DUKE COGEMA
STONE & WEBSTER

Mr. Eric J. Leeds, Chief
Special Projects Branch
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

15 December 2000
DCS-NRC-000030

Attention: Document Control Desk

Subject: Docket Number 070-03098
Duke Cogema Stone & Webster
Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF)
DCS Report on Choice of MFFF Process Glovebox Window Material

Dear Mr. Leeds:

This letter transmits ten copies of the DCS report DCS01-ZJJ-DS-NTE-M-40006-A, "Choice of MFFF Process Glovebox Window Material," dated December 2000. As discussed previously with the NRC Staff, DCS is seeking your concurrence with the selection of polycarbonate for use in process gloveboxes for the MFFF.

The Staff has indicated previously that the NRC is the "Authority Having Jurisdiction" described in the National Fire Protection Association's (NFPA's) *Standard for Fire Protection for Facilities Handling Radioactive Materials* (NFPA-801). Accordingly, and pursuant to Section 1-3 of that standard, DCS is requesting your concurrence that the use of polycarbonate is acceptable for use in glovebox windows. The Authority Having Jurisdiction should concur that, in lieu of using noncombustible materials, methods have been employed that secure as nearly as practical the level of fire protection intended by the standard. The enclosed report demonstrates that equivalent protection is afforded with polycarbonate, in light of the totality of safety considerations associated with glovebox window design.

The selection of polycarbonate for use in process glovebox windows is a key design decision that is crucial to maintaining consistency with our reference design (i.e., COGEMA's Melox and La Hague facilities). We are providing this report in advance of our submittal of the MFFF Construction Authorization Request (CAR) to facilitate your timely concurrence.

Please note that this report describes structures, systems, and components (SSCs), and personnel actions associated with the MFFF. Many of these SSCs and personnel actions are also described in the safety assessment of the design bases of principal SSCs required to support construction authorization pursuant to 10 CFR §§ 70.22(f), 70.23(a)(7), and 70.23(b). As you

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NMSS01 Public

are aware, however, at this time we have not specifically identified Items Relied On For Safety; this identification will occur as part of our Integrated Safety Analysis (ISA) and will be reflected in our subsequent application for a special nuclear material possession-and-use license.

Certain commitments to various codes and standards (such as NFPA) are contained in the upcoming CAR. The design features and personnel actions described in this report are intended to be representative of our design, and those features may vary as detailed design proceeds. However, as is evident in this report, the selection of polycarbonate material is largely insensitive to the specific design features or changes thereto, especially given DCS' commitment to these codes and standards.

Accordingly, DCS requests your concurrence as the Authority Having Jurisdiction that polycarbonate is an acceptable material, subject to the appropriate consideration of such material in the analyses supporting the ISA.

If you have any questions, please feel free to contact me at (704) 373-7820.

Sincerely,

Peter S. Hastings, P.E.
Licensing Manager

xc (without enclosure):

Edward J. Brabazon, DCS
Bruce E. Brunsdon, DCS
Lionel Gaiffe, DCS
Yawar H. Faraz, USNRC/HQ
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DUKE COGEMA
STONE & WEBSTER

DCS Report No. DCS01-ZJJ-DS-NTE-M-40006-A

Choice of MFFF Process Glovebox Window Material

Duke Cogema Stone & Webster

December 2000

ABSTRACT

This report documents the tradeoffs considered in the selection of polycarbonate for the process glovebox windows in the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). Operational experience with fires at the Rocky Flats Plant has focused safety on the combustibility of glovebox materials. The applicable fire protection design standard for the MFFF project, National Fire Protection Association (NFPA) 801, requires either use of noncombustible materials in glovebox construction or implementation of equivalent levels of fire protection by other means. Therefore, the decision to use polycarbonate requires evaluation and comparison of the risks posed by fire and other failure mechanisms, as well as other criteria important to design, especially in the context of overall safety. Other criteria considered in evaluating the material include nuclear safety, design code compliance, operability, maintenance, fabrication, and overall experience with the product when used in this application. Based on the evaluation and comparison of risks provided in this report, polycarbonate is preferred for the process glovebox windows in the MFFF.

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EXECUTIVE SUMMARY

The report documents the tradeoffs considered in the selection of polycarbonate for the process glovebox windows in the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). Operational experience with fires at the Rocky Flats Plant has focused safety on the combustibility of glovebox materials. The applicable fire protection design standard for the MFFF project, National Fire Protection Association (NFPA) 801, requires either use of noncombustible materials in glovebox construction or implementation of equivalent levels of fire protection by other means. Therefore, the decision to use polycarbonate requires evaluation and comparison of the risks posed by fire and other failure mechanisms, as well as other criteria important to design. Other criteria considered in evaluating the material include nuclear safety, design code compliance, operability, maintenance, fabrication, and overall experience with the product when used in the application. The report compares the use of polycarbonate or glass in MFFF process gloveboxes by considering glovebox window material properties, window performance under thermal loading, window performance under mechanical loading, lessons learned from the Rocky Flats fires, and other safety, maintenance, and operational considerations.

The report concludes that polycarbonate is the preferred material for glovebox window panels in the MFFF. This conclusion is based on results from the fire hazards analysis; the extensive design, fabrication, and operation experience available from the COGEMA La Hague and MELOX facilities; and the superior behavior that polycarbonate exhibits under seismic deflection and impact loads.

The desirable material properties for MFFF process gloveboxes fabrication and operation were determined by reviewing MFFF operations, appropriate codes and standards, and the potential failure mechanisms of the glovebox windows. Of these mechanisms, the potential failure mechanisms that could breach the glovebox windows include thermal degradation under a large fire and degradation under mechanical loads (e.g., ventilation pressure transients, seismic inertia, seismic deflection, or impact due to operational accidents and load drops). Of the available types of plastic materials, polycarbonate is the material used in the MELOX and La Hague gloveboxes that serve as the reference designs for the MFFF equipment. Other plastic materials do not exhibit appreciably better performance with respect to mechanical strength and resistance to fire than polycarbonate.

The performance of polycarbonate glovebox windows in case of fire is evaluated using traditional fire hazards analysis techniques. To adequately assess the fire performance of the windows, a fire starting on either side of the windows (i.e., internal or external to the glovebox) is analyzed. This analysis examines one room of the MFFF containing process gloveboxes (for the external glovebox fire) and one process glovebox (for the internal glovebox fire). The combustible loading and ignition sources in the analyzed room are bounding of loads and representative of ignition sources in the MFFF rooms containing process gloveboxes. Likewise, the combustible loading and ignition sources in the analyzed glovebox are bounding of loads and representative of ignition sources within the MFFF process gloveboxes.

An evaluation of gloveboxes indicates that the risk of a fire damaging a polycarbonate glovebox window is very low. The lack of ignition sources present in the process rooms or gloveboxes themselves would prevent a significant fire from ever occurring. Even if a fire were to start, the combustible properties of polycarbonate are so poor that a flame source must be maintained and trained directly on the polycarbonate in order to breach confinement. In addition, protective measures are provided to mitigate the consequences of a fire. These include the following:

- Fire detection devices inside and outside of the glovebox
- Fixed suppression system in rooms containing gloveboxes
- Portable suppression system for injection into the glovebox
- Separate dynamic confinement system with UL Class 1 HEPA final filters for the glovebox interior and the glovebox room
- Fire-rated barriers to prevent propagation of the fire.

Thus, even such a hypothetical situation would not result in any significant consequences to workers or an unacceptable release to the environment. Although polycarbonate is classified as a combustible material, its use is an acceptable alternative that does not induce any significant fire risk, given the design measures and level of fire protection features provided at the MFFF. Other attributes besides fire safety function performance should be considered in selecting a glovebox window material. The performance of both polycarbonate and glass windows under mechanical loading is measured by calculating stresses under the applied loadings and comparing them to material allowable values determined in accordance with the applicable design code. Maximum stresses under each loading condition are calculated using finite element models of several different window panel configurations. Analysis results indicate that the mechanical performance of polycarbonate window panels is better than glass under normal operating pressure and seismic inertia loading and is clearly superior to that of glass under seismic deflection and impact loading.

Other safety, maintenance, and operational attributes of both glass and polycarbonate such as compatibility with process materials and operations, specific gravity, optical clarity, wear resistance, radiation shielding, workability, and cost are considered. From a procurement viewpoint, the fabrication of glass glovebox windows would be difficult considering the large number of gloveports utilized in the MFFF design. The use of glass in lieu of polycarbonate would represent a significant technical and schedule risk to DOE's MOX Program.

A comparison of the two materials, based on nonsafety operability and maintenance criteria, indicates that glass is heavier and thus more difficult to replace. Notwithstanding any advantage to the use of glass, the operating experience at MELOX and La Hague indicates that polycarbonate performs suitably and is the most cost-effective choice from a design and procurement standpoint.

CHOICE OF MFFF PROCESS GLOVEBOX WINDOW MATERIAL

1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to justify the use of polycarbonate for the process glovebox windows in the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). The criteria considered in selecting the recommended material include nuclear safety, operability, maintenance, fabrication, design guidance, and overall experience in product use in the application.

1.2 SCOPE

The scope of this report is limited to the evaluation of window material for MFFF process gloveboxes.

1.3 APPLICABILITY

This report is only applicable to the window material of MFFF process gloveboxes. These windows are typically large and have stringent operability and maintenance requirements. However, this report may be applied to nonprocess glovebox applications (e.g., laboratory gloveboxes) when nuclear safety, operability, maintenance, fabrication, design guidance, and overall experience differences between process and nonprocess glovebox applications are considered.

1.4 BACKGROUND

1.4.1 Overall MFFF Design

The MFFF is designed to produce MOX fuel assemblies on an industrial scale from a mixture of uranium and plutonium oxides for use in mission light-water reactors. The MFFF will be constructed on a DOE site and will be licensed by the U.S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations (CFR) Part 70 (Ref. 1). The facility is designed to applicable U.S. codes and standards and operated by DCS, a private consortium under contract to DOE. The goal of the contract is to design, construct, and operate a facility to fabricate MOX fuel based on existing technology from the COGEMA MELOX and La Hague plants in France. To maximize the benefit of the existing technology, equipment designs from the MELOX and La Hague plants is duplicated, to the maximum extent possible, in the design of the new plant.

1.4.2 Glovebox Window Materials

Due to the industrial scale of the MFFF, the MFFF process gloveboxes and their windows are considerably larger than those that are commonly used in laboratories. In addition, manufacturing and maintenance operations require that the glovebox windows be as large as possible and that the gloveports located as necessary to provide access to the manufacturing operation and to equipment. This requires a high number of gloveports in each window. The choice of window material used to fabricate the gloveboxes that enclose process equipment has a significant impact on the overall equipment configuration and operation. Windows in the MELOX and La Hague gloveboxes are fabricated from polycarbonate. The high strength-to-weight ratio and workability of this material provide glovebox designs that are easier to build, operate, and maintain than those with glass windows and provide superior resistance to breaching caused by mechanical loads. Polycarbonate, however, can potentially degrade under extreme fire conditions, and because it is technically a combustible material, it contributes to the overall combustible load that must be considered in the fire hazards analyses for the facility.

1.4.3 Applicable Regulatory Guidance and Industrial Standards

The applicable fire protection design standard for the MFFF project, National Fire Protection Association (NFPA) 801 (Ref. 2), requires the use of noncombustible materials in glovebox construction, but permits alternative methods of meeting the requirements of the standard if these methods provide an equivalent level of protection (NFPA 801, Section 1-3). Alternative methods of compliance are required to be submitted to the authority having jurisdiction. The authority having jurisdiction may approve methods that secure as nearly as practical the level of fire protection intended by the standard. Therefore, the decision to use polycarbonate requires evaluation and comparison of the risks posed by fire and other failure mechanisms, as well as other criteria important to design and approval by the authority having jurisdiction (i.e., NRC). This report provides this evaluation and comparison of risks.

AGS-G001-1998, *Guideline for Gloveboxes*, by the American Glovebox Society (Ref. 3) indicates that the glovebox window material should be based on the overriding safety consideration (e.g., polycarbonate is appropriate where glass is susceptible to damaging chemicals or breakage and resulting loss of confinement). Based on the guidance of this document, glass should be used if fire is the primary risk and polycarbonate should be used if confinement concerns are the primary risk. Therefore, similar to the NFPA 801 guidance, the use of glass or polycarbonate requires evaluation and comparison of risks as given in this report.

The guidance provided in ASTM C852-93, *Standard Guide for Design Criteria for Plutonium Gloveboxes*, by the American Society for Testing and Materials (ASTM) (Ref. 4) demonstrates that the glovebox window material should be resistant to the effects of fire, mechanical shock, and radiation, of which a form of glass or polycarbonate are the preferred materials. The only conflict between the MFFF design and the ASTM C852 criteria specified is the proposed use of single-sheet polycarbonate as opposed to laminated polycarbonate. The choice of single-sheet polycarbonate is made based on fabrication considerations and the fact that the windows will be evaluated for accidents that could challenge confinement.

1.4.4 Regulatory Guidance (NUREG-1718)

The NRC recently issued NUREG-1718, *Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility*, August 2000 (Ref. 5). This document provides regulatory guidance that is applicable to the design of the MFFF. Section 7.4.3.2.W of NUREG-1718 states, in part, "Provisions are made to construct gloveboxes and windows of non-combustible materials." The basis for this guidance is implicitly identified in Section 7.4.2 of the NUREG as DOE-STD-1066-97, *Fire Protection Design Criteria* (Ref. 6).

Section 15.2.2.1 of DOE-STD-1066-97 provides guidance regarding glovebox window materials. Specifically, DOE-STD-1066-97 states the following:

- Glovebox windows should be constructed of wire glass, fire-rated glass, or laminated safety glass. The window gasketing material should be noncombustible, fire-retardant treated, or heat resistant.

- If laminated safety glass is used in locations where radiation levels may be high enough to cause yellowing of the plastic, a cerium additive should be specified to prevent yellowing of the plastic laminate.

- If either the glovebox atmosphere or operations require that an alternate window material be used, fire-retardant treated polycarbonate may be used. If fire-retardant polycarbonate must be used, it should be sandwiched with noncombustible material (such as wire or tempered glass) whenever possible. As an alternative, the exterior side of the polycarbonate should be protected with a noncombustible material to guard against the effects of exposure fires.

The guidance provided in DOE-STD-1066-97 is based upon numerous references and the lessons learned from the Rocky Flats fires of 1957 and 1969. Of these references, the preeminent reference for this guidance is *Glovebox Fire Safety* generated by the Factory Mutual Research Corporation (FMRC) in 1967 (Ref. 7).

The guidance provided in *Glovebox Fire Safety* does not stipulate that glovebox windows must be constructed of "noncombustible materials" as stated in NUREG-1718. Rather it explicitly states that a minimum property of a glovebox window material should be "non-self-propagation of flame." Therefore, to satisfy the underlying basis of the guidance provided in NUREG-1718, the glovebox window material to be used at the MFFF should have the property of being self-extinguishing. This is the case for polycarbonate (see Section 5.3). Based on fire tests and evaluation, FMRC recommends the use of polycarbonate, such as Lexan, for use in glovebox windows "where workability of the window material is important, or where the fire hazard is considered not serious."

Section 7 of this report discusses the impact of the Rocky Flats fires on the design of glovebox window materials at the MFFF.

1.5 APPROACH

The analyses that support the recommendations documented in this report are performed using parameters associated with typical glovebox installations in the MELOX and La Hague plants. A description of the typical glovebox window application and the polycarbonate and glass materials under consideration and their properties is presented first, followed by a general discussion of safety functions and requirements.

The risk of fire posed by the use of polycarbonate in glovebox windows is evaluated by comparing the thermal loading required to degrade polycarbonate to the potential to generate such thermal loading in the glovebox application. Standard fire hazards analysis techniques (e.g., reviewing ignition sources, combustible loads, and fire detection and suppression measures) are used to qualitatively assess the potential for fire in a typical glovebox installation.

The performance of both polycarbonate and glass under mechanical loading is also compared to assess risks posed by other failure mechanisms. Finite element stress analyses of window panels under typical normal operating and seismic loadings are used to calculate peak stresses, which are compared to allowable stresses determined in accordance with applicable design codes to determine factors of safety.

Finally, material selection considerations other than failure risk are evaluated by listing advantages and disadvantages for each material under consideration.

2. GLOVEBOX WINDOW DESCRIPTION

Process gloveboxes at both the MELOX MOX Fuel Production Facility and Fuel Customization Building are large (up to approximately 16.4 by 16.4 by 3.9 ft [5 by 5 by 1.2 m]) in order to house industrial-scale production equipment. They are designed using large window panels that occupy a significant percentage of the total glovebox wall area. The panels are clamped to the structural frames or glovebox shells around their periphery between Neoprene gaskets. The panels, which vary in size up to 3.3 by 4.9 ft (1 by 1.5 m), are fabricated from sheets of polycarbonate 0.39 in (10 mm) thick. Gloveports or bagports are mounted directly into the window panels. The other types of penetrations, including electrical penetrations, are installed in the stainless steel shell of the glovebox. This type of window design provides for greater visibility of internal equipment and flexibility in the placement of gloveports or bagports than other designs, which simplifies the task of operating, cleaning, and maintaining equipment inside the glovebox. Elevation views of a typical large glovebox showing the window panels, gloveport and bagport locations, and internal equipment are provided in Attachment A.

The ability of the glovebox window panels to resist mechanical loading is a function of the number, size, and spacing of the perforations in the panels. The design criteria established for MELOX gloveboxes provide maximum size and minimum gloveport spacing criteria, which must be met to ensure that the panels can retain sufficient mechanical strength to resist applied loads. Provided they meet the criteria, glovebox designers are allowed to locate gloveports as required to afford operators the best access possible to internal equipment.

The final location of gloveports in each window panel is typically determined after the glovebox internals have been assembled and is verified by specific maintenance tests performed during the equipment shop test phase of the procurement. The gloveport layout reflects an emphasis on day-to-day operations and radiological dose reduction.

3. GLOVEBOX WINDOW MATERIALS AND PROPERTIES

In nuclear facilities throughout the world, glovebox windows have been fabricated from a variety of different materials including many forms of glass (wire, tempered, and laminated), plastic (polymethyl methacrylate [Plexiglas], allyldiglycolcarbonate [ADC], and polycarbonate [Lexan]), and composites of both plastic and glass. There are tradeoffs associated with the use of any particular material in any given application. In this study, polycarbonate and laminated, heat-tempered glass are the two materials evaluated based on the following considerations:

- Polycarbonate window material is used in the MELOX and La Hague gloveboxes. These gloveboxes serve as the reference designs for the MFFF equipment. The considerable experience gained in fabricating, operating, and maintaining these gloveboxes has been very successful. Other plastic materials do not exhibit appreciably better performance with respect to mechanical strength or resistance to fire than polycarbonate.

- Safety glass (laminated or wire) is strongly preferred over nonsafety glass to maintain the physical integrity of the confinement barrier for as long as possible before rupture. Laminated glass is preferred over wire glass because it provides less interference for visibility inside the glovebox.

- Chemically tempered glass, which theoretically can produce rupture strengths of up to 43,500 psi (300 MPa), was not considered because of the lack of experience anywhere in the industry with producing chemically tempered, perforated glass panels of the size required.

- For applications where the risk of unacceptable consequences due to fires is otherwise mitigated, monolithic polycarbonate is considered preferable to glass/plastic composite materials, due to the impact resistance and workability of the material.

Nominal values for important material properties for the materials under consideration are given below.

Material Property	Polycarbonate	Tempered Safety Glass
Tensile Strength	9,425 psi (65 MPa)	14,500-29,000 psi (100-200 MPa)*
Flexural Strength	14,935 psi (103 MPa)	14,500-29,000 psi (100-200 MPa)*
Elongation at Yield	8%	1%
Elongation at Rupture	80%	1%
Specific Gravity	1.2	2.5
Optical Transmissibility	85%	89%

* The strength of glass varies widely due to small surface imperfections that are difficult to measure and evaluate.

Glass is a brittle material, characterized by the fact that it has virtually no capacity to absorb energy beyond the initial yield point. The yield point (ultimate strength) varies widely due to small surface imperfections. This strength also decreases as a function of time, due to fatigue of surface cracking. Glass has good optical properties and is not susceptible to abrasion. The density of glass is approximately twice that of polycarbonate, making it considerably more difficult to handle large window panels during installation or replacement operations. Vendors also indicate that it is far more difficult to produce large, highly perforated panels from glass than from polycarbonate, due to potential breakage during the hole fabrication and tempering process.

Polycarbonate is much less brittle than glass, as indicated by its "elongation at rupture" value and comparable values for tensile and compressive strength. Because polycarbonate is more ductile, its ultimate strength is less affected by surface imperfections. Polycarbonate abrades more easily than glass and transmits less light than glass, but it is much easier to handle due to its low density. Polycarbonate has excellent workability properties and machines easily.

4. SAFETY REQUIREMENTS

The performance requirements of 10 CFR 70.61 require that workers and the public be protected against the unacceptable consequences of accidents. Inhalation of small quantities of plutonium can cause unacceptable consequences.

The gloveboxes, together with their ventilation system, comprise the primary confinement system installed around the process equipment. The rooms that contain the gloveboxes, together with their ventilation system, comprise the secondary confinement system. The primary and secondary confinement systems protect the public and the environment against uncontrolled release of radioactive material. The primary confinement system also prevents contamination in the working areas, which allows personnel to move and perform their tasks without use of respiratory protection. (Plant personnel normally carry a respirator in the MOX Fuel Fabrication Building.)

The glovebox confinement boundary provides a physical barrier to prevent the spread of contamination. The glovebox and room exhaust ventilation systems work together to maintain a negative pressure inside the glovebox with respect to the room. This differential pressure ensures that any leakage across the confinement boundary is into the glovebox, preventing the spread of contamination.

The primary accident scenarios that could affect a glovebox confinement boundary and the corresponding safety requirements are as follows:

- Fire – In the case of an incipient fire, measures are provided to preclude damage to the glovebox confinement boundary (including the glovebox windows). These measures include fire detection and fire suppression system and training of the workers.

  However, the remote possibility of a large fire is taken into account in the MFFF design. If the glovebox confinement boundary is endangered, the workers are to be evacuated, and the secondary confinement system (composed of the process room and its ventilation system) is designed to remain operational to protect the rest of the facility, the environment, and public against any unacceptable release.

- Load Drop/Shock – Mechanical handling equipment is designed to prevent the drop of large loads in and on the gloveboxes. In addition, the glovebox boundary (including the windows) should resist the drop of small loads or the shocks that can occur in the course of operation. In the unexpected event of damage to the confinement boundary, any airborne contamination would be detected and workers would don their respiratory protection and evacuate. The environment and the public would be protected by the secondary confinement system (i.e., the process room and its associated ventilation).

- Pressure Transients – The glovebox ventilation system is designed to avoid any under- or over-pressure. In addition, gloveboxes are fitted with under- and over-pressure valves with filters. To protect the workers, the glovebox confinement boundary (including the windows) can resist pressures in excess of the pressure settings of these valves.

- Earthquake – An earthquake could affect the glovebox confinement boundary and disperse nuclear materials, potentially impacting any workers that may be present in the room. To protect the workers as they evacuate, the glovebox confinement boundary (including the windows) should remain in place.

The failure mechanisms induced by these accident scenarios, as well as other failure mechanisms, are listed and discussed in Attachment B. The bounding failure mechanisms that could breach the glovebox windows include thermal degradation under a large fire and degradation under mechanical loads (e.g., ventilation pressure transients, seismic inertia, seismic deflection, or impact due to operational accidents and load drops).

The performance of both polycarbonate and tempered glass windows is compared in the following sections under each of these accident scenarios to determine any constraints in their application.

5. WINDOW PERFORMANCE IN CASE OF FIRE

5.1 ANALYSIS DESCRIPTION

The performance of polycarbonate glovebox windows in case of fire is evaluated using traditional fire hazards analysis techniques. To adequately assess the fire performance of the windows, a fire starting on either side of the windows (i.e., internal or external to the glovebox) is analyzed.

This analysis examines one room of the MFFF containing process gloveboxes (for the external glovebox fire, i.e., exposure fire to the glovebox) and one process glovebox (for the internal glovebox fire).

- For the postulated external glovebox fire, the combustible loading and ignition sources in the analyzed room are based on the actual construction, fire protection features, and combustible loading in the pelletizing room of the MELOX facility. This is bounding of loads and representative of ignition sources in the MFFF rooms containing process gloveboxes.

- Likewise, for the postulated internal glovebox fire, the combustible loading and ignition sources in the analyzed glovebox are bounding of loads and representative of ignition sources within the other MFFF process gloveboxes.

5.1.1 Methodology

The basic methodology for conducting this analysis is as follows:

- External Glovebox Fire Scenario: Determine the MFFF room containing process gloveboxes that is bounding (worst-case room) of the MFFF rooms containing process gloveboxes. For this analysis, the room containing the largest quantities and types of combustibles and ignition sources best serves this purpose. If the chosen room has a MELOX counterpart room (e.g., both facilities have pelletizing rooms), the MELOX room is used in this analysis due to the availability of detailed information.

- Internal Glovebox Fire Scenario: Determine the MFFF process glovebox that is bounding (worst-case glovebox) of the MFFF process gloveboxes. For this analysis, the non-inerted glovebox containing the largest quantities and types of combustibles and ignition sources best serves this purpose.

- Obtain information regarding the representative room and glovebox necessary for the analysis (e.g., combustible types and loads, combustible and ignition source locations, fire detection and suppression system coverage, and passive fire protection).

- Determine the possible fire scenarios for the room and glovebox and the consequences of the fires based on the fire safety information that was obtained.

Based on the results of the analysis, the adequacy of the use of polycarbonate glovebox windows, given the glovebox design and fire safety features in the representative MFFF room and glovebox, is evaluated.

5.1.2 Assumptions

The following assumptions apply to this analysis:

- Low-energy ignition sources (e.g., electrical outlets and lighting fixtures) are considered to be unable to initiate a fire if they are located a significant distance (e.g., several feet) from any combustibles.

- Smoking is not considered an ignition source because it is prohibited anywhere in the MOX Processing Area and the Aqueous Polishing Area.

- Credit can be taken for MFFF design features that enhance the level of fire safety. For example, glovebox electrical feedthrough penetrations at the MFFF are not considered to be possible ignition sources because the penetrations are properly sized, the electrical circuits are provided with overcurrent protection, and most feedthroughs are low-power instrument signals.

- An administrative fire safety program is in place that limits transient combustibles and controls ignition sources.

5.1.3 Comparison Between MFFF and COGEMA Facilities

The MFFF fire protection and suppression measures are patterned after those of the La Hague and MELOX plants. Additionally, most of the MFFF gloveboxes are maintained under inert gas (i.e., nitrogen) for process constraints. This inert gas reduces the fire risk within the gloveboxes.

5.2 GLOVEBOX PROCESS ROOM AND PROCESS GLOVEBOX DESCRIPTION

5.2.1 General Description, Locations, and Layout

<u>Pelletizing Room</u>: Based on the methodology described in Section 5.1.1, the pelletizing room in the MFFF is analyzed. The counterpart room is Room A228 in the MELOX Fuel Fabrication Building. This room houses four pelletizing units within gloveboxes that are arranged as shown on Attachment C. The room itself is 24.3 ft (7.4 m) wide by 67.3 ft (20.5 m) long and is approximately 25.75 ft (7.85 m) high.

The MFFF has two pelletizing rooms. Each room contains only one homogenization-pelletizing unit and is approximately 26.25 ft (8 m) wide by 29.8 ft (9.1 m) long and approximately 24.3 ft (7.4 m) high.

KPB Mixer-Settler Glovebox: Based on the methodology described in Section 5.1.1, the specific MFFF glovebox to be analyzed is the solvent recovery (Unit KPB) mixer-settler glovebox. This glovebox is located in Room C233 of the Aqueous Polishing Area with other gloveboxes. The glovebox is situated approximately 1.57 ft (0.48 m) above floor level, and the glovebox itself is 3.67 ft (1.12 m) wide by 5.84 ft (1.78 m) long and is 6.56 ft (2.00 m) high. Within the glovebox, the mixer-settler is located no less than 0.82 ft (0.25 m) from the glovebox boundary (i.e., the glovebox windows) on the horizontal plane and the top of the mixer-settler motors is approximately 1.97 ft (0.60 m) below the top of the glovebox.

5.2.2 Operations and Processes

Pelletizing Room

The equipment in MELOX Room A228 produces MOX fuel pellets. Presses take the MOX powder mixture (a mixture of uranium oxide and plutonium oxide, which is formulated outside of the room), homogenize it, and, by applying high pressure, press the powder into pellets. The pellets are then transferred to another room for further processing (i.e., sintering).

The processes within this room are fully automated, such that the room is not normally occupied on a full-time basis. However, personnel performing maintenance, inspection, or other operation-related activities may be present at any time. Each glovebox is maintained at a negative pressure with respect to the surrounding atmosphere within the room. The atmosphere within each glovebox is inert (i.e., nitrogen), and the atmosphere outside the glovebox within Room A228 is air.

Most maintenance activities can be performed with the glovebox in a normal operating configuration. In the event that maintenance activities require a bagout operation through a large-diameter bagport (15.7 in [400 mm] or greater), the glovebox is isolated from the others and then purged with air instead of nitrogen. In this event, the compensatory measure of a fire watch is instituted to account for the loss of fire protection provided by the inert gas. If the maintenance operation requires more than one week to complete, the process materials in the glovebox typically are removed from the glovebox (i.e., no uranium oxide, plutonium oxide, or pellets remain in the glovebox). If the maintenance requires the introduction of an ignition source into the room (e.g., welding equipment), the ignition source is administratively controlled by permit and a fire watch is posted during the maintenance work.

KPB Mixer-Settler Glovebox

The MFFF mixer-settler within the glovebox is used to treat solvent being used within the Aqueous Polishing Area. For this specific glovebox, the mixer-settler performs the following processes:

- Recovers the used solvent from the purification cycle (Unit KPA) to prevent the accumulation of degradation products
- Renews the solvent and adjusts its tributyl phosphate (TBP) content
- Feeds continuously the purification cycle with treated solvent
- Performs a diluent wash operation on the aqueous effluents produced by this operation to remove traces of entrained solvent.

To perform these processes, the mixer-settler is comprised of seven interconnected banks, with each bank having its own motor/agitator. The mixer-settler is sealed and vented such that vapors are vented to the process vents, which prevents any accumulation of vapors within the glovebox itself. The processes within this glovebox room are fully automated and continuous, in conjunction with Unit KPA. The atmosphere within the glovebox is air, and the atmosphere outside the glovebox within Room C233 is air.

5.3 POLYCARBONATE COMBUSTIBILITY AND FIRE TESTS

Based on the Material Safety Data Sheet (MSDS) for polycarbonate (Ref. 8), polycarbonate is a combustible material that "can burn in a fire creating dense, toxic smoke" and "requires a continuous flame source to ignite." However, as discussed in the NFPA Handbook (Ref. 9), polycarbonate is "difficult to ignite and is self-extinguishing," which means that when the ignition source is removed from a polycarbonate fire, the polycarbonate fire will extinguish on its own.

The high temperature required for ignition of the polycarbonate supports the "difficult to ignite" qualification, and the self-extinguishing capability has been demonstrated in fire tests. The results from two fire tests were obtained from General Electric (GE) Structured Products. These tests demonstrate the fire and flammability properties of polycarbonate (Lexan). Test Report No. 117368 (Ref. 10) performed by SGS U.S. Testing Co., Inc., tested an approximately 0.5 inch by 0.5 inch by 4.9 inch (13 mm by 13 mm by 125 mm) sample of Lexan in accordance with ASTM D-635-91 (Ref. 11). In this test, a bar of material was supported horizontally, and the free end of the material was exposed to a specified flame for 30 seconds. The flame was removed after 30 seconds, and the extent of burning along the 4.9-inch (125-mm) length was measured after removal of the flame. Ten specimens were tested. The test results indicated that the average burn time was 15 seconds and that the burning extended for an average distance of 0.40 inch (10.1 mm). This test demonstrated that polycarbonate material is not easily ignited and is self-extinguishing after the heat of a flame source is removed.

The second test, Test Report No. LA 72202 (Ref. 12), was performed by the United States Testing Company, Inc. A nominal 0.125 inch (3.175 mm) thick sheet of Lexan was tested in accordance with ASTM D-1929-86 (Ref. 13). This test used a hot air furnace to heat a sample of Lexan to identify the flash ignition temperature and the spontaneous ignition temperature of the sample. This test indicated that

Lexan has a flash point of 870°F (466°C) and a self-ignition temperature of 1,070°F (577°C).

These tests demonstrate that the polycarbonate material is difficult to ignite and is self-extinguishing.

5.4 FIRE HAZARDS ANALYSIS

5.4.1 Fire Area Definition

To confine a fire in its area of origin and prevent its spread, structural barriers separate areas containing processes or materials involving fire hazards into fire areas. Structural barriers, including walls, floors, ceilings, and roofs that bound fire areas, have appropriate fire-resistance ratings, as determined by fire hazards analysis, to contain any potential fire within the confines of the fire area. Openings in the barriers that are boundaries of the fire areas (e.g., fire doors and fire dampers) have at least the same fire-resistance ratings as the barriers in which they are installed.

For the MFFF areas that contain process gloveboxes, fire areas are as small as possible and are typically constituted by a single room.

5.4.2 Fire Analysis

The room fire area analyzed is a single room of the MELOX facility, Room A228. This room contains four pelletizing units. Each pelletizing room at the MFFF will contain only one homogenization-pelletizing unit. Therefore, as discussed in Section 5.1.1, the MELOX pelletizing room is the bounding room for the MFFF rooms that contain process gloveboxes. The fire load and fire protection features for the pelletizing room at MELOX are used in this analysis.

The single glovebox fire analysis is related to the KPB mixer-settler glovebox, which is within Aqueous Polishing Area Room C233. As discussed in Section 5.1.1, this glovebox is bounding of the air-ventilated process gloveboxes at the MFFF.

5.4.2.1 Room Analysis

5.4.2.1.1 Description of Fire Hazards and Fire Load

The combustibles within Room A228 are primarily composed of the following:

- Polycarbonate sheets, which form the glovebox windows (58.0 million Btu/61,146 MJ)
- Lead-impregnated Plexiglas sheets (Kyowaglass) used as radiological shielding material, which overlays glovebox windows (48.3 million Btu/50,995 MJ)

- Window joint seals (16.4 million Btu/17,301 MJ)
- Radiological shielding (borated polyethylene plaster inside stainless steel casing) (7.6 million Btu/8,058 MJ)
- Hoods providing radiological shielding (encased with a stainless steel casing) around the process jars (7.4 million Btu/7,821 MJ)
- Polyvinyl chloride used in light covers, fire detectors, cable insulation, etc. (62.5 million Btu/65,649 MJ)
- Polyethylene used in bagport sleeves and chlorosulfonated polyethylene (Hypalon®) and polychloroprene (Neoprene) used as glovebox gloves (20.7 million Btu/21,804 MJ)
- Hydraulic fluid (Mobil DTE 26) within hydraulic lines (4.5 million Btu/4,740 MJ).

The fire load calculation for the MELOX facility does not include transient combustibles. For the MFFF facility, the fire hazards analysis uses a reasonably conservative transient fire load for each fire area. Administrative combustible control measures implemented prior to operations limit the accumulation of transient combustible materials in the process rooms (e.g., paper, polyethylene, waste drums) such that the fire rating of the fire barriers for the area is not exceeded.

Nuclear materials within the gloveboxes are PuO_2, which is fully oxidized, and UO_2, which cannot oxidize in an inert atmosphere and oxidizes very slowly in air under process temperature conditions. Thus, these nuclear materials pose no combustible hazard. Other materials within the gloveboxes, including cables, hoses, bag sleeves, and gloves, similarly pose no threat of combustion from inside the glovebox due to the inert atmosphere. In addition, the cables and hoses are fire-retardant.

Based on GE test data (Ref. 12), the auto-ignition temperature of polycarbonate is 1,070°F (577°C).

Based on the MSDS for PMMA (Ref. 14), which is the primary component of Kyowaglass, the Kyowaglass is stable (i.e., methyl methacrylate monomer is not released) below approximately 700°F (371°C).

Based on the NFPA Handbook (Ref. 9), the ignition temperatures of polyvinyl chloride and polyethylene are 945°F (507°C) and 910°F (488°C), respectively.

Neither the MSDS for Hypalon® (Ref. 15) nor the NFPA Handbook provides any ignition temperature information for Hypalon®, but the MSDS does indicate that the gloves "can be combusted only with difficulty." Since Hypalon® is chemically based upon polyethylene but much more complex, it is conservative to use the ignition temperature of polyethylene for Hypalon® in this analysis.

Neither the MSDS for Neoprene (Ref. 16) nor the NFPA Handbook provides an ignition temperature for Neoprene, but the MSDS indicates that temperatures above 392°F (200°C) must be avoided; heating the Neoprene above this temperature results in the evolution of hydrogen chloride gas.

Based on the Material Safety Data Bulletin for Mobil DTE 26 (Ref. 17), the flash point of the hydraulic fluid is 399°F (204°C).

The total fire load of MELOX Room A228 is approximately 237,000 MJ (225 million Btu). Since each of the two MFFF pelletizing rooms has only one pelletizing unit while the pelletizing room at the MELOX facility has four pelletizing units, the total fire load of the MFFF pelletizing room is approximately 60,000 MJ (57 million Btu).

5.4.2.1.2 Description of Ignition Sources

The ignition sources within Room A228 are the electric motors, lighting systems, electrical panels, and electrical circuits that could overheat or generate an electrical arc, and static electricity that could cause arcing. However, overcurrent protection by fuses and breakers is provided for the conductors to the motors, lighting units, and panels. The overcurrent protection opens the electrical circuit in the event of an overcurrent condition that is caused by events such as a short or ground in a circuit. This protection provides reasonable assurance that the circuit will open prior to the cable or component reaching an excessive or dangerous temperature level and provides reasonable protection from the possible ignition of combustible materials within the glovebox or room by an electrical fault.

The electric motors are situated both inside and outside of the gloveboxes. Motors outside the gloveboxes are typically 240- or 400-V electrical motors, normally ranging from 0.2 to 5 hp (0.15 to 3.73 kW) in size. Motors are installed underneath the stainless steel floor of the gloveboxes, attached to the sidewall, or occasionally installed on top of the gloveboxes. Motors installed underneath the glovebox are located anywhere from 0.8 to 3.3 ft (0.24 to 1.0 m) below the glovebox floor. Wall- and roof-mounted motors are typically installed a minimum distance of 1 ft (0.3 m) away from the glovebox and are supported off of stainless steel portions of the shell. The likelihood of a motor causing a fire is minimized by using totally enclosed motors correctly sized for the load, performing electrical installation in accordance with the applicable electric code, testing the motor and installation for insulation integrity, and keeping combustibles away from the motor and leads.

The lighting systems for the gloveboxes are typically enclosed fluorescent fixtures that are located at the ceiling or on top of the glovebox, separated by approximately 0.4 in (1.0 cm) from the top of the glovebox. Similar lighting is provided for the MFFF gloveboxes.

Glovebox electrical panels are typically floor-mounted, located approximately 3.3 ft (1.0 m) from the external wall of the glovebox. The panels are noncombustible enclosures that enclose combustibles and potential ignition sources. The typical size for these panels is approximately 3.9 ft (1.2 m) high by 3.9 ft (1.2 m) wide by 1.0 ft (0.3 m) deep.

The electrical cables in this room are routed in covered cable trays. One tray traverses the room directly over the gloveboxes such that the power and control cables for the gloveboxes are routed directly down to the gloveboxes. Cables from the cable tray to the gloveboxes are routed in conduit.

Static electricity is not considered to be a possible ignition source because it does not generate sufficient heat to start fires with the types of combustibles present in the room. Grounding gloveboxes and internal equipment prevents sustained arcing between energized equipment at different electrical potentials.

An additional ignition source is any ignition source that could be introduced into the room during maintenance, such as welding equipment. In this case, a permitting system administratively controls the ignition source. Additionally, a fire watch is established in the room during the use of the ignition source.

The hydraulic system for the pelletizing process press is not an ignition source since the power units for the press are installed in a separate fire area.

5.4.2.1.3 Fire Protection Features

<u>Passive Fire Protection Features</u>

The walls, doors, and penetrations of Room A228 are two-hour fire-resistant construction. As previously discussed, the fire load of Room A228 is approximately 225 million Btu (237,000 MJ). Given the floor area of this room [1,633-ft^2 (151.7-m^2)], the fire load density is approximately 138,000 Btu/ft^2 (1,562 MJ/m^2). Since a fire of one-hour duration is equivalent to 80,000 Btu/ft^2 (909 MJ/m^2), the two-hour fire-rated barriers of this room is capable of containing a totally involved fire within the room.

The MFFF pelletizing room has one pelletizing unit and has a total fire load of approximately 57 million Btu (60,000 MJ). Distributing this fire load evenly throughout the 782.5-ft^2 (72.8-m^2) room, the fire load density is approximately 73,000 Btu/ft^2 (829 MJ/m^2), which equates to a fire duration of less than one hour. This fire load is well below the two-hour rated fire barriers to be provided for each MFFF pelletizing room.

Fire Detection and Alarm Systems

Automatic fire detection is provided in Room A228 and within each glovebox in the room. Within the gloveboxes, thermal detection is provided. Outside the gloveboxes, smoke detection is provided. The reliability of the fire detection system is assured by continuous electrical monitoring (i.e., supervised) of itself to detect system failures; detector failure or loop failure is reported and alarmed.

Fire in either the room or the glovebox actuates the fire alarm system and results in an automatic shutdown of hydraulic oil distribution and automatic closure of process fire doors. The location of the fire is displayed on the fire detection system displays and on a local annunciation light located above the door to the room. A similar fire detection and alarm system is provided for the MFFF and is designed to actuate an alarm in the Fire Protection/Health Physics control room, which is constantly attended. During maintenance conditions in the room that introduce ignition sources, a fire watch supplements the automatic fire detection system as appropriate.

Fixed Fire Suppression Systems and Equipment

MELOX Room A228 is provided with a CO_2 fire suppression system. This system is activated manually, rather than automatically, due to worker safety concerns (e.g., asphyxiation and/or death) in the event of an inadvertent activation of an automatic CO_2 fire suppression system. The CO_2 supply for the suppression system is provided by two sources: (1) a permanently tied system of CO_2 bottles located within the building, and (2) a backup source located outside the building that can be tied in manually if needed. A water-based fire suppression system is not used due to critically concerns.

At the MFFF, automatic sprinkler protection is used in the corridors and in plant areas that do not present criticality concerns. The MFFF pelletizing rooms is provided with a manual CO_2 system, similar to the system installed at the MELOX facility, due to criticality and life safety concerns. This manual CO_2 fire suppression system is considered acceptable for the following reasons:

- Early warning fire detectors in both the pelletizing room and within the glovebox detect a fire at the incipient stage of combustion, permitting the fire to be promptly extinguished by facility personnel.
- The combustible materials within the glovebox cannot participate in a fire because ignition of these combustibles is not possible while the glovebox is inerted.
- Outside the glovebox, the most severe fire load is the Kyowaglass material that is installed over the polycarbonate windows at various locations on the gloveboxes. These windows are not a significant fire hazard, since they

must be exposed to a continuous ignition source and reach a temperature in excess of 700°F (371°C) before the material will ignite.

For process reasons, an inert (i.e., nitrogen) atmosphere is maintained within the MELOX pelletizing gloveboxes during operation. The gloveboxes in the pelletizing rooms of the MFFF are also inerted for process reasons.

The gloveboxes within MELOX Room A228 are equipped with connections allowing portable CO_2 bottles to be connected by personnel fighting fires that may occur within the gloveboxes. The pelletizing gloveboxes at the MFFF are also provided with this feature.

The MFFF process buildings are provided with portable fire extinguishers and a dry standpipe fire hose system. The standpipe system for the MFFF process buildings is provided outside of the process areas and is connected to the facility's fire protection water system but is maintained as a dry system due to critically concerns. Otherwise, the system is installed to meet the applicable requirements of NFPA 14 (Ref. 18). The fire extinguishers are installed in accordance with the applicable provisions of NFPA 10 (Ref. 19). MFFF personnel are trained to combat fires in the incipient stage. The Savannah River Site fire department responds for major fire fighting operations.

Ventilation Systems

The ventilation systems for the MFFF are designed to maintain confinement to prevent the spread of airborne contamination within the MOX and Aqueous Polishing buildings under normal and postulated accident conditions. Automatic fire dampers, when their actuation does not compromise the confinement system, are provided in the supply ductwork. If automatic fire damper actuation could compromise the confinement system, supply-side fire dampers are controlled by operators.

The glovebox exhaust [Very High Depressurization (VHD)] system provides the required exhaust from the nitrogen inerted gloveboxes, which are the primary confinement enclosures. The system is designed to maintain the gloveboxes at a constant negative pressure with respect to the room. The exhaust ductwork from each glovebox is connected to a common exhaust header that is routed to the inlets of the two 100% capacity final high-efficiency particulate air (HEPA) filter units. The system is designed to vary the speed of the operating exhaust fan and to start the redundant fan, as required, to maintain a constant negative pressure at the inlet of the operating final filter unit. Manually operated fire dampers are provided in the exhaust ductwork where it passes through fire barriers. Two HEPA filters in series, one inside and one outside the glovebox, are provided in each glovebox supply and exhaust duct.

The process room exhaust [High Depressurization Exhaust (HDE)] system provides the required exhaust from the secondary confinement areas that include the process room containing gloveboxes for the pelletizing units. The system is designed to maintain the process rooms at a negative pressure with respect to the adjacent tertiary confinement areas. The exhaust ductwork from the process rooms is connected to common exhaust headers that are routed to the inlets of the two 100% capacity multiple-unit final HEPA filter systems. The system is designed to vary the speed of the operating HDE exhaust fan and to start the redundant fan, as required, to maintain a constant negative pressure at the inlet of the operating final filter units. Manually operated fire dampers are provided in the process room exhaust ductwork where it passes through fire barriers. Filters with fire screens are provided at exhaust outlets from process rooms containing gloveboxes to remove larger smoke particles from the exhaust air to reduce the particulate loading on the final HEPA filters.

A fire is not considered likely for the nitrogen inerted gloveboxes, unless the nitrogen supply to the gloveboxes is not operable or the system fails. However, if a fire were to occur inside a glovebox, the temperature increase due to the fire would cause the air in the glovebox to expand and the pressure inside the glovebox to become less negative. Under this condition, if the dump (emergency exhaust) valve setpoint is reached, the dump valve in the glovebox exhaust system opens and discharges to the emergency exhaust duct of the VHD system. The VHD system is designed to automatically increase the speed of the VHD exhaust fan (which increases the system flow) upon sensing low pressure at the entrance to the final filter bank to correct this variation. The VHD system operates in this mode until the manually operated fire damper in the glovebox exhaust duct is closed.

The fire detection system detects a fire in the incipient stage and permits the fire to be extinguished before the glovebox is damaged by fire. However, in the unexpected event fire does threaten the glovebox and radiological contamination can be released into the process room, the workers would don their respiratory protection and evacuate and the spread of contamination from the process room to adjacent areas would be prevented by the negative pressure that is maintained in the process room by the HDE system. The glovebox ventilation can be isolated by the fire dampers installed on the inlet and exhaust so as to prevent any fire spreading through the ducts.

If a fire were to occur in the process room outside the glovebox, the temperature increase in the room due to the fire would cause the air to expand and the pressure in the room to become less negative. Radiological contamination could be released into the process room, and potentially to the adjacent areas, only if the fire caused a breach of the glovebox confinement. This scenario is not considered likely because a fire within the process room is detected by the fire detection system in the incipient stage and because the concentration of combustibles in the room is insufficient to damage the gloveboxes.

However, in order to prevent any spread of contamination in the unlikely event of a fire in the process room, the system is designed to control the exhaust fans as needed to maintain the required negative pressure setpoint at the inlet of the final HEPA filter unit and maintain a negative pressure in the process room containing the fire until the manually operated fire damper in the room exhaust duct is closed.

All penetrations between process rooms and adjacent areas are sealed, and airlocks are provided at the doors between secondary and tertiary confinement areas. These features minimize the spread of contamination from the process rooms to the non-process areas even under fire conditions. The primary confinement exhaust (VHD) and secondary confinement exhaust (HDE) systems are designed to continue operating under fire conditions. The ducts and fire dampers in the VHD and HDE systems are temperature-rated and the final HEPA filter units are protected against high temperature by dilution of the air from the area containing the fire with air from the other areas that are unaffected by the fire. Instrumentation is provided to monitor the temperature and differential pressures in the final HEPA filter unit during a fire. Even if the area containing the fire is isolated by closing the exhaust side manual fire damper, all other areas of the building are maintained at a negative pressure with respect to the outside atmosphere. Therefore, any contamination that spreads to adjacent secondary or tertiary confinement areas due to a fire in a process room is still confined within the building.

Administrative Controls on Activities with a Potential to Initiate Fires

Administrative controls in place prior to operation control the quantity of transient combustibles that may be stored or placed in the MFFF and to require fulltime monitoring of welding, cutting, or other heat-producing activities that are performed in the MFFF.

5.4.2.1.4 Possible Fire Scenarios

The possible fire scenarios for the pelletizing rooms at the MFFF are similar to those at the MELOX facility. Due to the limited type and quantity of ignition sources and combustible materials in MELOX Room A228 and the administrative controls placed on activities with a potential to initiate fires, the only identified fire scenarios result from conductor overheating or electrical arcing in one of the following:

- A motor located under or attached to the wall of a glovebox
- A lighting fixture installed at the ceiling or attached above the top of the gloveboxes
- An electrical panel located in the vicinity of a glovebox
- The cabling in the cable tray routed over the gloveboxes.

Additionally, in the event maintenance is being performed in the room; transient ignition sources (e.g., welding equipment) may be introduced into the room.

A fire involving the hydraulic system for the pelletizing process within the pelletizing room is not considered likely for the following reasons:

- The hydraulic power units and lubricant oil for the hydraulic press are located in a separate fire area with drip trays provided at the power units to catch any leaking fluid.

- The hydraulic piping system is designed and installed for the pressure of the hydraulic system and is adequately supported. The hydraulic piping within the process room is installed within a protective enclosure for personnel protection in the event of a pipe rupture. This barrier would prevent a pipe rupture from spraying leaking hydraulic fluid onto electrical equipment that could be an ignition source.

- The hydraulic fluid used in the system has a flash point of 399°F (204°C) and is difficult to ignite because the pelletizing rooms have minimal surfaces that would be at or in excess of the flash point temperature.

- The hydraulic hose and connections to the hydraulic press and process system are designed and installed in consideration of the pressure of the system.

<u>Motor Fire Scenario</u>

It is not expected that any arcing or overheating from a motor below or attached to a glovebox wall would impact the glovebox due to the motor casing and stainless steel surfaces adjacent to the motor. However, overheating or an electrical arc could be indicative of a catastrophic failure of the motor itself. In the event the motor does overheat such that the conductor insulation or lubricant burns, the heat generated would rise by convection and directly impact the underside of a glovebox or travel up the glovebox wall and indirectly impact polycarbonate windows and gloves. Lesser quantities of heat would radiate from the motor to the glovebox surfaces. Due to the limited amount of combustibles that exist inside the motor casing and the low heat release rate of the combustibles, the fire can be expected to be contained within the casing, with the primary effect being smoke and other combustion byproducts. Heat would be a minor product of such a fire.

The impact of such a fire on the glovebox is expected to be minor. Based on the metallic surfaces of the gloveboxes and the inert atmosphere inside the gloveboxes, it is anticipated that the indirect heat applied to the outside of the glovebox windows would have a greater impact than the direct heat applied to the stainless steel. However, due to the limited nature of this fire, this indirect heat would not adversely impact the polycarbonate windows, glovebox gloves, or the nearby Kyowaglass.

Lighting Fixture Fire Scenario

The lighting fixtures are the fluorescent type and the ignition risk from this type of fixture is negligible. At the MFFF, similar type lighting fixtures are used.

Panel Fire Scenario

Similar to the motor fire scenario, it is not expected that any arcing within an electrical panel would impact the glovebox because the ignition source is enclosed within a noncombustible panel. However, an electrical arc could be indicative of a fire inside the panel. In the event the panel does fail such that the contents of the panel ignite, the heat generated by the panel would indirectly impact the nearby polycarbonate windows and gloves as radiant heat. Due to the limited amount of combustibles that exist inside an electrical panel and the low heat release rate of the combustibles, the fire can be expected to be contained within the panel, with the primary effect being smoke and other combustion byproducts. Heat would be a minor product of such a fire.

The impact of such a fire on the glovebox would be minor. Due to the limited nature of this fire, this indirect heat would not adversely impact the polycarbonate windows, glovebox gloves, or the nearby Kyowaglass.

Cable Tray Fire Scenario

Any arcing or overheating that occurs from the cabling inside a cable tray is contained within the cable tray itself since the cable tray is of a covered solid metal construction. Therefore, although the cabling in the cable trays provides a possible ignition source, the ignition source is contained within the cable trays such that there is minimal potential to impact the gloveboxes below.

Transient Ignition Source Fire Scenario

The transient ignition source fire scenario can be expected to be a possible event if an ignition source brought into the room during maintenance is not properly controlled. These controls include, but are not limited to, using a permitting system, maintaining transient combustibles a suitable distance away from the ignition source, covering nearby fixed combustibles with fire-resistant tarp(s), and providing a fire watch.

5.4.2.1.5 Selected Fire Scenario Consequences

As discussed previously, the only fires identified for consideration are the fires resulting from an electrical failure of a motor situated under or adjacent to a glovebox or the failure of an electrical panel. Therefore, these are the selected fire scenarios for MELOX Room A228.

In the event of the selected motor fire, the worst-case consequences would be negligible due to the metallic underside of the gloveboxes, the metallic glovebox construction in the vicinity of the sidewall-mounted motors, and the inert atmosphere inside the gloveboxes. The indirect heat applied to the outside of the glovebox windows would have a greater impact than the direct heat applied to the underside. However, due to the limited nature of this fire, this indirect heat would not adversely impact the polycarbonate windows. Therefore, the selected motor fire is inconsequential.

In the event of the selected panel fire, the worst-case consequences would be negligible due to the separation of the panels from the gloveboxes, the noncombustible nature of the panel itself, and the inert atmosphere inside the gloveboxes. Due to the limited nature of this fire, the radiant heat produced by the fire would not adversely impact the polycarbonate windows. Therefore, the selected panel fire is inconsequential.

These conclusions are quantitatively verified by a fire model analysis of the selected motor and panel fires that determined the maximum temperature in the room outside of the gloveboxes for these fires to be 190°F (88°C) and 353°F (178°C), respectively.

During maintenance operations, the transient ignition source fire scenario is possible if there is a breakdown of administrative controls regarding the control of ignition sources. However, even if there is a breakdown, the polycarbonate itself is a difficult material to involve in a fire and is self-extinguishing. Additionally, as discussed previously, polycarbonate has the highest ignition temperature of the other major accumulations of combustibles in the room. Therefore, given an uncontrolled ignition source, the polycarbonate glovebox windows are the most difficult combustibles to ignite of the major combustibles in the room.

Since maintenance involving transient ignition sources is expected to be an infrequent operation, it is anticipated that extra care is taken in the preparation for and performance of any maintenance that would introduce a transient ignition source to the room. Therefore, it is not expected that a breakdown of ignition source controls will result to the extent a fire occurs in the room.

5.4.2.2 Glovebox Analysis

5.4.2.2.1 Description of Fire Hazards and Fire Load

The combustibles and the approximate fire load within the MFFF KPB mixer-settler glovebox, which is the bounding glovebox, are composed primarily of the following:

- Polycarbonate sheets, which form the glovebox windows (980,000 Btu/ 1,044 MJ)

- TBP within the mixer-settler (430,000 Btu/456 MJ)
- Dodecane (commercial) within the mixer-settler (1,540,000 Btu/1,626 MJ)
- Polyvinyl chloride used in cable insulation (79,000 Btu/83 MJ)
- Polyethylene used as a neutron absorber on the underside of the mixer-settler (495,000 Btu/522 MJ)

The total combustible loading within the glovebox does not include the following items since these items are not normally located within the glovebox:

- Chlorosulfonated polyethylene (Hypalon®) and polychloroprene (Neoprene) used as glovebox gloves
- Polyethylene used in bagport sleeves

Based on the test data supplied by GE (Ref. 12), the auto-ignition temperature of the polycarbonate is 1,070°F (577°C).

Based on NFPA 325 (Ref. 20), the flash point for TBP is 295°F (146°C).

Based on *Science and Technology of Tributyl Phosphate, Volume I Synthesis, Properties, Reactions, and Analysis* (Ref. 21), the flash point of the dodecane ranges from approximately 147°F to 154°F (64°C to 68°C).

Based on the NFPA Handbook (Ref. 9), the ignition temperatures of polyvinyl chloride and polyethylene are 945°F (507°C) and 910°F (488°C), respectively.

Neither the MSDS for Hypalon® (Ref. 15) nor the NFPA Handbook provides any ignition temperature information for Hypalon®, but the MSDS does indicate that the gloves "can be combusted only with difficulty." Since Hypalon® is chemically based upon polyethylene but much more complex, it is conservative to use the ignition temperature of polyethylene for Hypalon® in this analysis.

Neither the MSDS for Neoprene (Ref. 16) nor the NFPA Handbook provides an ignition temperature for Neoprene, but the MSDS indicates that temperatures above 392°F (200°C) must be avoided; heating the Neoprene above this temperature will result in the evolution of hydrogen chloride gas.

The bounding glovebox has a total fire load within the glovebox of 3,731 MJ (approximately 3,534,000 Btu).

5.4.2.2.2 Description of Ignition Sources

The ignition sources within the KPB mixer-settler glovebox are electric motors, lighting systems, an electrical panel, and electrical circuits that could overheat or generate an electrical arc, and static electricity that could cause arcing.

However, overcurrent protection is provided for the conductors to the motors, lighting units, and panel. The overcurrent protection features (breakers/fuses) opens the electrical circuit in the event of an overcurrent condition caused by events such as a short or ground in the circuit. This protection provides reasonable assurance that the circuit will open prior to the cable or component reaching an excessive or dangerous temperature level, thus preventing the ignition of combustible materials within the glovebox.

The electric motors (total of six) are part of the mixer-settler and are physically the uppermost part of the mixer-settler. Each of the motors is 0.13 hp (100 W). The centerline of the motors is located approximately 4 ft (1.21 m) above the bottom of the glovebox, and no motor is closer than 0.82 ft (0.25 m) from the glovebox windows. The likelihood of a motor causing a fire is minimized by using totally enclosed motors correctly sized for the load, performing electrical installation in accordance with the applicable electric code, testing the motor and installation for insulation integrity, and keeping combustibles away from the motor and leads.

The lighting system for the glovebox consists of two glass-enclosed 100-W incandescent fixtures that are located inside and at the top of the glovebox.

A low-voltage (i.e., 48 V) terminal panel for the glovebox sensors is located near the bottom of the glovebox and is physically beneath the mixer-settler. The determination of the precise location and size of this panel within the glovebox is part of the ongoing design process. For the purposes of this analysis, it is conservatively assumed that the panel is located directly under the mixer-settler and equidistant between the bottom of the glovebox and the bottommost part of the mixer-settler. Additionally, it is assumed that this panel is approximately 1.0 ft (0.3 m) high by 1.0 ft (0.3 m) wide by 0.5 ft (0.15 m) deep. Based on these assumptions, the bottom of the panel is 0.4 ft (0.12 m) above the bottom of the glovebox and the top of the panel is 0.4 ft (0.12 m) below the bottom of the mixer-settler. Due to their low level of voltage and their use, the sensor cables are not expected to have electrical faults of a nature that would be of sufficient intensity to ignite their cable insulation. The electrical power cables in this glovebox (e.g., the cables to the mixer-settler motors) are fire retardant.

Static electricity is not considered to be a possible ignition source because it does not generate sufficient heat to start fires with the types and configurations of combustibles present in the glovebox. Grounding the glovebox and internal equipment prevents sustained arcing between energized equipment at different electrical potentials.

5.4.2.2.3 Fire Protection Features

Fire Prevention Features

The MFFF mixer-settler is sealed and vented such that the TBP and dodecane vapors are vented to the process vents, which prevents any accumulation of vapors within the glovebox itself. In addition, the glovebox is provided with drip trays to catch and retain any leakage from the mixer-settler process.

Fire Detection and Alarm Systems

Automatic fire detection is provided within the glovebox by thermal type fire detectors. The reliability of the fire detection system is assured by continuous electrical monitoring (i.e., supervised) of itself to detect system failures; detector failure or loop failure is reported and alarmed.

Fire in the glovebox actuates fire alarms, and the location of the fire is displayed on the fire detection system displays and on a local annunciation light located above the door to the room. One display is located within the Fire Protection/Health Physics control room, which is constantly attended.

Fixed Fire Suppression Systems and Equipment

The KPB glovebox is not maintained under an inert gas system and is not provided with an automatic fire suppression system. These features are not considered necessary in view of the following:

- Flammable liquids (i.e., liquids with a flash point less than 100°F/38°C) are not used in the glovebox.
- The quantity of combustible liquids (i.e., liquids with a flash point at or above 100°F/38°C) used by the process in the glovebox is low. Approximately 3.6 gallons (13.6 liters) of TBP and 11.9 gallons (25.12 liters) of dodecane are used. These liquids have a high flash point. In addition, these liquids are normally contained within the mixer-settler process piping system, which is vented to the process vent system.
- Continuous air ventilation is provided to remove any combustible vapors that could be released in the glovebox.

The glovebox is equipped with connections allowing portable CO_2 bottles to be connected by personnel fighting any fires that may occur within the glovebox. The need for, and acceptability of, a fixed limited-water volume suppression system to protect the inside of the glovebox, similar to the system currently provided for mixer-settler gloveboxes at La Hague, is under evaluation.

The MFFF process buildings are provided with portable fire extinguishers and a dry standpipe fire hose system. The standpipe system for the MFFF process buildings is provided outside of the process areas and is connected to the facility's fire protection water system but is maintained as a dry system due to critically concerns. Otherwise, the system is installed to meet the applicable requirements of NFPA 14 (Ref. 18). The fire extinguishers are installed in accordance with the applicable provisions of NFPA 10 (Ref. 19). MFFF personnel are trained to combat fires in the incipient stage. The Savannah River Site fire department responds for major fire fighting operations.

Ventilation Systems

The ventilation systems for the MFFF are designed to maintain confinement to prevent the spread of airborne contamination within the facility under all normal and postulated accident conditions.

The glovebox exhaust system (VHD) provides the required exhaust from the gloveboxes, which are the primary confinement enclosures. The system is designed to maintain the gloveboxes at a constant negative pressure with respect to the process room in which the glovebox is installed. The exhaust ductwork from each glovebox is connected to a common exhaust header that is routed to the inlets of the two 100% capacity final HEPA filter units. The system is designed to vary the speed of the operating exhaust fan and to start the redundant fan, as required, to maintain a constant negative pressure at the inlet of the operating final filter unit. Manually operated fire dampers are provided in the exhaust ductwork where it passes through fire barriers. Two HEPA filters in series, one inside and one outside the glovebox, are provided in each glovebox supply and exhaust duct.

The process room exhaust (HDE) system provides the required exhaust from the secondary confinement area, which is the process room containing the gloveboxes. The ventilation and exhaust system for the process rooms is described in Section 5.4.1.2.3.

A fire in the air-ventilated gloveboxes of such magnitude to extend from the glovebox into the process room is not considered likely due to the low quantity of combustible materials within the glovebox. In addition, the fire detection system within the glovebox provides notification of the fire in the incipient stage to permit extinguishment before the fire damages the glovebox and extends into the process area. However, if a fire were to occur inside a glovebox, the temperature increase due to the fire would cause the air in the glovebox to expand and the pressure inside the glovebox to become less negative. Under this condition, if the dump valve setpoint is reached, the dump valve in the glovebox exhaust system opens and discharges to the emergency exhaust duct of the VHD system. The VHD system is designed to automatically increase the speed of the VHD exhaust fan (which increases the system flow) upon sensing low pressure at the entrance to the final filter bank. The VHD system operates in this mode until the manually operated fire damper in the glovebox exhaust duct is closed.

In the unlikely event that the fire threatens the glovebox and radiological contamination can be released into the process room, any workers present in the room don their respiratory protection and evacuate, and the spread of contamination from the process room to adjacent areas is prevented by the negative pressure that is maintained in the process room by the HDE system. This exhaust system is designed to remain operational during the fire as described previously in Section 5.4.2.1.3.

This system, in conjunction with the seals and airlock isolation provided for the doors and other openings between the secondary and tertiary confinement areas, prevents the spread of contamination from the process rooms to the non-process areas of the facility, even under fire conditions. Therefore, the fire spread from a glovebox to a process room is still confined within the building.

5.4.2.2.4 Possible Fire Scenarios

Based on the type and quantity of ignition sources and combustible materials in the KPB mixer-settler glovebox, the possible fire scenarios result from conductor overheating or electrical arcing in one of the following locations:

- One of the mixer-settler motors
- A lighting fixture inside and at the top of the glovebox
- The electrical terminal panel located within the glovebox
- The cabling routed within the glovebox.

Motor Fire Scenario

It is not expected that any arcing or overheating within a mixer-settler motor will impact its surroundings due to the enclosed casing of the motor and the small size of the motor itself. However, overheating or an electrical arc could be indicative of a catastrophic failure of the motor itself. In the event the motor does overheat such that the conductor insulation or lubricant burns, the heat generated would rise by convection to directly impact the top inside of a glovebox. Lesser quantities of heat would radiate in other directions from the motor. Due to the limited amount of combustibles that exist inside the motor casing and the low heat release rate of the combustibles, the fire can be expected to be contained within the casing, with the primary effect being smoke and other combustion byproducts. Heat would be a minor product of such a fire. Therefore, the impact of such a fire on the glovebox would be insignificant and would not adversely impact the solvent or diluent within the mixer-settler or the polycarbonate windows.

Lighting Fixture Fire Scenario

A noncombustible glass globe encloses each of the two lighting fixtures within the KPB mixer-settler glovebox. Therefore, any arcing or failure of the lighting fixture is limited to the fixture itself. As such, a lighting fixture fire has no impact on the glovebox or its windows.

Low-Voltage Terminal Panel Fire Scenario

The cable connections to and from the low-voltage terminal panel provide a possible ignition source; however, these low-voltage cables are not expected to arc with sufficient intensity to ignite any combustible material within the glovebox.

Cabling Fire Scenario

The cable fire scenario is limited to power cabling since the low-voltage sensor cabling, as discussed previously, is not expected to be an ignition source. Therefore, any arcing or overheating that occurs from the cabling inside the glovebox will be limited to the mixer-settler motor power cabling. Since fire retardant cables are specified, cables are properly terminated, and adequate overcurrent protection is provided in accordance with appropriate specifications, this cabling is not anticipated to provide a possible ignition source of any potential to impact the combustibles within the glovebox.

5.4.2.2.5 Selected Fire Scenario Consequences

As discussed previously, the only fires identified for consideration are the fires resulting from an electrical failure of a mixer-settler motor. Therefore, this is the selected fire scenario for the mixer-settler.

In the event of the selected motor fire, the worst-case consequences would be negligible due to the configuration and construction of the motors (i.e., small, enclosed, and high in the glovebox). The heat resulting from this fire would primarily impact the ceiling of the glovebox, which is composed of stainless steel. Due to the limited nature of this fire, this heat would not adversely impact the polycarbonate windows. Therefore, the selected motor fire is inconsequential.

5.4.3 Hazardous Materials Analysis

The hazardous materials within Room A228 are the plutonium oxide and uranium oxide that are being processed within the pelletizing gloveboxes. As discussed previously, the selected fire is not expected to release these materials from the confinement of the gloveboxes and associated ventilation system.

The hazardous materials within the KPB mixer-settler glovebox are the TBP and dodecane. As discussed previously, the selected fire is not expected to release these materials from the confinement of the KPB mixer-settler glovebox.

5.4.4 Alternatives to Fire Safety Industry Practice

The common glovebox design standards and guidance used by the industry for the design of gloveboxes permit the use of polycarbonate for glovebox window material. NFPA 801 prohibits the use of combustible materials in glovebox and glovebox window construction, but allows the Authority Having Jurisdiction a certain degree of latitude in complying with specific requirements through a clause in Section 1-3.2 of the standard, which states:

> "The specific requirements of this standard shall be permitted to be modified by the authority having jurisdiction to allow alternative arrangements that will secure as nearly as practical the level of fire protection intended by this document. In no case shall the modification afford less fire protection than that which, in the judgement of the authority having jurisdiction, would be provided by compliance with the corresponding provisions contained in this standard."

Therefore, it is acceptable to use glovebox windows composed of a combustible material if an alternative arrangement is provided that secures an equivalent level of fire protection. (In fact, few, if any, of the gloveboxes currently in use follow the guidance prohibiting combustible materials because there are not practical noncombustible alternatives to the gasket and bag sleeve materials normally specified.) This report analyzes this alternative to ensure that an equivalent level of fire protection is provided. The following provisions basically provide the equivalent level of fire protection:

- The glovebox window material (polycarbonate) is self-extinguishing.
- Most gloveboxes are inerted with nitrogen.
- Fire detection is provided inside and outside the gloveboxes.
- Fixed fire suppression systems are provided for rooms that contain gloveboxes.
- Glovebox connections are provided to allow portable CO_2 bottles to be used to suppress fires inside of the gloveboxes.

5.5 ANALYSIS RESULTS AND CONCLUSIONS

The analysis of the selected fires demonstrated that the use of polycarbonate does not induce a significant risk over the use of glass for the glovebox windows, given the design features and management measures taken at the MFFF. The risk of a fire involving or breaching the polycarbonate windows of the gloveboxes is very low.

Therefore, the use of polycarbonate for the glovebox window material is an acceptable risk.

6. WINDOW PERFORMANCE UNDER MECHANICAL LOADING

The mechanical performance of polycarbonate and glass glovebox windows is measured and compared using finite element analysis of a typical glovebox window configuration. Stresses calculated under normal operating and hypothetical accident loading conditions are combined and compared to material allowable stress values determined in accordance with the applicable design code.

6.1 ANALYTICAL MODEL

Finite element models are used to determine maximum stresses in the glovebox window panels. The panels are modeled using plate elements with periodically spaced circular cutouts representing the gloveports. Element stiffness properties are determined based on typical panel cross sections specified for each type of window material. The polycarbonate cross section consists of a single panel, 0.39 in (10 mm) thick, which represents the current baseline design. The glass cross section is based on typical safety glass construction, consisting of two layers of glass, 0.24 in (6 mm) thick, bonded with a urethane interlayer. Flexible boundary conditions representing gasket compliance are included around the periphery of each window panel model in the in-plane and out-of-plane translational and circumferential rotational directions.

6.2 DESIGN CODE CONSIDERATIONS

The design code used to qualify the glovebox confinement boundary for structural integrity is the American Institute of Steel Construction (AISC) N690 nuclear facility steel code (Ref. 22). This code requires stress evaluations to be considered for both normal operating and seismic loading conditions. Normal operating loads include deadweight and ventilation differential pressure loads. The seismic loading condition includes normal operating loads, as well as seismic inertia and differential deflection loads. Concentrated loads due to missile impact may also be considered in some cases, as applicable. Stresses resulting from these applied loads are combined and compared to allowable stress limits in accordance with code equations. Allowable stress limits for each equation are determined as a percentage of the yield or tensile stress of the material under consideration.

Most mechanical and structural design codes, including AISC N690, provide allowable stress values for metallic materials but not for other materials like glass and polycarbonate. For the purposes of this report, allowable stress values for glass and polycarbonate are determined based on guidance obtained from mechanical codes that address materials with comparable properties. Cast iron, for instance, exhibits a stress-strain behavior up to rupture and brittle failure mechanism similar to glass. The American Society of Mechanical Engineers (ASME) B31.3, Process Piping Design (Ref. 23) permits use of cast iron materials in fluid pressure applications and specifies a basic allowable tensile stress value equal to 0.1 times the material tensile strength. This same methodology is used in this report to determine allowable tensile stress values for glass.

Polycarbonate, on the other hand, exhibits a stress-strain behavior similar to ductile metals, therefore it is reasonable to specify an allowable stress based on code provisions for ductile materials. Basic allowable tensile stresses, determined in accordance with common design code rules for ductile metals, range from a minimum of 0.25 times the material tensile strength (ASME Section VIII, Boiler and Pressure Vessel Code [Ref. 24]) to a maximum of 0.5 times the material tensile strength (AISC N690). Allowable tensile stresses for polycarbonate used in this report are determined using the most conservative of these factors, or 0.25 times the material tensile strength.

6.3 LOADING CONDITIONS

6.3.1 Normal Operation

The principal load on the window during normal operation is the uniformly distributed differential pressure maintained between the interior and exterior of the glovebox. During normal operation, the differential pressure is maintained at a value of 0.0507 psi (350 Pa), which is equivalent to 1.4 inches H_2O at 68°F. The glovebox windows are analyzed for a conservative pressure loading of 0.1015 psi (700 Pa), which is equivalent to 2.8 inches H_2O at 68°F.

Maximum stress results for the pressure loading analyses are tabulated below.

Loading	Stress Type	Glass Panel	Polycarbonate
Maximum Pressure	Peak Stress	905 psi (6.24 Mpa)	674 psi (4.65 MPa)

6.3.2 Seismic Inertia

In this loading condition, stresses in the window panel are induced by the inertial response of the window to vibration of the frame. The magnitude of the inertial force is a function of the mass and stiffness of the window, the amplifications of the building and equipment structural systems, and the design ground motion spectrum. Since the elastic modulus of polycarbonate is approximately 25 times less than that of glass, and the mass density is only about half that of glass, the natural frequency of vibration of polycarbonate panels is less than that of glass panels of equal thickness. Vibrating structures often exhibit a greater response to earthquake induced motions than structures of a higher natural frequency due to the distribution of energy across a typical seismic acceleration response spectrum. Therefore, inertial loads on polycarbonate panels may be somewhat higher than the inertial loads on comparable glass panels. (Seismic inertial loads on window panels cannot be calculated until the specific vibrational characteristics of the glovebox and building structure are known.) In lieu of actual values, a nominal acceleration of 40 m/sec^2 (4.0 g) is used to calculate window stresses in the glass panel. This value is considered to bound accelerations developed at glovebox windows, based on analyses for comparable sized gloveboxes and seismic hazards. An acceleration equal to twice that value, or 80 m/sec^2 (8.1 g), is used to calculate the inertial response of the polycarbonate panel, to conservatively address the potential increased response due to the lower panel natural frequency. Since the panels are very stiff in-plane, their inertial response is unamplified and does not contribute significantly to the overall stress level. Therefore, only out-of-plane vibrations are considered in the seismic inertia analysis.

Maximum stress results for the seismic inertia analyses are tabulated below.

Loading	Data Type	Glass Panel	Polycarbonate
Seismic Inertia	Natural Frequency	15 Hz	5.3 Hz
	Applied Acceleration	40 m/sec^2	80 m/sec^2
	Peak Stress	3060 psi (21.1 Mpa)	3756 psi (25.9 MPa)

6.3.3 Window Frame Distortions Under Seismic Loading

Glovebox windows are also stressed by distortions of the window frames caused by seismic loading of the gloveboxes. The principal vibratory modes cause out-of-plane bowing deflections, although deflection patterns that cause panel warping are possible in highly irregular geometries. Two displacement patterns are used to represent the behavior of the window panels under forced displacement conditions: (1) a distribution from an actual seismic qualification analysis, and (2) a synthesized warping displacement distribution. Peak deflections in both displacement distributions were approximately 1 in (2.5 cm). While it is not expected that gloveboxes would warp to this extent under seismic loading, the analytical results portray the difference in the performance of polycarbonate and glass under this type of loading.

Maximum stress results for the frame distortion analyses are tabulated below.

Loading	Stress Type	Glass Panel	Polycarbonate
Window Frame Seismic Distortion	Peak Stress	7671 psi (52.9 Mpa)	632 psi (4.36 MPa)

Stress results from the window frame distortion analysis indicate that polycarbonate panels are much more flexible than glass panels, resulting in a much higher capacity to absorb imposed displacements without overstressing.

6.3.4 Impact Loading

The confinement integrity of glovebox windows can also be challenged by the impact of falling objects internal or external to the glovebox. In general, the consequences of these accidents are mitigated by seismically supporting equipment inside and outside of the glovebox to prevent them from becoming projectiles and impinging on the windows. However, the glovebox windows must also exhibit a measure of resistance to loading caused by the impact of small objects or dropped loads. Polycarbonate, by virtue of its lower elastic modulus, is capable of absorbing much more energy without yielding than the glass. This higher capacity is independent of any energy absorption beyond the material yield point. As mentioned previously, polycarbonate also exhibits a significant energy absorption capacity beyond yield, while glass has virtually none. This impact-resistant quality of polycarbonate provides a margin of safety for maintaining confinement during accident conditions above that provided by glass.

6.4 ANALYSIS RESULTS AND CONCLUSIONS

In order to meet design code requirements, peak stresses calculated for the loading conditions above are combined on an element-by-element basis and compared to allowable stress values determined in accordance with the AISC N690 design code. Stresses reported for the normal operating condition are the stresses due to the applied ventilation differential pressure between the inside and outside of the glovebox. Deadweight stresses are quite small and do not significantly influence reported stress results. Stresses reported for the seismic loading combination include the effects of deadweight and pressure loads, as well as seismic inertia and seismic frame distortions. Allowable stress values for both loading combinations are determined using room temperature flexural strengths, factored in accordance with the design code.

Loading Combination	Stress Type	Glass Panel	Polycarbonate Panel
Normal Operating	Peak Stress	905 psi (6.24 Mpa)	674 psi (4.65 MPa)
	Allowable Stress	1450 psi (10.0 Mpa)	3727 psi (25.7 MPa)
Seismic Condition	Peak Stress	8860 psi (61.1 Mpa)	4437 psi (30.6 MPa)
	Allowable Stress	2320 psi (16.0 Mpa)	5974 psi (41.2 MPa)

The stress results indicate that both panels meet allowable stress criteria for the normal operating condition, and the polycarbonate panel meets the allowable stress criteria for the seismic condition. Since actual seismic displacements are likely to be less than those used in the warping displacement distribution, peak stresses should be less than the values reported, particularly for the glass panels. However, the stress results indicate that even without considering additional stresses caused by window frame deformation, seismic inertia stresses for the glass panel exceed the code allowable stresses calculated based on the provisions for brittle materials discussed previously. If glass were selected for the actual design, provisions to modify the gloveport layout, reduce the panel size (both of which conflict with operability and maintenance requirements), or modify the window design to increase panel thickness (and weight) would be required.

7. OPERATIONAL EXPERIENCE CONSIDERATIONS

7.1 NRC OPERATIONAL EXPERIENCE

The NRC event reporting database, Licensing Event Reports, bulletins, generic letters, information notices and circulars were reviewed using the individual key words "polycarbonate," "Lexan," and "glovebox." The searches identified one Information Notice that was specifically relevant to MFFF gloveboxes: NRC Information Notice 92-14, "Uranium Oxide Fire at Fuel Cycle Facilities." The Information Notice discussed fire events at fuel fabrication facilities and identified a number of preventative measures that should be considered by NRC licensed facilities.

Incident 1

The first event involved a fire in a hood, hopper, and feed screw assembly that was used to transfer calciner drop powder (uranium oxide) to a nitric acid dissolver tank. The fire consumed the combustible components of the hood, including the "Lexan" face of the hood, and damaged the primary stage of the HEPA filter for the room. The fire was extinguished by the plant emergency team. The cause of the fire was identified as the oxidation of the calciner drop powder (uranium oxide) and other unstable oxides of uranium that could oxidize at elevated temperatures conceivably caused by friction of the feed screw sliding on the powder.

Incident 2

A fire at another fuel facility occurred in a slugger press containment housing. Uranium oxide powder, following a blending process, was being gravity-fed from a second-floor hammermill baghouse through a "Viton" hose connected to a first-floor slugger press. The slugger press shuttle area, including the Viton hose, was enclosed by the containment housing, which had two "Lexan" access panels to the shuttle area. Containment ventilation was provided through primary and secondary HEPA filters and a water scrubber before exhausting to the environment.

The fire was identified by an operator and by the ventilation system smoke detector. Employees extinguished the fire using portable fire extinguishers. The combustible elements of the containment housing between the hammermill and slugger press (including the Viton hose, Neoprene boot, and Lexan parts of the containment housing) were consumed by the fire. The primary HEPA filters were extensively damaged. The cause of the fire was attributed to the heat generated by oxidation of the powder, which ignited adjacent combustible materials.

Other Incidents

The Information Notice references several other fire incidents since 1977 involving calciner discharge lines and at least one fire event involving a hammermill hood. In these events, oxidizing uranium powder was believed to be the source of ignition, and combustible materials (e.g., transfer hoses and boots) provided the fuel. All of these fires were promptly extinguished. The Information Notice identified a number of fire preventive and protection measures that should be considered at fuel facilities.

The type of fire scenarios identified by this Information Notice are not expected to occur at the MFFF for the following reasons:

- Most of the MFFF process gloveboxes are inerted. The gloveboxes used to process uranium oxide that are subjected to heating from mechanical processes, similar to those identified in the Information Notice, are inerted.

- Gloveboxes that contain uranium oxide powder are equipped with de-dusting equipment.

- The process equipment and components (e.g., hose, cable) within the glovebox are not constructed of materials that can be easily ignited.

- The fire detection devices that are provided for the MFFF process gloveboxes does not allow the existence of hot unburned combustible gases to occur undetected.

- The provision of connecting portable CO_2 bottles as a fire extinguishing system for the gloveboxes, as well as operator training, enables a fire to be extinguished quickly before any significant consequences can occur.

- The ventilation filters are Underwriters Laboratory (UL) Class 1 filters, which are essentially noncombustible.

- Manually operated fire dampers in the glovebox and process room exhaust ventilation system ducts, as well as fire dampers in the glovebox and process room supply ventilation system ducts, are provided at the penetrations through the fire barrier at each process room containing a glovebox. This design permits the ventilation ducts to and from the glovebox to be isolated to protect final HEPA filters from excess temperatures.

- Filters with fire screens are provided at exhaust outlets from process rooms containing gloveboxes to remove larger smoke particles from the exhaust air to reduce the particulate loading on the final HEPA filters.

7.2 DOE OPERATIONAL EXPERIENCE

Within the DOE fire protection community, the operational experience from the 1957 and 1969 fires at the Rocky Flats Plant near Denver, Colorado (for example, see Ref. 25), has a direct impact on the level of attention applied to fire safety at DOE facilities. Therefore, the salient aspects of each of these fires, as they apply to the MFFF, are evaluated as discussed below.

7.2.1 Rocky Flats 1957 Fire

The fire at Rocky Flats that occurred on September 11, 1957, started in a glovebox within a building and was discovered by plant guards who smelled burning rubber. The fire was determined to have started from the spontaneous ignition of pyrophoric plutonium metal turnings within the glovebox that spread to the PMMA (i.e., Plexiglas) glovebox windows. The glovebox windows were composed of Plexiglas in lieu of glass because of the difficulty in fabricating glass enclosures that could be contamination-tight without breaking. Unburned combustible gases from the fire passed through the ventilation ductwork and ignited the combustible filters in the building's exhaust filter plenum. This type of fire scenario is not expected to occur at the MFFF for the following reasons:

- The primary materials being processed within the gloveboxes (plutonium oxide and uranium oxide) are not pyrophoric, plutonium oxide is fully oxidized, and uranium oxide is not combustible under process conditions.
- Most of the MFFF process gloveboxes are inerted.
- The glovebox window material is not an easily combustible material such as PMMA, which was used at Rocky Flats.
- The fire detection that is provided for MFFF process gloveboxes does not allow the existence of hot unburned combustible gases to occur undetected.
- The provision of connecting portable extinguishing systems to gloveboxes, as well as operator training, enables a fire to be extinguished quickly before any significant consequences can occur.
- The ventilation filters are Underwriters Laboratory (UL) Class 1 filters, which are essentially noncombustible; the Rocky Flats filters were combustible.
- The MFFF ventilation systems are designed to protect the filters from excess temperatures as follows:
  - Manually operated fire dampers in the glovebox ventilation system allow the glovebox to be isolated if necessary.
  - The room ventilation exhaust system is designed to enable continued exhaust in the event of a fire while protecting the last filtration barrier.

7.2.2 Rocky Flats 1969 Fire

The fire at Rocky Flats that occurred on May 11, 1969, started in a glovebox and was detected by the building fire detection system after burning for several hours. The fire was determined to have started from the spontaneous ignition of pyrophoric metallic plutonium chips stored in oily rags within the glovebox. Combustion of the rags eventually spread to the PMMA (i.e., Plexiglas) glovebox windows and glovebox gloves. Prior to igniting the glovebox windows and gloves, the heat and combustible gases from the fire ignited other plutonium and combustibles within the glovebox. The fire propagated throughout the glovebox production line. Smoke from the fire passed through the ventilation ductwork and clogged the ventilation filters. This type of fire scenario is not expected to occur at the MFFF for the following reasons:

- The fire detection that is provided for MFFF process gloveboxes does not allow the existence of a fire to go undetected for any significant length of time.
- The primary materials being processed within the gloveboxes (plutonium oxide and uranium oxide) are not pyrophoric, plutonium oxide is fully oxidized, and uranium oxide is not combustible under process conditions.
- Process fire doors are provided to prevent propagation of a fire through the MFFF process line and its transfer gloveboxes.
- Combustible materials within the gloveboxes are minimized.
- Most of the MFFF process gloveboxes are inerted.
- The glovebox window material is not an easily combustible material such as PMMA.
- Provisions for connecting portable extinguishing systems to gloveboxes, as well as operator training, enables a fire to be extinguished quickly before any significant consequences can occur.
- The MFFF ventilation systems are designed to protect the filters from clogging as follows:
  - Manually operated fire dampers in the glovebox ventilation system allow the glovebox to be isolated if necessary.
  - The room ventilation exhaust system is designed to enable continued exhaust in the event of a fire while protecting the last filtration barrier.

Therefore, the circumstances that initiated and propagated the 1957 and 1969 Rocky Flats fires, namely pyrophoric material inside gloveboxes, inadequate glovebox fire detection and ventilation systems, continuity of combustibles, lack of fire separation between gloveboxes, and high combustible load inside the gloveboxes in close proximity to ignition sources, have been taken into account so as to preclude such conditions at the MFFF.

7.3 DOE OCCURRENCE REPORTS

Utilizing the DOE Occurrence Reporting and Process System (ORPS), a search for DOE events was conducted using the individual key words "polycarbonate," "Lexan," and "glovebox." A number of events associated with these words were identified; however, only one of these events was specifically related to the use of polycarbonate window material in gloveboxes. It was Occurrence Report No. RFO-KHIl-771OPS-2000-0019, "Lexan Ceiling Window in Glovebox 24 Melted by Halogen Light."

This potential fire occurred on April 20, 2000, at Rocky Flats. The event occurred following relamping activities in which maintenance electricians installed a portable halogen light fixture above the ceiling window of a glovebox. The portable halogen fire fixture was placed on the ceiling window of the glovebox to improve the lighting within the glovebox. The ceiling window panel was constructed of polycarbonate (Lexan). The heat generated by the portable light fixture partially melted the polycarbonate window material; the window bowed in approximately eight inches. However, the polycarbonate window material did not ignite and no contamination was released from the glovebox.

This incident is not expected to occur at the MFFF for the following reasons:

- The design of the MFFF gloveboxes includes adequate fluorescent lighting for the gloveboxes.
- Administrative procedures implemented prior to operation control the use and installation of temporary electrical equipment, portable electrical equipment, and portable lighting for temporary use and during maintenance activities.

8. OTHER SAFETY, MAINTENANCE, AND OPERATIONAL CONSIDERATIONS

Other attributes besides fire safety and mechanical performance should be considered in selecting a glovebox window material. There is no particular advantage to using either material with respect to compatibility with process materials and operations. The principal process functions of the glovebox windows are to maintain confinement and to maintain the atmosphere within a glovebox to ensure product quality, and both materials perform this function comparably. In other areas, however, the advantages of using one material over the other are more distinct.

Specific Gravity – The specific gravity of glass is more than twice that of polycarbonate. The weight of a large panel of glass can exceed 80 lb (36.3 kg) as opposed to 40 lb (18.1 kg) for the same panel of polycarbonate. This difference poses a challenge from a design perspective because the glovebox shells must be designed to support the additional mass, and carts, lifting mechanisms, or other devices must be designed to facilitate handling of the heavier glass panels during open glovebox maintenance.

Maintenance – From a maintenance perspective, heavy panels are difficult to handle inside contamination control areas, increasing exposure to the worker and the risk of handling accidents. Also, the polycarbonate panels are less likely to break during handling, thus minimizing the potential for longer confinement breaches caused by replacing fissured glass. The largest polycarbonate window panel (3.3 by 4.9 ft [1 by 1.5 m]) at the MELOX facility can be replaced by two operators. However, if these panels were made of glass, the additional weight of glass would require three or four operators with special lifting equipment to replace the panels.

Optical Clarity – The optical clarity of glass is slightly better than that of polycarbonate. In comparative terms, glass transmits approximately 89% of the visible light spectrum, as opposed to 85% for polycarbonate. While this difference is detectable, the experience at MELOX and other COGEMA facilities indicates that the optical clarity of polycarbonate is suitable.

Wear Resistance – The abrasion resistance of glass is substantially better than that of polycarbonate. This material attribute is not a factor with respect to performance of most safety requirements but can affect the long-term optical clarity of the windows. Whereas equipment in the gloveboxes operates automatically and is designed not to contact window surfaces, the principal challenge to window clarity is periodic glovebox internal cleaning activities. Experience at MELOX indicates that no severe degradation in optical clarity has been observed after several years of operations with a glovebox cleaning frequency ranging between two to six months. Moreover, longer experience (up to 20 years) in the Belgonucléaire and Cadarache MOX facilities, as well as in the La Hague facilities, does not indicate a significant polycarbonate degradation that would lead to operational difficulties.

Chemical Resistance – Both glass and polycarbonate windows are used at DOE facilities. DOE STD-1066-97, Appendix I (Ref. 6), identifies glass as having an excellent resistance to chemicals and polycarbonate as having a good resistance to chemicals. The experience at the MELOX and La Hague facilities has demonstrated that the polycarbonate windows provide a good resistance to chemicals. At the MFFF, the processes performed within the gloveboxes use chemical liquids similar to those that have been used in the MELOX and La Hague facilities. Therefore, the chemicals to be used in and around the MFFF gloveboxes are anticipated to have an insignificant impact on the polycarbonate windows.

Radiation Shielding – Polycarbonate, being somewhat hydrogenous, contributes to the overall shielding of neutron radiation from source terms inside the gloveboxes. While its shielding contribution is minor, it is nevertheless measurable. In addition, polycarbonate provides greater reflection of neutrons back into the gloveboxes, which is a minor effect. Since criticality calculations are performed assuming a bounding reflection condition, the use of glass or polycarbonate has no consequences with respect to the Criticality Safety Evaluations for the gloveboxes.

Fabrication – The workability of the glovebox window material is an important consideration with respect to the feasibility of the fabrication and the total installed cost of the windows. The use of glass poses a significant schedule and financial risk to the project, based on the ability of vendors to fabricate and temper panels without cracking or generating flaws. The difficulties involved with fabricating flawless glass panels translate into schedule risks and increased costs, which are estimated to range between a factor of 5 and 10 over the cost of polycarbonate panels.

Experience – The experience using large polycarbonate panels in MELOX and La Hague gloveboxes has been very successful from design, procurement, fabrication, installation, operations, and maintenance perspectives. On the other hand, there is very little experience in designing or producing highly perforated glass panels of the size required for glovebox applications. The design of the windows at the MELOX facility was based on a life expectancy for the window panels of approximately 25 years. This design concept has been validated by the satisfactory performance of these windows at the MELOX and La Hague facilities. Windows have only been required to be removed for the following reasons:

- Modification inside a glovebox that added new penetrations.
- Removal of large equipment components installed inside a glovebox.

9. CONCLUSIONS

Polycarbonate is an acceptable material for the process glovebox windows in the MFFF. The use of polycarbonate versus glass for large MFFF process glovebox windows has been evaluated, considering design standard compliance, nuclear safety, operability, maintenance, fabrication, and overall experience in product use in the application.

MFFF operations were reviewed to determine potential failure mechanisms of the glovebox windows. Of these mechanisms, the potential failure mechanisms that could breach the glovebox windows include thermal degradation under a large fire and failure under mechanical loads (e.g., ventilation pressure transients, seismic inertia, seismic deflection, or impact due to operational accidents and load drops).

An evaluation of gloveboxes in the event of fire, performed using traditional fire hazards analysis techniques, indicates that the risk of a fire damaging a polycarbonate glovebox window is very low. The lack of ignition sources present in the process rooms or gloveboxes themselves would prevent a significant fire from ever occurring.

Even if a fire were to start, the combustible properties of polycarbonate are so poor that a flame source trained directly on the material would be required for a considerable period of time in order to breach confinement. In addition, protective measures are provided to mitigate the consequences of a fire. These include the following:

- Fire detection devices inside and outside of the glovebox
- Fixed suppression system in rooms containing gloveboxes
- Portable suppression system for injection into the glovebox
- Separate dynamic confinement system with UL Class 1 HEPA final filters for the glovebox interior and the glovebox room
- Fire-rated barriers to prevent propagation of the fire.

Thus, even such a hypothetical situation would not result in any significant consequences to workers or an unacceptable release to the environment. Although polycarbonate is classified as a combustible material, its use is an acceptable alternative that does not induce a significant risk, given the design features and management measures taken at the MFFF.

Analysis of the major glovebox fires (Rocky Flats Plant in 1957 and 1969) has demonstrated that the glovebox window material can contribute to the severity of glovebox fires. However, the glovebox window material involved in these fires was an easily combustible material and not polycarbonate. Additionally, it has been shown that the factors that initiated and propagated the Rocky Flats fires do not exist at the MFFF.

The performance of polycarbonate has also been analyzed and compared to that of glass under mechanical loading capable of breaching the confinement boundary. Analysis results indicate that the mechanical performance of polycarbonate window panels is better than glass under normal operating pressure and seismic inertia loading and is clearly superior to that of glass under seismic deflection and impact loading.

A comparison of the two materials, based on nonsafety operability and maintenance criteria, indicates that glass offers better optical and scratch-resistant properties, but operating history indicates polycarbonate performance is more than adequate in this regard. Glass is heavier and harder to fabricate.

From a procurement viewpoint, the fabrication of glass glovebox windows would be difficult considering the high perforation ratio due to the large number of gloveports utilized in the MFFF glovebox design. The use of glass in lieu of polycarbonate would represent a significant technical and schedule risk to DOE's MOX Program.

The operating experience at MELOX indicates that polycarbonate is the optimum choice from a design and operating standpoint. The MELOX and La Hague facilities serve as the reference design for the MFFF.

These factors lead to the overall conclusion that the use of polycarbonate not only represents an alternative arrangement "that will secure as nearly as practical the level of fire protection intended" by NFPA 801, but actually provides for a substantially safer design in consideration of the application for which it is used. Therefore, based on the evaluation and comparison of risks in this report (i.e., there is no significant fire risk introduced by the use of polycarbonate windows in the MFFF, there is extensive experience with the use of polycarbonate, and the behavior of polycarbonate is significantly superior under seismic deflection and impact loading), polycarbonate has been selected for use to fabricate the window panels of the MFFF process gloveboxes.

10. REFERENCES

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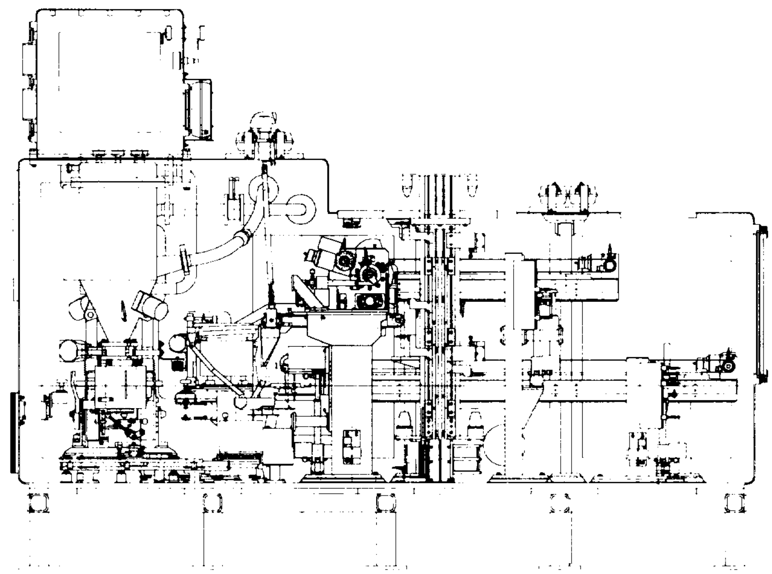
11. ATTACHMENTS

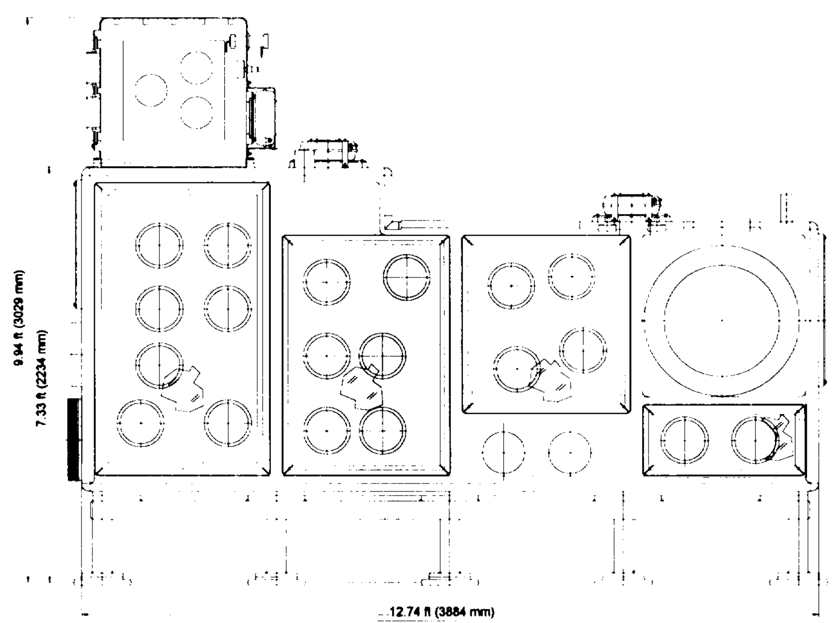
Attachment A – Typical Glovebox Elevations

Attachment B – Potential Glovebox Window Failure Mechanisms

Attachment C – MELOX Pelletizing Room (Room A228) Layout

<u>Attachment A – Typical Glovebox Elevations</u>





Attachment B – Potential Glovebox Window Failure Mechanisms

Failure Mechanism	Discussion
Internal impact	Refer to Section 6.3.4 for details.
External impact	Refer to Section 6.3.4 for details.
Fire	Refer to Section 5 for details.
Earthquake	Refer to Sections 6.3.2 and 6.3.3 for details.
Pressure (high or low)	Refer to Section 6.3.1 for details.
Temperature (high)	High temperature, as a failure mechanism, is considered to be bounded by the fire failure mechanism in the short term. In normal and accident conditions (fire excluded), the window temperature remains below the maximum recommended continuous operating conditions for polycarbonate (248°F [120°C]).
Seal failure	Under normal glovebox operating conditions, typical glovebox seal materials are compatible with either type of window material.
Direct radiation	Based on Appendix I of DOE-STD-1066-97 (Ref. 6), non-browning (cerium-added) glass has an "excellent" resistance to radiation. Linear polymers, in general, exhibit a tendency to degrade under high radiation fields, especially in the presence of oxygen. However, no significant degradation is expected for the low lifetime accumulated doses projected for the glovebox windows. Operational data from MELOX and other COGEMA and Belgonucléaire facilities (with up to 20 years of experience) support this conclusion.
Corrosion (window or seals)	Neither glass nor polycarbonate exhibits any tendency to corrode under normal glovebox operating conditions, nor has any effect on the degradation rate (loss of pliability) of seal materials over time.
Maintenance	Refer to "Experience" subsection of Section 8 for details.
Criticality risk	Conservative calculational assumptions and methodology bound the criticality moderator effects of polycarbonate and glass.
Thermal excursion	Thermal excursion as a failure mechanism is considered to be bounded by the fire failure mechanism.
Contact with laboratory chemicals	Based on Appendix I of DOE-STD-1066-97 (Ref. 6), glass has an "excellent" resistance to chemicals and polycarbonate has "good" resistance. Therefore, both materials are acceptable for MFFF applications.
Operability/manufacturing issues	Refer to Sections 3 and 8 for details.

Attachment C – MELOX Pelletizing Room (Room A228) Layout