests shall be conducted for both positive and negative pressures. The glazing frame and retention devices shall be the same as those used in production transit vehicles or simulated to the satisfaction of the authority.

Test Method/Verification. The contractor test setup must be approved by the transit authority.

Rationale/Discussion. This is a safety requirement. The transit authority may want to enforce this requirement only on new vehicle procurements and rely on additional testing or engineering analysis in the event of a material system change for in-service windows. This recommended requirement is based on common transit authority practice.

5.3.2.3.12 Water Infiltration

Requirement. The window system must not leak under specified test conditions.

Test Method/Verification. The test shall cover the surface area of the side of the vehicle including the window/frame assemblies. The water spray shall be located so that full overlap between nozzle patterns is obtained on the surfaces of the transit vehicle body. Distances from the nozzles to the transit vehicle surfaces shall be as required to obtain overlap but shall not exceed 5 ft. Each nozzle shall deliver a minimum of 6 gal of water per minute with a nozzle velocity that will simulate 75 mph (or other velocity specified by the transit authority) transit vehicle speed conditions and transit vehicle wash conditions. The actual arrangement shall be subject to transit authority approval.

Rationale/Discussion. For new procurements or complete window system refurbishment or replacement contracts, the transit agency may desire to require water infiltration testing. This recommended requirement is based on common transit authority practice.

5.3.2.3.13 Flammability

Requirement. The flame propagation index, I_s, may not exceed 100 when measured per ASTM E 162. For acrylic bus window applications, flammability shall be less than 1.1 in./min when measured per ASTM D 635.

Test Method/Verification. ASTM E 162 and ASTM D 635.

Rationale/Discussion. Material flammability requirements shall be specified. Flammability requirements shall apply to all nonmetallic materials. Glass windows do not need to be tested, nor do requirements need to be given for glass windows, unless the glass has a plastic or elastomeric material on the inside window surface. As an example, a glass window with a plastic anti-spall ply on the inside surface would need to be tested to meet flammability requirements, while a single-ply glass window or a glass/PVB/glass laminate would not. Different modes of transit have used different flammability requirements. For commuter and intercity rail vehicles, recommendations for testing the flammability characteristics of materials can be found in the *Federal Register* (Vol. 54, No. 10, Jan. 17, 1989, pp. 1837–1840). National Fire Protection Association (NFPA) 130 is a standard for fixed guideway transit systems and includes flammability requirements that are essentially the same as those from the *Federal Register*.

5.3.2.3.14 Smoke

Requirement. Optical density of smoke generated, D_s, in both flaming and nonflaming modes, may not exceed 100 within 90 seconds of the start of the test and may not exceed 200 within 4 minutes of the start of the test.

Test Method/Verification. ASTM E 662. An alternative test method that has been recommended by a plastics manufacturer is ASTM D 2843, but there is no known relationship between this method and ASTM E 662, and there are no established requirements for ASTM D 2843.

Rationale/Discussion. Material smoke emission requirements shall be specified. The smoke emission requirements shall apply to all combustible materials. Glass windows do not need to be tested, nor do requirements need to be given for glass windows, unless the glass has a plastic or elastomeric material on the inside window surface. As an example, a glass window with a plastic anti-spall ply on the inside surface would need to be tested to meet smoke generation requirements, while a single-ply glass window or a glass/PVB/glass laminate would not. Different modes of transit have used different smoke requirements. For commuter and intercity rail vehicles, recommendations for testing the smoke emission characteristics of materials can be found in the *Federal Register* (Vol. 54, No. 10, Jan. 17, 1989, pp 1837–1840). NFPA 130 is a standard for fixed guideway transit systems and includes smoke emission requirements that are essentially the same as those from the *Federal Register*.

5.3.2.3.15 Vandal Resistance

Requirement. None.

Test Method/Verification. None.

Rationale/Discussion. Currently, the only known requirements that address vandal resistance are the ballistic and impact requirements. Also useful are chemical resistance tests (which can be used to evaluate the durability of the window when it is cleaned with graffiti-removal solvents). Specific requirements and corresponding test methods to measure resistance to scratching, scribing, etching, and carving do not exist.

5.3.2.3.16 Quick Change-Out

Requirement. It is recommended that the requirement for change-out time for the transparent window panel ("glass")

be 15 minutes or less; a time of 5 minutes or less is the most desirable. The transit authority should also specify the side on which the window will be changed-out—either the inside or the outside of the vehicle.

Test Method/Verification. This requirement should be verified with a demonstration of quick change-out.

Rationale/Discussion. To minimize maintenance time and cost, quick change-out should be specified. Passenger side windows may require frequent change-outs in areas with vandalism problems. It should be specifically stated that the change-out time is for the transparent portion of the window only, not the entire window/frame assembly. In the past, vendors have met this requirement by changing-out the entire window/frame assembly when the transit authority actually wanted to be able to change-out just the glass in the specified time period.

5.3.2.3.17 Refurbishment

Requirement. Windows must be refurbishable if required. Refurbished windows must meet all requirements for new windows.

Test Method/Verification. This requirement should be verified with a refurbishment demonstration.

Rationale/Discussion. A specification should be written for transit window refurbishment efforts. Also, for new window procurements, the authority may desire to specify that the window be refurbishable. As an example, the transit authority may require the window vendor to demonstrate that its acrylic windows can be refurbished. This demonstration could include stripping the production coating, grinding/ polishing the surface, recoating the window, and testing the window to ensure that it still meets the requirements. Refurbished windows should meet all requirements for new windows.

5.3.2.3.18 Coating

Requirement. Coating requirements are system specific. An example follows. For coatings on polycarbonate, there shall be no detectable cracking, as indicated by fine radial cracks at the point of impact, when struck with a 2.5-ft-lb energy dart with a 0.5-in. tip radius. The affected specimen shall be examined for visible radial cracks. Also, no detectable cracks in the coating shall develop when the specimen is stressed to a 2 percent strain. Stress may be applied by imposing 6,000-psi loading using a tensile testing machine.

Test Method/Verification. ASTM D 3002 and others based on special requirements.

Rationale/Discussion. A guide to specialized test methods for coatings may be found in ASTM D 3002. ASTM D 3002 includes both performance and durability test methods. Coatings from different manufacturers can be expected to have different levels of performance. The exterior coating is the primary protection system for the window. When the coating fails, the window substrate will be directly affected by chemical attack, weathering, abrasion, and so forth. To check durability, it is extremely important to subject the coating to as much testing as can be economically justified. At a minimum, the coating should be subjected to abrasion, adhesion, and chemical resistance testing *after* it has been subjected to natural or artificial weathering, such as that described in the Weathering/Environmental Resistance section (5.3.2.4.3).

5.3.2.3.19 Weight

Requirement. Part weight shall not exceed ———— pounds.

Test Method/Verification. Weigh the part.

Rationale/Discussion. The weight of the window is not usually specified. It may be desirable for future procurements to specify window weight as part of an overall effort to reduce vehicle curb weight and, thus, the cost of fuel over the life of the vehicle. Maximum window weight should be listed. This will allow use of innovative windows that are significantly lighter than the maximum weight; whereas specifying a weight, with a tolerance factor, may eliminate innovative windows that are much lighter.

5.3.2.3.20 Delamination

Requirement. No delaminations shall be allowed.

Test Method/Verification. The delamination requirement should be verified by inspection.

Rationale/Discussion. This requirement is applicable to laminated (multiple-ply) windows and windows with coatings. Delaminations affect window optical quality and passenger perception of system quality; delaminations may also affect structural performance of the window.

5.3.2.3.21 Maintainability

Requirement. Maintainability is usually specified in terms of a warranty for the windows. Typical wording is that the contractor shall guarantee all parts to be free from defects of material and workmanship for a period of 5 years (other time periods may be specified) from date of delivery of the windows. Specific failure modes may also be named; for example, "Windows supplied under this contract shall also be guaranteed against delamination for a period of five (5) years from date of installation, assuming normal service."

Test Method/Verification. Maintainability is proven by in-service performance.

Rationale/Discussion. Maintainability guarantees for the window glazings ensure that the window will perform for the required length of time and thereby meet the expected cost. This requirement may also include, for instance, a guarantee against deterioration of coatings exposed to cleaning chemicals for a certain length of time. The cleaning chemicals must then be defined in the Chemical Resistance section (5.3.2.4.4) to allow vendors to test their products against the chemicals.

5.3.2.3.22 Design and Construction

Requirement. Minimum essential requirements that are not controlled by other requirements or referenced documents shall be specified. Included shall be appropriate design standards; requirements governing the use and selection of materials, parts, and processes; interchangeability requirements; operation safety requirements; and human engineering requirements. For instance, a special requirement for polycarbonate is that the window shall be fabricated so that the orientation of extrusion grain/ripples is horizontal.

Test Method/Verification. These requirements should be verified by test or inspection.

Rationale/Discussion. Any requirement not found elsewhere should be defined either here, under a new descriptive subject heading, or in the General Requirements (5.3.1) sections.

5.3.2.3.23 Storage

Requirement. Windows shall be storable (with vendorspecified storage conditions) for periods up to 5 years before successfully meeting service life requirements.

Test Method/Verification. The storage requirement should be addressed by warranty or test.

Rationale/Discussion. This requirement should be used to ensure that parts may be maintained in storage without losing capability. Certain organic plastics and coatings may lose critical properties, such as impact resistance or craze resistance, because of natural aging, which may be accelerated by high temperatures and/or high humidity in a warehouse.

5.3.2.4 Durability Requirements

Durability of consumable systems or subsystem components of ground transportation vehicles influences operating costs and fleet operational readiness. Window glazings have become or are becoming consumable components of a vehicle transparency system. In addition, window glazings are a highly visible component of a transportation system that affect the consumer's/rider's perception with regard to the cleanliness, safety, trust, and respect of the transportation system. The durability of a window system is a function of the environment in which it is placed and of the material system. The environment the window must endure is composed not only of the natural environment (which would include moisture, temperature, and sunlight), but also of the imposed operating environment (which would include cleaning chemicals and substances, the effects of vehicle washing, solvents associated with painting and paint overspray, greases and oils, pollution, maintenance damage from impact or abrasion, and intentional damage from vandalism).

Durability could be considered a performance requirement. The definitive assessment of durability is in-service performance. Although coupon scale testing provides some measure of performance, only after a system has been fielded and has seen multiple years of service can true durability performance be known. Therefore, limited procurements should be made of new systems and these procurements should be used to assess in-service durability. In-service assessments (sometimes referred to as operational tests and evaluations) should last a minimum of 6 months, including the summer months. The preferred duration is 1–2 years. If in-service assessments are not made, contracts should include language to allow the transit authority to terminate contracts because of poor durability performance.

5.3.2.4.1 Abrasion Resistance

Requirement. ANSI/SAE Z26.1, Tests 17 (plastic) and 18 (safety glass) should be used for buses. Examples of abrasion-resistance requirements for these and other test methods are listed below. There are no known correlations among the three different test methods. The transit authority may also wish to require weathering prior to abrasion testing.

Property	Test Method	Requirement
Mar Re-sistance	ASTM D 673	The change in haze after 1600 g of falling silicone carbide shall be less than 5 percent for coated plastics.
Abrasion	ASTM F 735	The change in haze after 600 cycles shall be less than 10 percent for coated plastics.
Abrasion	ASTM D 1044 ANSI/SAE Z26.1	The change in haze after 100 cycles shall be less than 15 percent for plastics, less than 4 percent for glass-plastics; and after 1,000 cycles the change in haze shall be less than or equal to 2 percent for safety glass. (See SAE/ANSI Z26.1, Tests 17 and 18 for additional details.)

Test Method/Verification. The tests shall include weathering, per the Weathering/Environment Resistance section (5.3.2.4.3) followed by ANSI/SAE Z26.1, Tests 17 and 18 (ASTM D 1044); ASTM F 735; or ASTM D 673.

Rationale/Discussion. There are three common test methods for measuring abrasion resistance of coatings and plastics. These test methods may also be used on glass. They are Bayer Abrasion (ASTM F 735), Taber Abrasion (ASTM D 1044), and Mar Resistance (ASTM D 673). Bayer Abrasion uses a coarse sand material to produce a rubbing/scratching type of abrasion; the requirement given above is based on average performance characteristics of current generation coatings. Taber Abrasion uses an abrasive wheel or disk to produce abrasion; the requirement given above is based on ANSI/SAE Z26.1, Tests 17 and 18 (although many transit authorities have used more stringent requirements for this test). The Mar Resistance test method uses a falling silicone carbide to produce abrasion; the requirement given above is based on common transit authority practice.

5.3.2.4.2 Scratch Resistance

Requirement. None.

Test Method/Verification. None.

Rationale/Discussion. Currently, there are no standardized test methods for evaluating scratch resistance, and thus no requirements. Test methods should be developed for evaluating scratch and gouge resistance, vandalism resistance, and resistance to scratches from other sources, such as tree branches, signs, and so forth. One test technique that is being evaluated to measure scratch resistance uses a weighted stylus that is pulled across the surface of the test material. The stylus can be some type of hard jewel or carbide. The pressure is increased until the stylus penetrates the surface causing a scratch or gouge. The resistance to scratching is defined by the minimum pressure that causes damage. No published standard or commercial equipment currently exists to use this technique.

5.3.2.4.3 Weathering/Environmental Resistance

Requirement. ANSI/SAE Z26.1 includes a number of different requirements and tests that address the effects of the environment on windows. These include Test 1—Light Stability, Test 3—Humidity Test, Test 4—Boil Test, Test 5—Bake Test, and Test 16—Weathering Test. For acrylic, ASTM D 4802 includes weathering requirements. Other specific requirements may be used as needed.

Test Method/Verification. ANSI/SAE Z26.1 is the main source, and ASTM D 4802 includes a test for acrylic. Other test methods may be used as needed.

Rationale/Discussion. Resistance to weathering is extremely important. The combined effects of humidity/moisture, UV light, and temperature can result in severe degradation of the transparency system. These effects cause an increase in yellowness of plastics and coatings, an increase in haze, a decrease in luminous transmission, delamination of the window or coating, and reductions in other properties, such as impact strength, chemical resistance, abrasion resistance, and coating adhesion.

The best way to measure weathering performance and resistance to the environment is to place a part in service and evaluate its performance over time. Unfortunately, this approach is not usually feasible because 2 years or more are needed to obtain even an initial evaluation. Therefore, natural or accelerated natural weathering, such as that conducted by DSET Laboratories Inc., in Phoenix, Arizona, may be used, as may various other accelerated artificial weathering techniques. A number of test methods apply to natural or accelerated natural weathering of plastics and coatings, including ASTM G 7, ASTM G 90, ASTM D 1435, ASTM D 4364, and ASTM D 5272. None of these tests are as good a measure of performance as actual service life because the different natural and artificial weathering techniques include only part of the total environment to which a transit window may be subjected.

A number of different laboratory scale conditioning techniques can be used to evaluate the effects of humidity/moisture, UV light, and temperature (either individually or in combination with each other). Requirements for weathering resistance are written with performance parameters for specific tests. In general, weathering testing should be tailored to the specific climate of the transit authority. For instance, southern Florida has a subtropical climate. Both humidity testing and UV testing should be specified. In contrast, for Phoenix, Arizona, humidity testing is not as important, but high-temperature "bake" testing may be required to simulate the arid desert environment. UV testing would still be important.

A variety of artificial means have been introduced to accelerate the exposure of materials to weathering. The three major types of light sources are xenon arc (such as the Xenotest® device manufactured by DSET), carbon arc (such as the Weather-Ometer® manufactured by Atlas Electric Devices), and fluorescent (such as the QUV® machine manufactured by Q-Panel Corporation). These devices can be equipped with moisture-producing mechanisms to simulate hot/wet, hot/dry, or cool/wet cycles produced by rain or nighttime dew. Of the three types of devices, fluorescent light devices tend to be the least expensive and easiest to operate.

Using carbon-arc devices, weathering should be conducted in accordance with ASTM G 23 and ASTM D 1499. ANSI/SAE Z26.1 Test 16 requires 1,000 hours of carbon-arc weathering. Many authorities have specified that this weathering be conducted in accordance with ASTM D 1499 and ASTM G 23.

Some authorities have also allowed the use of xenon-arc instead of carbon-arc devices to meet the weathering require-

ments of ANSI/SAE Z26.1. Using xenon-arc devices, weathering should be conducted in accordance with ASTM G 26 and ASTM D 2565. According to ASTM D 4802 for acrylic sheet, 1,400 hours of xenon-arc weathering per ASTM D 2565 using a cycle of 102 minutes of light followed by 18 minutes of light and water spray, borosilicate inner and outer (or equivalent) filter system, and 0.35 W/m^2 at 340 nm irradiance is approximately equivalent to 1,000 hours of carbonarc weathering per ASTM D 1499 (see ASTM D 4802 for more details).

Using fluorescent devices, weathering should be conducted in accordance with ASTM G 53 and ASTM D 4329. In the absence of other requirements, ASTM D 4329 Cycle B should be used with 336 hours (2 weeks) of exposure represents approximately 1 year of desired service life. For example, 10 weeks (1,680 hours) of weathering per ASTM D 4329 Cycle B would be used to simulate 5 years of service life. As an aid for comparing different weathering techniques, 1,875 hours of weathering using ASTM D 4329 Cycle B is approximately equivalent to 1,400 hours of xenon arc (see details above) per ASTM D 2565 and is approximately equivalent to 1,000 hours of carbon arc per ASTM D 1499 (which is the ANSI/SAE Z26.1 weathering requirement), based on UV light output.

There are also a variety of tests that can be used to evaluate the resistance of materials to humidity alone, high temperatures alone, or combinations of humidity and high temperatures. ASTM D 4585 can be used with devices, such as the QCT® humidity cabinet from Q-Panel Corporation, to evaluate the performance of materials in high humidity conditions.

In general, the requirement should state the weathering/conditioning parameters, reference applicable standards, and state the specific requirements for pass/failure criteria. Test requirements might include haze and luminous transmission (ASTM D 1003), yellowness index (ASTM D 1925), tape peel adhesion (ASTM D 3359), and visual inspection for imperfections, including coating delamination or delamination between plies. As an example, a typical requirement for long-term resistance to humidity would be that after 1,000 hours at 40°C per ASTM D 4585, there be less than 5 percent change in haze or luminous transmittance, no coating loss in tape peel adhesion (ASTM D 3359), no coating delamination or removal, and no delamination between plies. Or, ASTM D 756 includes a number of different accelerated service life conditioning procedures, including both temperature and humidity, that can be used to evaluate durability of plastics. To ensure a very robust/durable coating system, it is advisable to require weathering testing followed by all of the other types of durability tests in this section. This sequence of tests ensures that the coating system is durable and can continue to perform after weathering. Some authorities have required that weathering be conducted prior to some of the tests in ANSI Z26.1, such as 300 hours of carbon-arc weathering prior to Test 17 of ANSI Z26.1.

5.3.2.4.4 Chemical Resistance

Requirement. ANSI/SAE Z26.1 Tests 19 and 20. For chemical stress craze, ANSI/SAE Z26.1 Test 20 requires that none of the chemicals tested shall cause crazing for stresses of 1,000 psi. A more severe but realistic requirement would be to test for 30 minutes using ASTM F 791 and allow no crazing at less than 2,000 psi. Chemicals shall be listed.

Test Method/Verification. ANSI/SAE Z26.1 Tests 19 and 20, ASTM D 543, and ASTM F 791.

Rationale/Discussion. Chemical resistance is not an issue for glass windows, and, consequently, no requirements for chemical resistance should be placed in a specification for glass windows. Plastic windows and windows that include elastomeric anti-spall plies, elastomeric peel-plies, or plastic sacrificial plies must include requirements for chemical resistance. Chemicals usually affect plastic systems by causing stress crazing, dissolving the plastic, and/or attacking the plastic. Chemical stress crazing looks like many fine cracks at the surface of the plastic. These cracklike features will sparkle under certain lighting conditions, making it impossible to see through a heavily crazed window. Chemicals in which the plastic is soluble or partially soluble may cause the plastic to swell, become sticky, lose engineering properties, and lose transparency. Chemical attack may be very obvious, resulting in discolored or hazy plastic; or it may be subtle, resulting only in a loss of engineering properties, such as ductility for polycarbonate.

There are two broad classes of tests for evaluating resistance to chemicals: chemical tests that include stress (commonly referred to as chemical stress crazing tests) and tests that do not include stress. In chemical stress crazing tests, such as ASTM F 791 or Test 20 of ANSI/SAE Z26.1, a cantilevered beam test coupon is loaded with weight to produce a specified maximum tensile stress at the fulcrum of the beam. Chemicals are placed on the specimen for a specified time period (30 minutes for ASTM F 791), after which the surface of the coupon is examined to determine if crazing has occurred. Other tests that do not include stress and that evaluate the effect of chemicals on plastics include Test 19 of ANSI Z26.1 for chemical resistance and ASTM D 543. These tests can be used to evaluate weight and dimension changes and/or changes in mechanical properties resulting from contact with chemicals.

The windows should be required to withstand chemicals that are commonly used by the individual transit authority. These chemicals should include bus-washing fluids, graffitiremoval substances, window-washing fluids, and other routine chemicals. The transit authority should provide a list of chemicals in the specification. Some of the chemicals listed in the past are contained in Table 5. The transit authority may dramatically increase the service life of its plastic windows by craze testing all chemicals used on or near the windows

TABLE 5 Chemicals that have been used for chemical resistance testing

Chemical Type	Common Examples
Fuels, Oils, Lubricants	Kerosene Diesel fuel Gasoline Denatured alcohol[a]
Cleaning Materials	Windshield cleaner[b] A 1% solution of nonabrasive soap Graffiti-removal substances Commercial glass cleaners[c]
Bus Washing Fluids	Diluted and undiluted acid cleaners[d] Key-Chem 209 Fine Organics FO3796 Neleco Lexol OE Other oxalic acid–type cleaners Potassium hydroxide neutralizers
Others	Toluene Lacquer thinner

[a]A solution of 1 part methyl alcohol and 10 parts 190-proof ethyl alcohol by volume.

[b]An aqueous solution of isopropanol and glycol ether solvents, each in concentration not greater than 10 percent nor less than 5 percent by weight; and ammonium hydroxide not greater than 5 percent nor less than 1 percent by weight. This solution simulates typical commercial windshield cleaner.

[c]Glass Plus®, Windex®, and so forth.

[d]In dilution ratios between 1:15 and 1:30.

and eliminating any chemicals that attack the plastic. This simple, inexpensive procedure could save the transit authority significant resources.

5.3.2.4.5 Color Stability

Requirement. The windows shall have stable color, and they shall not fade or lose properties after extended exposure to the environment.

Test Method/Verification. Verification includes weathering per the Weathering/Environmental Resistance section (5.3.2.4.3) followed by ASTM D 1925 (Yellowness Index) or ASTM E 1478 when a new part is used for comparison to a used part.

Rationale/Discussion. Fading or color change affects window optical quality and passenger perception of system quality.

5.3.2.4.6 Coating Adhesion

Requirement. The coating shall pass the test if no coating is removed from the substrate material on unweathered specimens or on specimens that have been subjected to specified weathering conditions.

Test Method/Verification. The test method shall include weathering per the Weathering/Environmental Resistance section (5.3.2.4.3) followed by ASTM D 3359. For coated acrylic, ASTM D 4802 includes a test method for coating adhesion.

Rationale/Discussion. Continued coating adhesion is important to maintain a durable transparency.

5.3.2.4.7 Environmental Conditions

Requirement. Test requirements shall be used as needed.

Test Method/Verification. Test methods shall be included which address the requirements.

Rationale/Discussion. Environmental conditions that the system, product, item, or material is expected to experience in shipment, storage, service, and use shall be specified. It shall be specified if equipment will be required to withstand or be protected against specified environmental conditions. Criteria shall be included, as necessary, to cover environmental conditions, such as climate, shock, vibration and noise.

5.3.3 Frame and Attachment Requirements

5.3.3.1 Material Requirements

Requirement. Material may be specified as needed. Federal specifications or ASTM specifications may be referenced for metals.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. Material requirements for the frame and mechanisms should be included in this section. It is recommended that the material requirements be general, and that performance requirements be used to ensure that the system meets the transit authority's overall requirements. To reduce corrosion concerns, the authority may desire to specify that all metal components and fasteners be stainless steel or anodized aluminum. It is recommended that contacting surfaces of latch mechanisms be made of similar metals so that one portion of the latch does not wear away the mating surface. Finish is a very important part of the material requirement. In the past, many window frame and attachment components have been painted black or have been black anodized if aluminum. This black finish has proven to be a target for vandalism. Vandals carve through the black surface of the frame, exposing the "white" metal underneath. This effect tends to highlight the graffiti. It is recommended that window frame and attachment components be clear anodized if aluminum or left bare if stainless.

5.3.3.1.1 Marking

Requirement. Each major component of the windshield frame assembly shall be marked with the manufacturer's name, part number, and date of manufacture. The part number should consist of the drawing number and the dash number for the part. For example, Part Number 7420–22 would be found on Drawing Number 7420. For drawings produced by the transit authority or sources other than the vendor, the vendor shall use a part number that includes the drawing number for the part as the first digits in the part number followed by a dash and either the dash number from the drawing or a number assigned by the vendor.

Test Method/Verification. The marking requirement should be verified by inspection.

Rationale/Discussion. The nameplate or markings, in some cases, may be the only means of identifying a product after delivery. Such identification is important from the standpoint of stock, replacement, and repair parts.

5.3.3.2 Geometry Requirements

Specific geometry requirements may be addressed by incorporating or, at a minimum, referencing the appropriate engineering drawing(s). If engineering drawings are referenced or incorporated into the specification, they should include the following topics.

5.3.3.2.1 Overall Design

Requirement. The overall design shall be per specified engineering drawings or shall be stated.

Test Method/Verification. The overall design requirements should be verified by inspection.

Rationale/Discussion. The general window type shall be specified. The three basic categories of window types are fixed, sliding, and transom. Transit authorities should specify window systems for new procurements that have provisions to include sacrificial ply protection (peel-ply protection does not typically require any special provisions since it does not require its own frame). Transit authorities should procure the least complex window system possible. Fixed windows are the least complex. Transom windows are more complex, and sliding windows are the most complex and the most troublesome.

Incorporation of sacrificial plies may be an important part of the overall window design. Sacrificial plies are typically fabricated from acrylic, with or without a coating, or coated polycarbonate and are nominally 1/8 in. thick. These plies are placed on the inside of the window and provide a sacrificial surface that protects the more expensive main window glazing. Sacrificial plies have a number of unique attachment requirements. The three current systems for installing sacrificial plies are (1) an external channel or **Z**-shaped frame around the perimeter of the window, (2) an integral window frame that includes a recess or slot along the perimeter of the window for the sacrificial ply, and (3) two-sided tape that adhesively bonds the sacrificial ply to the main window glazing. The main advantage of sacrificial plies is that once they are vandalized, they can be replaced very quickly and at a fraction of the cost of the main window. It is recommended that new procurements consider specifying frames that include integral provisions for sacrificial plies. The sacrificial ply must be removable without removing the window frame from the vehicle. Screw fasteners that hold in attachment frames for sacrificial plies must have tamperproof heads (specialty heads, such as TORX®) to prevent vandals from removing the fasteners.

Attachment methods for sacrificial plies should be specified.

5.3.3.2.2 Size and Location

Requirement. Size and location shall be per specified engineering drawings or shall be stated.

Test Method/Verification. Size and location requirements should be verified by inspection; a check fixture may be used for individual parts.

Rationale/Discussion. All physical dimensions, and tolerances on the dimensions, of the window assembly and the components should be defined (i.e., width, length, thickness, etc.). Referencing or incorporating engineering drawings into the specification will satisfy this requirement.

The transit authority should maintain current accurate drawings that can be used as a definitive document for specifying the transparency geometry. As part of new vehicle

procurements, window system modifications, or upgrades, engineering drawings for all systems should be required to ensure that the transit authority has possession of drawings that can be used for procurement of spare parts.

For new vehicle procurements, size and location may be defined in only a general way or by reference to other standards, such as SAE Recommended Practice J1050, which defines driver's field-of-view requirements. Common requirements for side windows include statements such as, "Side windows shall extend from the shoulder height of a 5th-percentile, seated, female passenger to the eye level of a 95th-percentile, standing, male passenger." For openable windows, the maximum window opening shall be 9 in., that is, with the window fully open, a sphere larger than 9 in. in diameter shall not fit through the window opening.

5.3.3.2.3 Contour

Requirement. Contour shall be per specified engineering drawings or shall be stated.

Test Method/Verification. Contour requirements should be verified by inspection; a check fixture may be used for individual parts.

Rationale/Discussion. For new procurements, all vehicle windows should be flat. Flat windows offer distinct advantages over curved windows. Flat windows are easier to fabricate, less expensive to procure (and they can be procured from multiple sources), and easier to handle, cut, work with, and store. In addition, it is easy to change material systems or add-on specialty materials, such as sacrificial plies, with flat windows. Although windows with curvature may offer cosmetic and aesthetic advantages, they are not worth the additional problems they create.

5.3.3.3 Performance Requirements

5.3.3.3.1 Passenger Emergency Egress

Requirement. Passenger emergency egress issues for buses are covered in 49 CFR, Chapter 5, Part 571, Section 217, which includes requirements for bus window retention relative to operating forces. The revision to this regulation (effective June 8, 1996) can be found in the *Federal Register* (Vol. 60, No. 89, May 9, 1995, pp. 24562–24572). Passenger emergency egress issues for rail are covered in 49 CFR, Chapter 2, Part 223, Section 15, *Requirements for Existing Passenger Cars.*

Side window egress systems shall meet all local, state, and federal requirements. Exit windows shall be provided with an emergency exit feature designed for quick resetting by the operator while the vehicle is in service. If the escape device of the windows is top-hinged, it shall be captive (i.e., shall not allow the window to fall out after being pushed open).

Test Method/Verification. Passenger emergency egress requirements should be verified by inspection and/or demonstration.

Rationale/Discussion. This is a mandated safety requirement.

5.3.3.3.2 Quick Change-Out

Requirement. It is recommended that the requirement for change-out time for the transparent window panel ("glass") be 15 minutes or less; a time of 5 minutes or less is the most desirable. It should be specifically stated that the change-out time is for the transparent portion of the window only, not the entire window/frame assembly. A change-out time for the window/frame assembly may also be specified. The transit authority should also specify the side on which the window will be changed-out—either the inside or the outside of the vehicle.

Test Method/Verification. Quick change-out requirements should be verified by inspection and/or demonstration.

Rationale/Discussion. To minimize maintenance time and cost, quick change-out should be specified. Passenger side windows may require frequent change-outs in areas with vandalism problems. In the past, vendors have met the window glass change-out requirement by changing-out the entire window/frame assembly when the transit authority actually wanted to be able to change-out just the glass in the specified time period. To achieve quick change-out of the window transparency, the window frame assembly may require items, such as dry seals on the outboard side of the window and a clamped interior frame, that can be easily removed after removal of a number of specialty-head (e.g., TORX®) quarter-turn fasteners. Specialty-head fasteners are recommended to reduce the temptation for passengers to remove the fasteners. For systems that have push-out emergency egress windows, it may be desirable to change-out the entire window/frame assembly (the part that swings out) in a specified time period. If so, the change-out time for this assembly should be specified.

5.3.3.3.3 Weight

Requirement. The specified part shall not exceed ——— pounds.

Test Method/Verification. Weigh the part.

Rationale/Discussion. The weight of the window frame and attachments is not usually specified. It may be desirable for future procurements to specify weight as part of an overall effort to reduce vehicle curb weight and, thus, the cost of fuel over the life of the vehicle. Maximum weight

should be listed. This will allow use of innovative designs for frames and attachments that are significantly lighter than the maximum weight, whereas specifying a weight, with a tolerance factor, may eliminate innovative designs of much lighter parts. One method for controlling weight indirectly is to specify aluminum for the window frame material.

5.3.3.3.4 Maintainability

Requirement. Maintainability is usually specified in terms of a warranty for the window frame and attachments. Typical wording is as follows:

> The contractor shall guarantee all parts to be free from defects in material and workmanship for a period of five (5) years from date of delivery of the window system.

For the window frame and attachment, a requirement may be that the assemblies supplied under this contract shall also be guaranteed against opening and closing mechanism (including latches, hinges, gas cylinders, etc.) failure for a period of 5 years from date of installation, assuming normal service.

Test Method/Verification. Maintainability is proven by in-service performance.

Rationale/Discussion. Guarantees of maintainability for the window frame and attachments are used to ensure that the window will perform for the required length of time and will and thereby meet the expected cost.

5.3.3.3.5 Reliability

Requirement. Reliability requirements shall be stated numerically with confidence levels, if appropriate, in terms of task success or hardware mean-time-between-failures, mean-time-between-maintenance, or other appropriate reliability measures. Numerical maintainability requirements shall be stated in mean-time-to-repair, maintenance personhours per operational hours, or other appropriate maintainability measure. Technical documents may be quoted as applicable. Qualitative requirements for accessibility, modular construction, test points, and other design requirements may be specified. An end-of-useful-life prediction may be quoted in this paragraph. Technical documents, such as MILSTD-785, may be quoted as applicable.

Test Method/Verification. See the Maintainability (5.3.3.3.4) and Mechanism Strength and Fatigue (5.3.3.4.2) sections.

Rationale/Discussion. The only significant reliability issue is for mechanisms for window systems that open and close (sliding windows and transom windows). The reliability of the window mechanisms can be addressed in the durability fatigue testing described in the Mechanism Strength and Fatigue (5.3.3.4.2) section, or by requiring a warranty against failure of the opening and closing mechanisms.

5.3.3.3.6 Design and Construction

Requirement. Minimum essential requirements that are not controlled by other requirements or referenced documents shall be specified. Included shall be appropriate design standards; requirements governing the use and selection of materials, parts, and processes; interchangeability requirements; operation safety requirements; and human engineering requirements.

For instance, a requirement may be that each side window shall have an upper section (transom window) that can be opened inward, but only by the maintenance key. The uppermost 9 in. (the transom window) shall be hinged to open inward and shall be equipped with an over-center feature to hold the transom window open or closed, or shall incorporate gas-charged cylinders to hold the transom window open and a positive latch to hold the transom window closed. The transom window, its hinge, and the mechanism that holds the transom window open shall be designed to withstand pulling when the transom window is fully open. The transom window shall open approximately 5 in. at the top and shall be weather-sealed on all four edges. The bottom edge shall be designed to overlap the fixed portion to protect and drain water away from the hinge.

Another requirement might be that the window frame and the window frame mounting rubber shall be installed so that passengers cannot remove them. The body sash construction shall be such that the sash drain will prevent water from entering or backing up into the coach. Drains shall be incorporated at the bottom of the sash to drain interior condensation on the sash to the exterior of the coach.

Test Method/Verification. These requirements shall be verified by test or inspection.

Rationale/Discussion. Any requirement not found elsewhere should be defined either here, under a new descriptive subject heading, or in the General Requirements (5.3.1) sections.

5.3.3.4 Durability Requirements

5.3.3.4.1 Corrosion Resistance

Requirement. No corrosion of any components shall occur when tested. Test duration, such as 7 days, shall be specified.

Test Method/Verification. ASTM B 117.

Rationale/Discussion. Requirements may be necessary to address corrosion. Typically, corrosion resistance is evaluated by conducting salt-fog testing per ASTM B 117. A

mock-up shall be tested that is representative of the actual frame assembly in the sense that the interaction of the different metals, fasteners, rivets, joints, and so forth, is consistent with the actual design. The mock-up shall include the production coatings, sealants, and paints. Normally the test must be conducted for a given period of time, such as 7 days. At the conclusion of the test, the mock-up is disassembled and examined for corrosion and for paint, coating, or sealant failure. The cause of any failures must be identified and corrected, and the system must be retested. Retesting the exact same system is unacceptable.

5.3.3.4.2 Mechanism Strength and Fatigue

Requirement. Windows, window frames, and mechanisms shall withstand, without damage, peak forces of 100–200 lb applied in any direction. The window shall withstand a specified number of cycles of open-and-close testing with no degradation in performance.

Test Method/Verification. Testing shall be per contractor setup with transit authority approval.

Rationale/Discussion. Window system designs that have moving parts, such as sliding or transom windows, may experience wear and failure in service. Fatigue testing of the window system can be specified to ensure a given life. Estimates for opening-and-closing cycles for various time periods are presented in Table 6. These estimates are based on the windows being used 6 months out of the year and being opened and closed (one cycle) 3 to 12 times per day with the vehicle in service 85 percent of the year. The transit authority may choose to use other numbers based on climate and best estimates of realistic use. For instance, on transom windows that may be opened only by the vehicle operator and that are intended to be opened only in emergencies, fatigue testing is probably not warranted. However, in vehicles that have passenger-openable windows, fatigue of the mechanisms is a problem. Requirements for fatigue testing (opening and closing the window) of a representative mock-up of the window system should include a safety factor of 1.5 to 2 for intended service life. If the vehicle is expected to be in service 10 years, the window mechanism should be fatigue tested for enough cycles to represent 15 to 20 years of use. It is recommended that the fatigue testing equipment used to open and close the windows be set to reverse at 20 to 30 lb of force, which is representative of the force used by an individual to open or close a window. It may also be desirable to specify a peak force—negative and positive—that the window must be able to withstand without damage to the window, frame, or latching mechanism. This peak force should be 100 to 200 lb.

5.3.3.4.3 Environmental Conditions

Requirement. Test requirements shall be used as needed.

Test Method/Verification. Test methods shall be included that address the requirements.

Rationale/Discussion. Environmental conditions that the system, product, item, or material is expected to experience in shipment, storage, service, and use shall be specified. It shall be specified if the equipment will be required to withstand or be protected against specified environmental conditions. Criteria shall be included, as necessary, to cover environmental conditions, such as climate, shock, vibration, and so forth. A vibration magnitude of 2 to 3 g's across a wide spectrum of frequencies would be considered reasonable for normal operation and high-cycle fatigue. Shock loadings could reach 10 to 25 g's in crash conditions. To prevent unnecessary injuries, windows should not break or come out of their frames during a crash. Section 5.3.2.3.11 includes strength requirements for windows and provides for some measure of resistance to shock in the direction normal to the window surface.

5.3.4 Seal Requirements

Many fixed windows (windows that do not open) are held in place with rubber seals. Other window designs use rubber dry seal gaskets on one or both sides of the window. It is recommended that "wet" seals (seals that must cure and that physically adhere to the window and/or the frame) be avoided. Wet seals are more difficult and labor intensive to remove than dry seals.

TABLE 6 Estimated[a] number of opening- and-closing cycles for openable transit passenger windows for various time periods

Number of Open-and-Close Cycles per Day	5 Years of Service	10 Years of Service	15 Years of Service	20 Years of Service
3	2,327	4,654	6,981	9,308
6	4,654	9,308	13,961	18,615
9	6,981	13,961	20,942	27,923
12	9,308	18,615	27,923	37,230

[a]Based on the window being used 6 months per year with the vehicle in service 85 percent of the time.

5.3.4.1 Material Requirements

Requirement. Material may be specified as needed. One material specification that addresses lock-strip glazing rubber gaskets is ASTM C 542.

Test Method/Verification. The contractor must certify that the material meets the specification.

Rationale/Discussion. Most material specifications do not include performance and durability testing sufficient to meet transit authority requirements. It is highly recommended that material requirements be kept as general as possible. Geometry, performance, and durability requirements should be used to ensure that the product performs as desired. It is likely that a number of materials can be used to meet the geometry, performance, and durability requirements. Requiring a specific material or a specific chemical formulation may stifle competition, result in increased cost, and preclude the use of acceptable alternative materials. In addition, requiring a specific material formulation forces the vendors to use what is in the specification and does not allow them to change to new, better, or less expensive materials that would otherwise meet all other requirements. One material specification that addresses lock-strip glazing rubber gaskets is ASTM C 542. This specification includes a number of requirements that are addressed in following sections.

5.3.4.1.1 Marking

Requirement. Each seal shall be marked with the manufacturer's name, part number, and date of manufacture. The part number should consist of the drawing number and the dash number for the part. For example, Part Number 7420–22 will be found on Drawing Number 7420. For drawings produced by the transit authority or sources other than the vendor, the vendor shall use a part number that includes the drawing number for the part as the first digits in the part number followed by a dash and either the dash number from the drawing or a number assigned by the vendor.

Test Method/Verification. The marking requirement should be verified by inspection.

Rationale/Discussion. The nameplate or markings, in some cases, may be the only means of identifying a product after delivery. Such identification is important from the standpoint of stock, replacement, and repair parts.

5.3.4.2 Geometry Requirements

Specific geometry requirements may be addressed by incorporating or, at a minimum, referencing the appropriate engineering drawing(s).

5.3.4.2.1 Size and Tolerances

Requirement. All physical dimensions and tolerances on the dimensions of the seals should be defined (width, length, thickness, etc.). This requirement may be accomplished by referencing or incorporating engineering drawings into the specification. All elastomer moldings shall be arranged so that they are easily removable for repairs or replacements from the specified side (inside or outside) of the vehicle. The moldings shall have rounded corners, both inside and outside the vehicle, to facilitate cleaning.

Test Method/Verification. The size and tolerance requirements should be verified by inspection.

Rationale/Discussion. The transit authority should maintain current accurate drawings that can be used as a definitive document for specifying the seal geometry. As part of new vehicle procurements, procurements of new window systems, or changes in seal design, engineering drawings should be required to ensure that the transit authority has possession of drawings that can be used for procurement of spare parts.

5.3.4.3 Performance Requirements

5.3.4.3.1 Color

Requirement. The color of all seals and gaskets shall be black unless otherwise specified.

Test Method/Verification. Color requirements should be verified by inspection.

Rationale/Discussion. Black is a standard color for gaskets.

5.3.4.3.2 Hardness

Requirement. Per ASTM C 542, the durometer hardness shall be 70 ± 5. Filler strip rubber may be specified at a durometer hardness of 80 ± 5.

Test Method/Verification. ASTM D 2240.

Rationale/Discussion. This recommended requirement is based on common transit authority practice.

5.3.4.3.3 Permanent Deformation Under Load

Requirement. ASTM C 542 allows a maximum of 35 percent permanent deformation under load; however, some agencies use a more restrictive maximum of 25 percent.

Test Method/Verification. ASTM D 395.

Rationale/Discussion. This requirement addresses longterm sealing capability. This recommended requirement is based on common transit authority practice.

5.3.4.3.4 Tensile Strength

Requirement. The requirements shall be as per ASTM C 542.

Test Method/Verification. ASTM D 412.

Rationale/Discussion. This recommended requirement is based on common transit authority practice.

5.3.4.3.5 Ultimate Elongation

Requirement. ASTM C 542 requires a minimum of 175 percent elongation; however, some agencies require a minimum of 300 percent elongation.

Test Method/Verification. ASTM D 412.

Rationale/Discussion. This recommended requirement is based on common transit authority practice.

5.3.4.3.6 Flammability

Requirement. Window gaskets shall pass the flame requirements of ASTM C 542 (must not propagate flame or exhibit flame dripping).

Test Method/Verification. ASTM C 542.

Rationale/Discussion. This requirement is recommended by the recently updated NHTSA guidelines for commuter and intercity rail vehicles and can be found in the *Federal Register* (Vol. 54, No. 10, Jan. 17, 1989, pp.1837–1840).

5.3.4.3.7 Smoke

Requirement. Optical density of smoke generated, D_s, in both flaming and nonflaming modes, may not exceed 100 within 90 seconds of the start of the test and may not exceed 200 within 4 minutes of the start of the test.

Test Method/Verification. ASTM E 662.

Rationale/Discussion. This requirement is recommended by the recently updated NHTSA guidelines for commuter and intercity rail vehicles and can be found in the *Federal Register* (Vol. 54, No. 10, Jan. 17, 1989, pp. 1837–1840).

5.3.4.3.8 Maintainability

Requirement. Maintainability is usually specified by requiring a warranty for the seals. Typical wording states that all elastomeric parts shall be compounded and cured so that they will perform their intended function in a certain type of environment for not less than 10 years. Or, the vendor shall guarantee all elastomeric parts to be free from defects of material and workmanship for a period of 5 years from date of installation.

Test Method/Verification. Maintainability is proven by in-service performance.

Rationale/Discussion. Ten years of window service life is possible with glass-glazing systems. The seal should perform as long as the window performs. This recommended maintainability requirement is based on common transit authority practice.

5.3.4.3.9 Storage

Requirement. All elastomeric seals shall be storable (with vendor-specified storage conditions) for periods up to 5 years before successfully meeting service life requirements.

Test Method/Verification. The storage requirement should be addressed by warranty or test.

Rationale/Discussion. This requirement should be used to ensure that parts may be maintained in storage without losing capability. This recommended requirement is based on common transit authority practice.

5.3.4.3.10 Design and Construction

Requirement. Minimum essential requirements that are not controlled by other requirements or referenced documents shall be specified. Included shall be appropriate design standards; requirements governing the use and selection of materials, parts, and processes; interchangeability requirements; operation safety requirements; and human engineering requirements. Some typical requirements follow.

- The rubber glazing strips shall be designed so that they will hold the glass in the car and be watertight without the use of sealants or filling materials.
- All glazing strips shall be installed with the joint at the top of the window, except as otherwise specified.
- Glazing rubber shall be one continuous piece with vulcanized ends, except as specified otherwise.

Test Method/Verification. These requirements should be verified by test or inspection.

Rationale/Discussion. Any requirement not found elsewhere should be defined either here, under a new descriptive subject heading, or in the General Requirements (5.3.1) sections.

5.3.4.4 Durability Requirements

5.3.4.4.1 Ozone Resistance

Requirement. The requirement shall be per ASTM C 542.

Test Method/Verification. The elastomeric material shall be tested per the requirements of ASTM C 542 using ASTM D 1149.

Rationale/Discussion. While in service, rubbers must resist the deterioration that ozone cracking produces. This recommended requirement is based on common transit authority practice.

5.3.4.4.2 Heat Aging Resistance

Requirement. The requirement shall be per ASTM C 542.

Test Method/Verification. ASTM D 573.

Rationale/Discussion. This recommended requirement is based on common transit authority practice.

5.3.4.4.3 Oil Aging Resistance

Requirement. There shall be no more than 80 percent change in volume.

Test Method/Verification. ASTM D 471.

Rationale/Discussion. This recommended requirement is based on common transit authority practice.

5.4 QUALITY ASSURANCE PROVISIONS

5.4.1 General

Where applicable, the general test and inspection philosophy shall be described with a statement of responsibility for inspection, classification of examinations and tests, sampling, lot information, and other information pertinent to the quality assurance provisions but not directly associated with a specific examination or test. Technical documents, such as ANSI Z1.4, may be quoted as applicable. There are three types of test and inspection requirements: qualification requirements, acceptance requirements, and quality control requirements.

Any special tests and examinations or associated actions required for sampling, qualification evaluation, and so forth, shall be specified under an appropriate heading. When a tabular presentation would provide a better understanding of requirements or would clarify the test requirements for qualification, acceptance, and quality control, a tabular presentation may be used. It is recommended that tables, such as those in the Appendix A, be used to provide a concise summary of both the requirements and the tests.

5.4.2 Responsibility for Inspection and Testing

Unless otherwise specified in the contract or purchase order, the contractor is responsible for performing all inspections and tests listed in the specification. Unless specifically disapproved by the transit authority, or forbidden in the contract or purchase order, the contractor may use the contractor's own facility or any other suitable for the performance of the inspection and testing requirements specified. The transit authority may require that sufficient notification be given to allow transit authority personnel to witness designated tests. The transit authority may reserve the right to perform any of the inspections set forth in the specification if such inspections are deemed necessary to ensure that supplies and services conform to prescribed requirements.

5.4.3 Responsibility for Compliance

All items shall meet the requirements set forth in the specification. The inspections and tests set forth in the specification shall become a part of the contractor's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibility of ensuring that all products or services supplied to the transit authority for acceptance comply with all requirements of the contract. Sampling inspection as part of manufacturing operations is an acceptable practice to ascertain conformance to requirements. However, this does not authorize submission of known defective material, whether indicated or actual, nor does it commit the transit authority to accept defective material.

5.4.4 Workmanship

Where applicable, reference to workmanship shall be stated and shall include the necessary requirements relative to the standard of workmanship desired, such as uniformity, freedom from defects, and general appearance of the finished product. This workmanship section is intended to indicate, as definitively as practicable, the standard of workmanship quality that the product must meet to be acceptable. The requirements shall be worded to provide a logical basis for rejection in those cases where workmanship is such that the item is unsuitable for the purpose intended.

5.4.5 Qualification Requirements

Qualification refers to the verification and validation of product performance in a specific application. This qualification results from design review, test data review, and

configuration audits. Where performance qualification of a design or an end product (including its components) is required, provisions for such qualification testing shall be stated in this paragraph. Requirements shall be included that state the conditions for testing, time of testing, period of testing, number of units to be tested, and other requirements relating to qualification or requalification.

Qualification requirements are those requirements that must be satisfied before a vendor is qualified to manufacture parts. Typically, qualification requirements include *every* requirement. As part of the qualification procedure, the requirement of a preproduction sample (first article inspection) is recommended (see below). The contractor shall document all qualification efforts, supply a copy of this documentation to the transit authority, if requested, and shall maintain a copy of the documentation on file. In addition, transit authorities may require advance notification of test times so they may witness testing.

This section shall list all examinations and tests required to verify that all requirements of the specifications in Sections 5.3 (Requirements) and 5.5 (Preparation for Delivery) have been achieved. These examinations and tests shall include or reference, as appropriate, the following:

- Tests and checks of the material, geometry, performance, and durability requirements;
- Verification of workmanship with specific criteria; and
- Test and inspection methods for ensuring compliance.

Conditions that require requalification shall be specified. These shall include but not be limited to the following: change in material supplier, change in manufacturing process, change in design, failure of parts to meet acceptance or quality control requirements, or poor field performance. If the contractor makes or contemplates a change in material supplier, change in manufacturing process, or change in design, the contractor shall notify the transit authority of the change, and the transit authority shall dictate what, if any, requalification testing is required. It is critical that the transit authority be cautious in allowing changes without requalification testing. Subtle changes in material or process can have significant effects on performance.

5.4.5.1 Preproduction Sample
(First Article Inspection)

If it is essential to a contract or order that a preproduction sample be inspected and tested for design approval before or during regular production, the requirements shall be specified in this section.

5.4.6 Acceptance Requirements

Acceptance requirements must be satisfied for every part delivered. Acceptance tests must be nondestructive since they apply to every part delivered. Acceptance requirements are typically limited to geometry, weight, and optics. Acceptance requirements directly influence part cost since they may add direct labor costs to every part produced.

5.4.7 Quality Control Requirements

Quality control requirements ensure that a manufacturing run, batch, or lot is meeting all requirements. Any of the qualification requirements could be included in quality control requirements. For example, at certain intervals or milestones during production, quality control sampling and testing of performance would be merited. The transit authority may wish to specify sampling intervals or leave this choice to the vendor but require the vendor to submit quality assurance (QA) plans, procedures, and documentation as noted below. Testing and sampling requirements must be specified. At a minimum, it is recommended that each buy or production run of a product be tested. Any changes in formulation or manufacturing technique shall also require retesting to satisfy the Qualification Requirements section (5.4.5).

The transit authority may wish to specify QA requirements for the vendor. In this section, a list of the contractor's QA program requirements shall be stated. These requirements shall include, as appropriate, the following:

- Contractor to submit QA manuals and procedures for transit authority review and approval;
- Contractor to allow transit authority to audit for implementation of QA program; and
- Contractor to allow transit authority to inspect and audit the facility and QA-related documents.

5.5 PREPARATION FOR DELIVERY

5.5.1 General

This section shall include the applicable requirements for the preservation and packaging of the title item and for the marking of packages and containers.

5.5.2 Specific Requirements

The specific requirements for materials to be used in packing, marking, and drying shall be covered in this section either directly or by reference to other specifications, publications, or drawings. These materials shall not be deleterious to the equipment or component being packaged.

5.5.3 Detailed Preparation

Requirements may be included by reference to other specifications and applicable standards or, where these do not exist, by detailed instructions. The requirements shall include

appropriate headings, as required, for disassembly, cleaning, drying, preservation, packaging, and marking for packing and shipment. These requirements shall be specifically related to each required level of preparation and will leave no doubt as to the requirements applicable to each level. Detailed preparation for delivery requirements should be covered, as is practicable, in the categories that follow.

5.5.4 Preservation and Packaging

These requirements shall cover adequate cleaning, drying, and preservation methods to prevent deterioration in addition to appropriate protective wrapping, package cushioning, interior containers, and package identification. Where no suitable reference is available, step-by-step procedures shall be included. If pressure sensitive masking is used, it shall be easily strippable from the material and not leave any residue on the material.

5.5.5 Packing

The requirements for packing shall cover the exterior shipping container, the assembly of items or packages therein, and any necessary blocking, bracing, cushioning, and weatherproofing. It may be desirable to require that only one type of part be packaged in a crate. Mixing of different types of parts in a single crate may cause problems in inventory and in locating parts when needed.

5.5.6 Marking for Shipment

This section shall establish the marking requirements essential to the safety, protection, and/or identification of an item. Requirements in detail or by reference to recognized documents shall include the following:

- Appropriate identification of the product (on both packages and shipping containers), including manufacturer, date of shipment, part number, stock number, description, and so forth;
- All markings necessary for delivery and for storage;
- All markings required by regulations, statutes, and common carriers; and
- All markings necessary for safety and safe delivery; for example, "Fragile," "Handle With Care," "Do Not Drop—Do Not Use Hooks."

5.6 NOTES

5.6.1 General

This section shall contain no requirements, but rather general or explanatory information, including contractually nonbinding information (such as additional reference data, changes in product designations, standard sample, etc.), to assist in determining the applicability of the specification. This section may include the following or other information as applicable: intended use, ordering data, definitions, miscellaneous notes, and a glossary for special terms and definitions used in the text.