Jefferson Lab Thomas Jefferson National Accelerator Facility	TITLE:	ES&H Manual
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1.0 Purpose

This appendix provides requirements and Jefferson Lab experience for the design and testing of thin windows. A thin window at Jefferson Lab is any closure device for a vessel, chamber, detector, beam line, or target that due to extreme minimal thickness cannot be designed using the ASME codes. This section contains alternative methods that are used at Jefferson Lab to safely design thin windows.

2.0 Scope

Thin windows at Jefferson Lab are widely used primarily in the Experimental Halls to enclose vessels, detectors, targets, beam lines and vacuum chambers where there is a requirement for minimal interaction of either the primary electron beam or scattered beams with the window material. The most frequent reasons for a thin window requirement are to reduce site boundary dose, reduce background radiation, reduce multiple scattering interactions of scattered beams or reduce unwanted target wall interactions. Thin windows are usually air cooled but they may be water cooled. Water cooled thin windows are always considered as thin windows for the purposes of design and the stress limits established below in Section 4.1 shall apply. Typically thin windows are located at the following areas:

- primary beam line,
- beam dump line,
- scattering chamber beam exit or entrance flanges,
- scattering chamber,
- scattered particle exit ports to spectrometers,
- cryogenic liquid target entrance, exit windows, or the flask itself,
- spectrometer beam vacuum entrance or exit windows,
- detectors windows such as Cerenkov Counter entrance or exit windows,
- spectrometer magnet insulating vacuum spaces where scattered particles share the same vacuum as in the G0 SC magnet.

Many of these applications are vacuum spaces and, if properly protected by pressure limiting devices, may be considered exempt from the formal requirements of ES&H Manual Chapter 6151 Pressure Systems. Some of the systems in use at Jefferson Lab with thin window requirements such as the beam dump line, Pressure Cerenkov Counters and Cryogenic Liquid Targets are, in fact, pressure systems with thin windows, and must be designed to ensure a level of safety greater than or equal to the level of protection afforded by the ASME codes.

This appendix collects the design experience, materials, processes and procedures commonly in use at Jefferson Lab to implement thin windows designs. It is the recommendation of the Pressure Systems Committee that these processes be used to design all thin windows at Jefferson Lab, both for thin windows in exempt vessels and for thin windows in pressure systems.

2.1 Materials

The following materials are listed as examples of thin window materials that either are or have been used successfully at Jefferson Lab along with typical applications. The below materials can be used flat; deformed in place for one time or multiple uses; preformed, i.e., hydroformed; machined or pre-welded to mounting flanges. All Beryllium windows are purchased, typically from Brush Wellman, ready to use with a proprietary protective non oxidizing coating. Flat or formed non Beryllium windows are typically made at Jefferson Lab either from flat stock or from precut blanks. Similarly, foam windows are typically machined at Jefferson Lab either from flat Rohacell structural foam stock or layers of Rohacell epoxied together. Titanium and Aluminum window blanks can be laser cut or water jet cut. Mylar-Kevlar-Mylar laminates can be cut from flat stock at Jefferson Lab with special carbide tipped scissors and hole punches.

2.1.1 Beam Line entrance or exit windows

Beryllium
Al. 6061 T6
Hydroformed Alclad 2024 dished windows
Hydroformed Alclad 2024 with a welded Beryllium insert
Beryllium with Gold plating- no longer used and not recommended due to activation

2.1.2 Beam Dump Windows

Al 6061 T6

2.1.3 Scattering chamber scattered particle exit windows

Al 5054
Kapton
Rohacell foam

2.1.4 Spectrometer entrance or exit windows

Mylar-Kevlar-Mylar laminate
Titanium (90-6-4)
Hydroformed Alclad 2024 dished windows
Al 5054

2.1.5 G0 magnet exit windows

Titanium (90-6-4)

2.1.6 Cryogenic target flasks and windows

Al 6061 T6 machined flasks

2.1.7 Detector windows

Al
Kapton
Mylar
Mylar-Kevlar-Mylar

3.0 Responsibilities

3.1 **Design Authority** is responsible for designing the thin window. The Design Authority must also determine if the application is exempt (delta Pressure < 15 psi) or if the application is part of a pressure system requiring alternative design rules due to the presence of the thin window.

4.0 Process Steps or Expectations

4.1 The Design Authority shall determine whether a proposed thin window design is a part of an exempt system or is part of a pressure system to be designed to alternative rules. In either case, the thin window design shall follow the guidelines presented here. For pressure system thin windows, the Design Authority shall ensure that the rules applied are Peer Reviewed and documented according to the requirements provided in ES&H Manual Chapter 6151 Appendix T1 Pressure System Project Implementation and Documentation Requirements.

4.2 The design of flat thin windows can proceed from either the formulas in Roark and Young, Chapter 10-11 for circular or rectangular thin plates under large deflection or through use of the Brookhaven National Laboratory (BNL) thin window guideline. The BNL thin window guideline has been adopted for use at Jefferson Lab. The BNL guideline requires that thin windows be designed to the lesser of 50% of ultimate stress or 90% of yield stress. Many successful flat thin windows exist at Jefferson Lab that were designed to this criterion. Typically, flat thin windows are high strength materials like Titanium or Beryllium since the BNL stress criteria can only be met for small deflections.

4.3 Thin windows that are deliberately dished through hydroforming or some other process can be safely made from much thinner material than a corresponding flat window of the same diameter. Typically, a thin flat disc of Aluminum is hydroformed into a predetermined spherical shape. A typical hydroforming pressure is two to three times the usual operating pressure (14.7 psi). This pressure is necessary to yield the material into the desired shape and has the benefit of an inherent overpressure test. Many hydroformed windows exist at Jefferson Lab typically made to Alclad 2024 Aluminum which comes in a half soft state and has a large elongation and a moderately high yield and ultimate strength.

The stress of a spherical window is equal to qR/2t, where R is the radius of curvature of the window, q the load in psi and t is the window thickness. The designer selects a radius of curvature and thickness in accordance with the above stress criteria (90% Yield or 50% ultimate). The next step is to calculate the elongation required to accomplish the desired window shape. It is recommended that the only 30% of the available elongation be used so that adequate reserve remains in the window material to provide safety against foreign object penetration. A successful window design results from an optimized choice of forming radius that results in both a low operating stress and large reserve elongation. Over-forming a window (too small radius of curvature) results in a lower operating stress but is accompanied by a low remaining elongation which increases the risk of failure due to penetration. The forming stress can be estimated by making a linear relation between the elongation and the stress plotted between yield and ultimate. 0% elongation occurs at initial yield and full elongation occurs at ultimate stress. The stress required to achieve any elongation can be calculated by a simple proportion.

The materials to be used for hydroformed windows must be tested to verify the ultimate strength. This is usually accomplished during hydroforming by deforming until failure. It is essential that at least one window from each material batch be tested to ultimate to validate the materials used. The thin window stock or precut blanks should be carefully inspected prior to use to insure that there are no defects, deep scratches or wrinkles that could easily compromise the strength of these thin materials.

4.4 Deform-in-place windows are simply thin pre-tested materials that are highly deformed during the initial evacuation. Examples of thin windows of this type are the spectrometer entrance and exit windows that are made from Mylar-Kevlar-Mylar laminates and the Aluminum (5054) or Kapton scattering chamber windows. These materials must be pre-qualified by test to determine that, after the initial deformation, adequate safety margin exists. Once these materials are pre-qualified, replacement windows to the same size and shape can be easily made. The Mylar-Kevlar-Mylar windows are typically clamped and tested off line in a transfer flange. This permits an initial pressurization and overnight creep test to be performed. The use of a transfer flange eliminates uncertainty due to repeated installation. It is accepted practice in Physics to permit use of identical materials in any subsequent window application that is smaller or equal in size to a pre-qualified window. All new material stocks must be pre-qualified to verify that the new material is, in fact, identical to seemingly identical previous materials. Experience at Jefferson Lab shows that laminated window materials can vary substantially with each batch while metal window materials have always been consistent within the normal range for materials specifications. All new material stock must be pre-tested prior to use especially for deform-in-place thin windows.

4.5 Machined foam windows are used in the scattering chamber for CLAS where a lower total mass and a homogenous mass distribution, providing the equivalent angular acceptance as CLAS are desired. The scattering chamber is made of several different composite structures. (See Foam Scattering Chambers for CLAS in References). The support tube and flanges are aluminum and are located out of the acceptance region of CLAS. The scattering region of the chamber is made of layers of Rohacell structural foam epoxied together with West System® epoxy and Microlight® filler. Rohacell is a polymethacrylimide rigid foam that is 100% closed cell, isotropic, non-toxic and has a unique strength and stiffness to weight ratios, (see Reference). At the end or the exit beam tube there is a .0028" 5052 MF aluminum window. Structural analysis of the foam windows uses Roark's Formulas for Stress & Strain, 6^{th} Ed. The stress was analyzed using Cases 1d and 2b of Table 32. A buckling analysis was done using cases 20a and 22a of table 35. Prototype foam windows are tested to destruction to demonstrate a factor of safety of 3 or above.

4.6 It is recommended that a transfer flange be used for any installation of thin windows where there is risk of window creep and failure due to improper bolt torque or other installation error. The windows most susceptible to this type of problem are the Mylar-Kevlar-Mylar laminate windows where friction between flat flanges is the primary window restraint mechanism.

4.7 Some materials commonly used for thin windows have lifetime limitations that must be carefully considered to avoid failure related to material property degradation. Beryllium beamline windows, Mylar-Kevlar-Mylar laminate spectrometer vacuum windows and Rohacell foam windows are subject to degradation.

Beryllium windows in use at Jefferson Lab come with a proprietary coating that is an organic epoxy type overcoat that prevents oxidation and provides a surface that is free from contaminate that could be picked up by handling. This coating can not be expected to survive for a long exposure to electron beams. It is the policy of the Physics Division to permit Beryllium beamline windows to be used only once due to oxidation considerations. Beryllium windows can be expected to last for 12 months of typical service. A visual inspection especially near the welded edges of the Beryllium window can readily detect the onset of oxidation. Beryllium windows are removed from service at approximately one year service intervals and carefully stored for disposal. New unused Beryllium windows are stored in a locked safe inside Hall C as a further precaution against hand contamination or misplacement.

The Mylar-Kevlar-Mylar (MKM) windows commonly in use are subject to deterioration due to ultraviolet light coming from room fluorescent lighting and also from radiation sources. It is the policy of the Physics Division to remove and replace MKM type windows after six months of service. New MKM material must be stored in a light tight container to prevent loss of shelf life. The MKM materials will acquire a brown discoloration within a week of exposure to room lights which is the first sign of deterioration. MKM windows, especially the major HMS exit window (40 inch diameter), are usually tested after removal. To date, no window removed and retested failed to perform indicating that the 6-month replacement interval is completely safe and appropriate. This regimen is based on the experience of the K-TEV experiment where a large MKM window failed after about 18 months of use resulting in a significant economic loss.

Radiation damage to Rohacell foam has been documented in industry literature. Foam windows have been successfully used without radiation damage in Hall B where the CLAS system operates with low beam current and relatively low radiation environment. If foam windows were to be used in higher radiation environments such as those in Hall A or C then radiation effects would need to be considered.

4.8 Installation safety related requirements apply to thin windows when in service. These include engineered controls to prevent foreign object contact with the window such as shrouds or remote actuated shutters or temporary installed barriers. Jefferson Lab has examples of all three of these barrier styles currently in use. Personal Protective Equipment is also required when working near a thin window consisting of hearing protection, eye protection or face shields. Signage and barriers to warn staff of the presence of a thin window are also required. ES&H staff are available to provide guidance to the Design Authority to insure a safe installation. Special requirements may also arise from the Experimental Equipment Safety Review Process since one of the express purposes of these safety reviews are to identify unique situations that require special considerations.

5.0 References

ES&H Manual Chapter 6122 Hot Work (i.e. Welding, Cutting, Brazing, and Grinding) Safety Program
Roark's sixth edition has analysis methods for thin and thick plates as well as circular membranes.
Technical Memo 1380 by JL Western has similar methods and includes rectangular windows.
Brookhaven National Laboratory "Occupational Medicine Guide" Section 1.4.2.
American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code, Section VIII: Rules for Construction of Pressure Vessels, Divisions I & II
Foam Scattering Chambers for CLAS by Kashy, etal. REV 1.02 dated 10/16/00

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ISSUING AUTHORITY	TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	EFFECTIVE DATE	EXPIRATION DATE	REV.
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