Marine Composites

Webb Institute
Senior Elective

Performance in Fires

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Fire Performance Parameters

Flame Spread

The rate that flame travels along the surface

Fire Resistance

The ability of a boundary to contain a fire

Time-to-Ignition

Time required before a combustible material ignites

Heat Release Rate

The heat release of a material is measures the amount of fuel that a combustible material contributes to a fire

Structural Integrity

Hull, deck and bulkheads must support design loads during and after a fire

Composite Panels being Tested to ISO 9705 as per the International Maritime Organization

Composite Vessel Fires



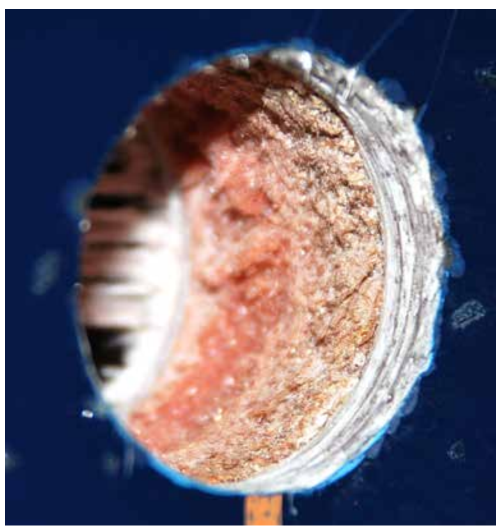
images from Fire Safety & Training in the United Kingdom

Damage to Boats from Fire










USCG Inspected Passenger Vessels

The commercial designer is primarily concerned with the following general restrictions and excerpts from the Code of Federal Regulations (see appropriate Code of Federal Regulation for detail):

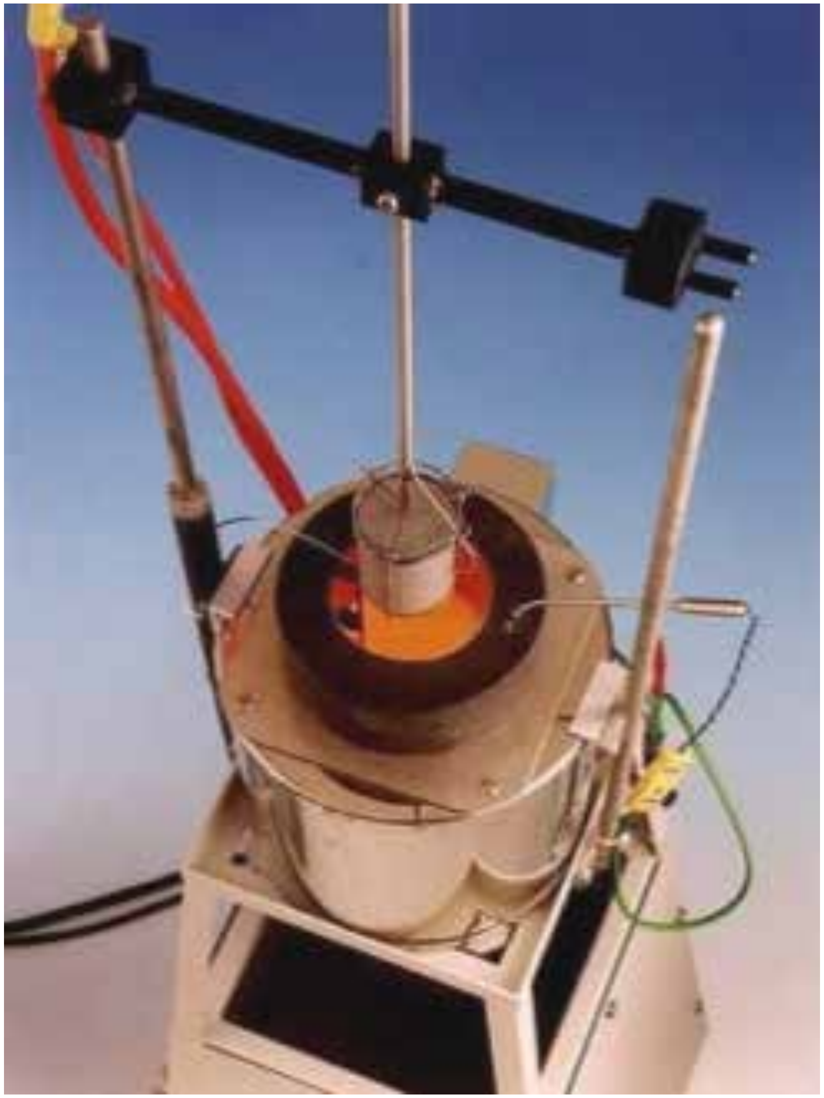
<ins>Subchapter T</ins> - Small Passenger Vessels: Use of low flame spread (ASTM E 84 <100) resins;

<ins>Subchapter K</ins> - Small Passenger Vessels Carrying More Than 150 passengers or with overnight accommodations for 50 - 150 people: must meet SOLAS requirement with hull structure of steel or aluminum conforming to ABS or Lloyd's;

<ins>Subchapter I</ins> - Cargo Vessels: Use of incombustible materials - construction is to be of steel or other equivalent material; and

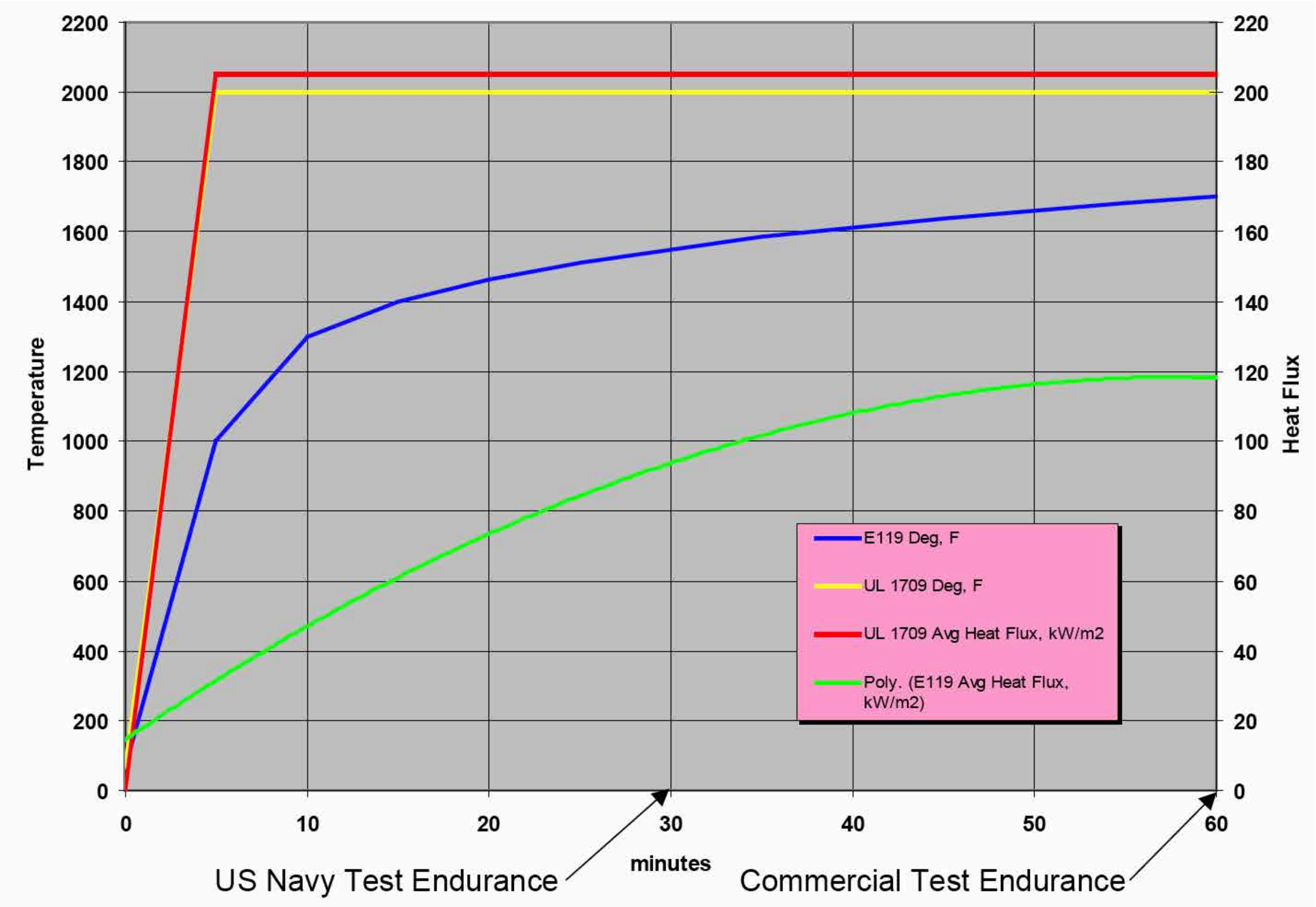
<ins>Subchapter H</ins> - Passenger Vessels: SOLAS requires noncombustible structural materials and insulated with approved noncombustible materials so that the average back face temperature will not rise above designated values.

Non-combustibility

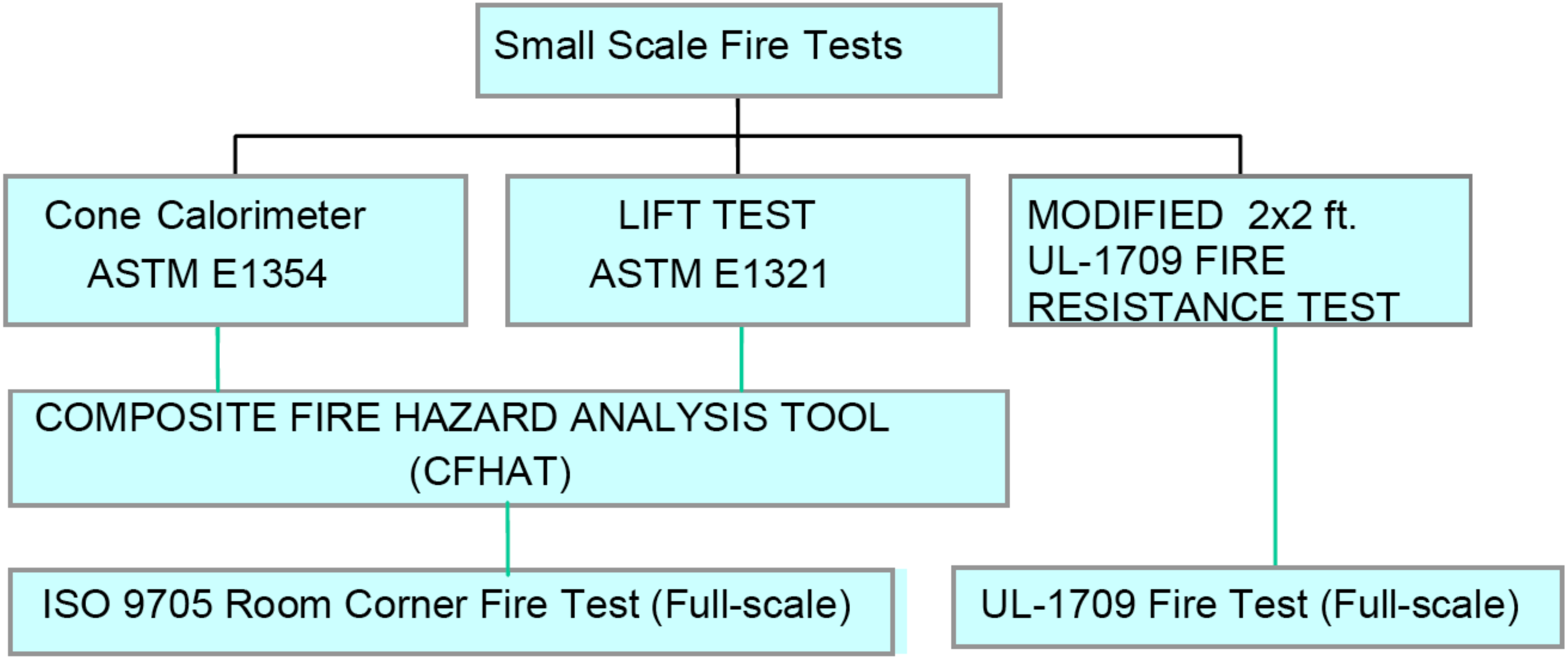


- Any material not passing is "combustible"
- Specimen heated to approximately 750°C
- No flaming
- Mass loss criteria (50%)
- Different apparatus than ASTM E 136
- Solid inorganic materials with little organic binder

Commercial and Naval Fire Curves



Small-Scale Screening Fire Test Methodology



Sorathia, Usman, DDS-078-1, "Composite Materials, Surface Ships, Topside Structural and other Topside Applications – Fire Performance requirements," NSWCCD, August, 2004.

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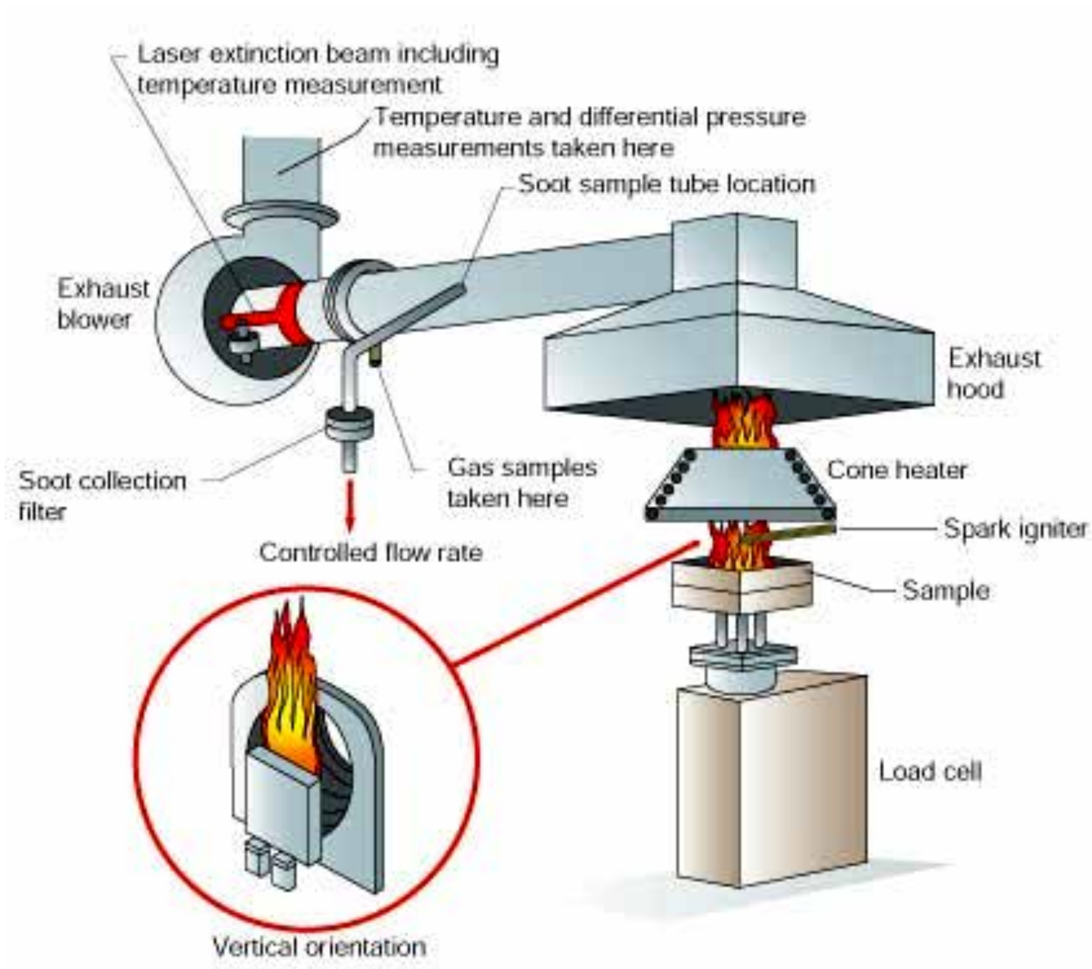
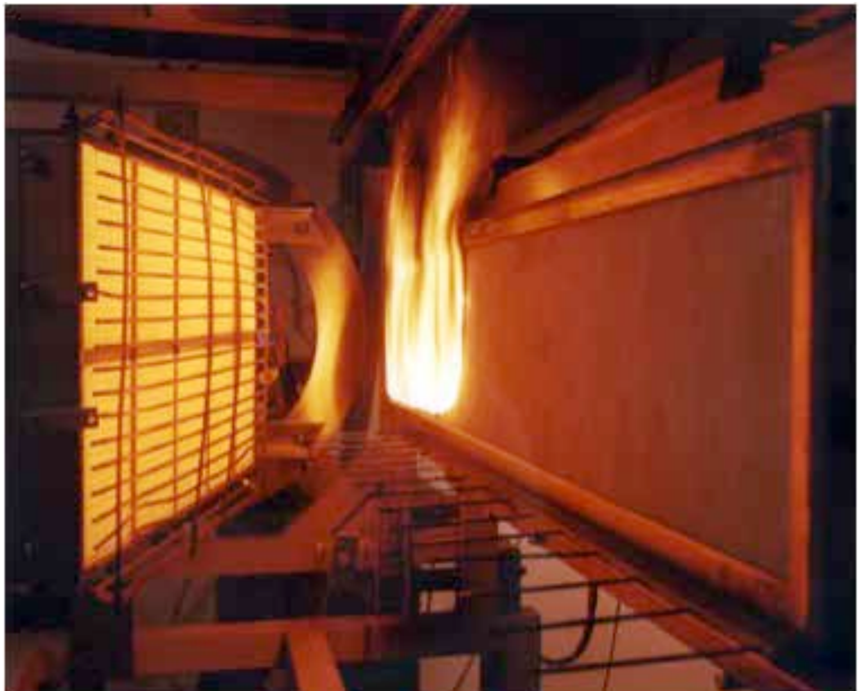
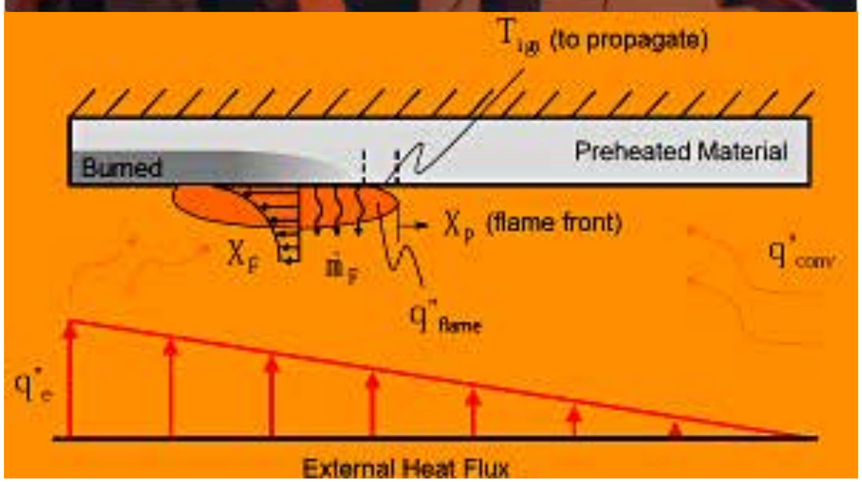
Cone Calorimeter



Lateral Ignition & Flame Transport (LIFT) Test





- Surface will adequately restrict the spread of flame
- Test protocol detailed in IMO Res. A.653(16) and ASTM E1321
- For the flame spread tests, a radiant panel is used to establish a heat flux distribution along an 800 mm long test specimen. The flame spread velocity is measured as a function of incident heat flux along the specimen.

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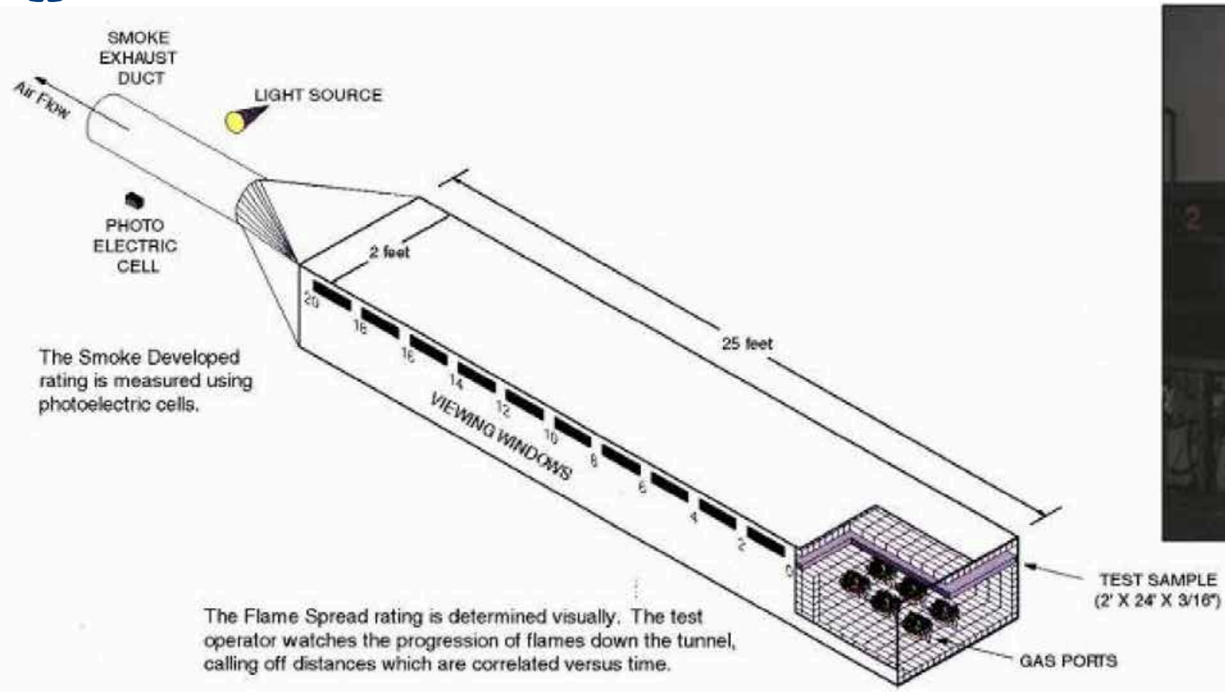
ASTM E84 Test Protocol

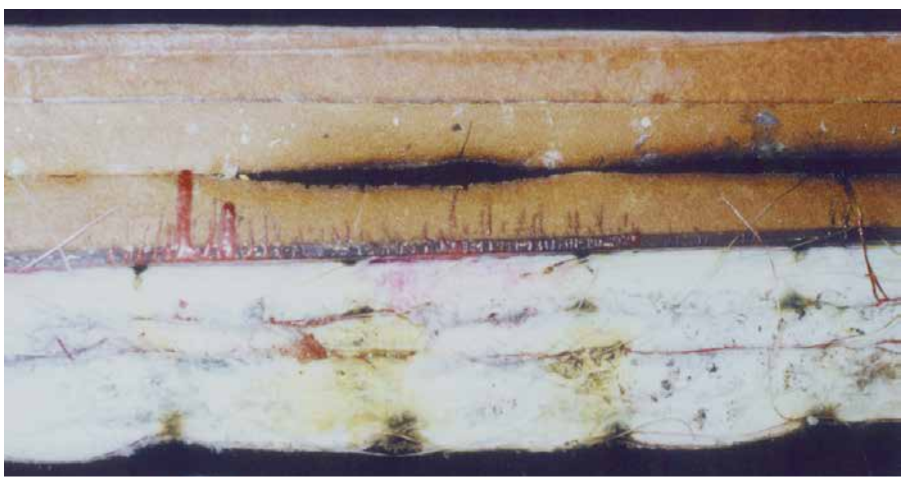


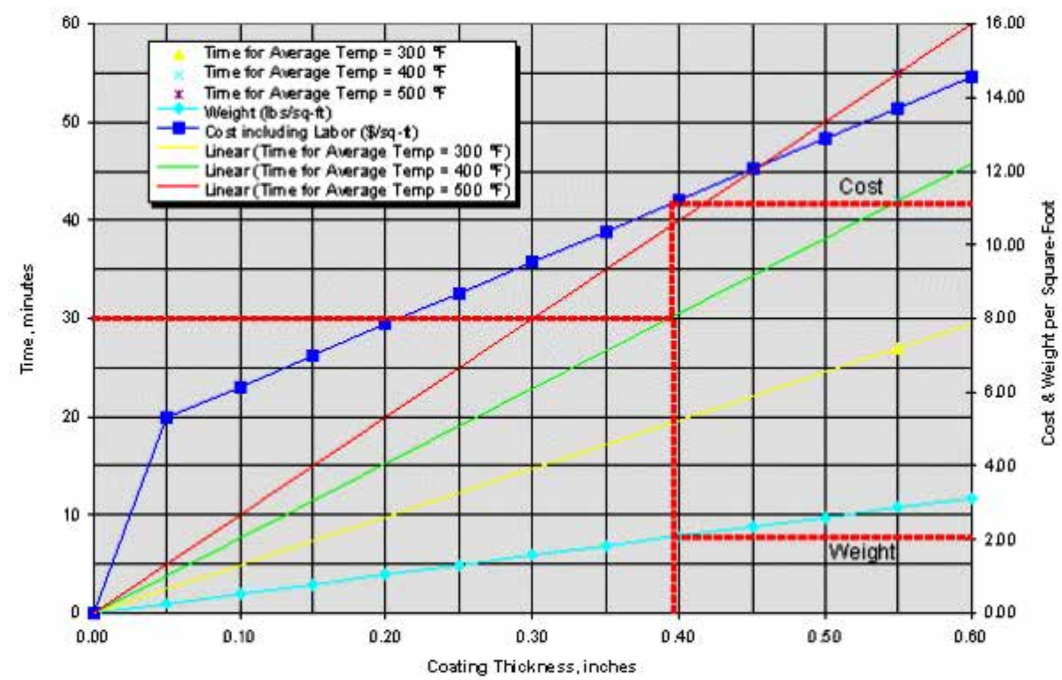
The Steiner tunnel fire test method for surface flame spread and smoke development remains the traditional test used to assess fire performance of interior finish materials.

In the test, a specimen (7.3 m x 0.56 m, normally up to 0.15 m thick), either in one unbroken length or in separate sections joined end to end, is mounted face downwards so as to form the roof of a horizontal tunnel 305 mm high.

The fire source, two gas burners, ignites the sample from below with an 89 kW intensity, and the combustion products are carried away by a controlled linear air velocity of 73 m/min (or, exactly, 240 ft/min). The normal output is a flamespread index (FSI) and a smoke-developed index (SDI).

3 x 3 Foot UL 1709 Tests

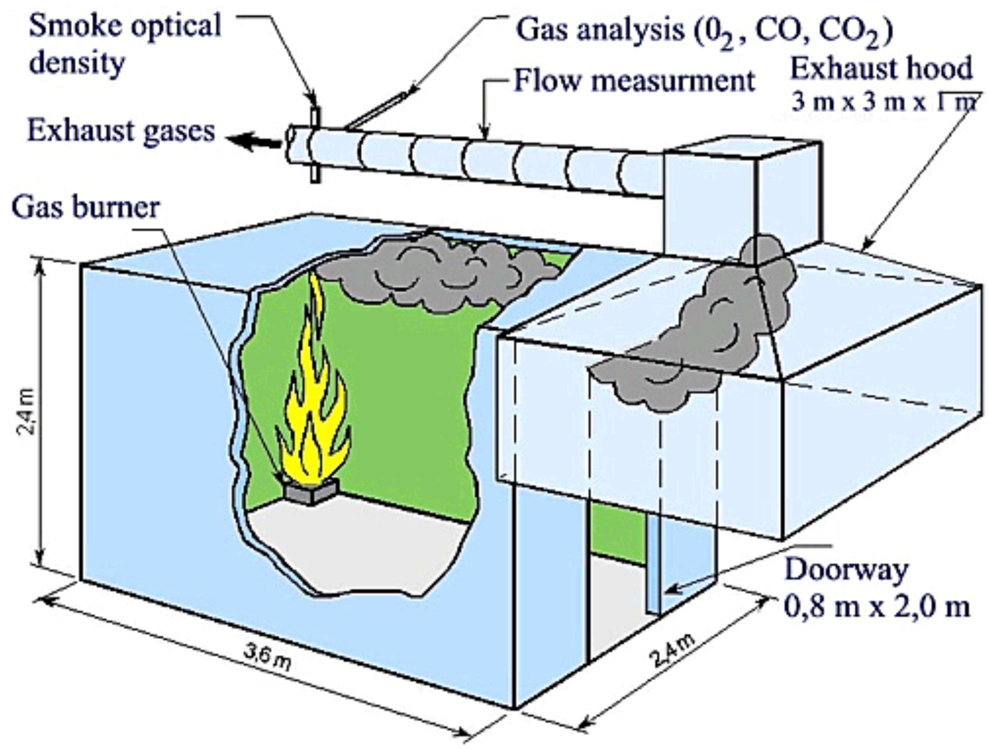




Intermediate-Scale Fire Testing

ISO 9705 Room Corner Test

Lighting of Burner to Start Modified ISO 9705 Room Corner Test at VTEC Laboratories



Schematic of ISO 9705 Room Corner Test to Determine Flame Spread and Smoke Generation

Full-Scale Fire Testing

Bulkhead Test

Test Arrangement for Burn Through Resistance of 10 x 10 - foot Panel

Module Test

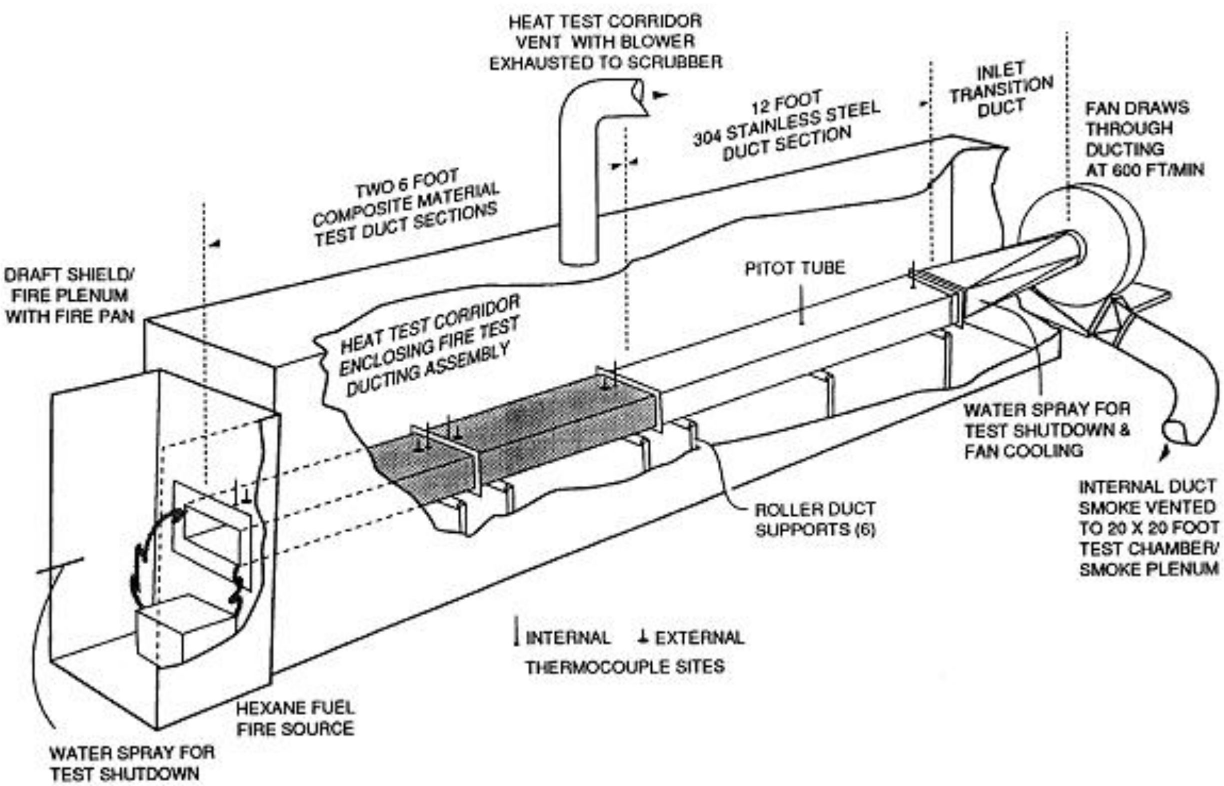
Full-Scale Fire Test for Helicopter Hanger Project with Fire Protection Around Door for Fire Test Only

Composite Pipe

Testing to IMO Resolution A.753(18)

Fire Test for Ventilation Ducts

Navy-Modified FM 4922 Test Subjected Duct to 1200º F Fire



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Navy N-Class Divisions

The Navy N-Class system for classifying fire resistant boundaries is analogous to the commercial IMO system (e.g., A-Class divisions). However, some changes and modifications have been made to accommodate fire threats and combat environment.

The key difference is the Navy N-Class fire exposure AFTER SHOCK TESTING. N- Class fire exposure uses the more severe temperature and heat flux requirements of a hydrocarbon (class B) fire exposure in accordance with the fire curve of UL-1709.

An N-Class division boundary shall comply with the following:

a. Constructed of steel or other equivalent material; "other equivalent material" includes composite construction for topside structures when they pass the fire test requirements.
b. Prevent passage of smoke and flame to the end of the N-Class Division Fire Test for the specified period.
c. For composites, they shall be capable of supporting the maximum load for structural integrity fire testing to the end of the specified period.
d. Limit the average (250 deg F) and peak (325 deg F) unexposed face temperature rise during the fire test within the time listed below:

Class N-60 60 min
Class N-30 30 min
Class N-0 0 min

Usman Sorathia, NSWCCD, “N-Class Divisions U.S. Navy Requirements for Fire Protection and Testing,” Dec, 2011

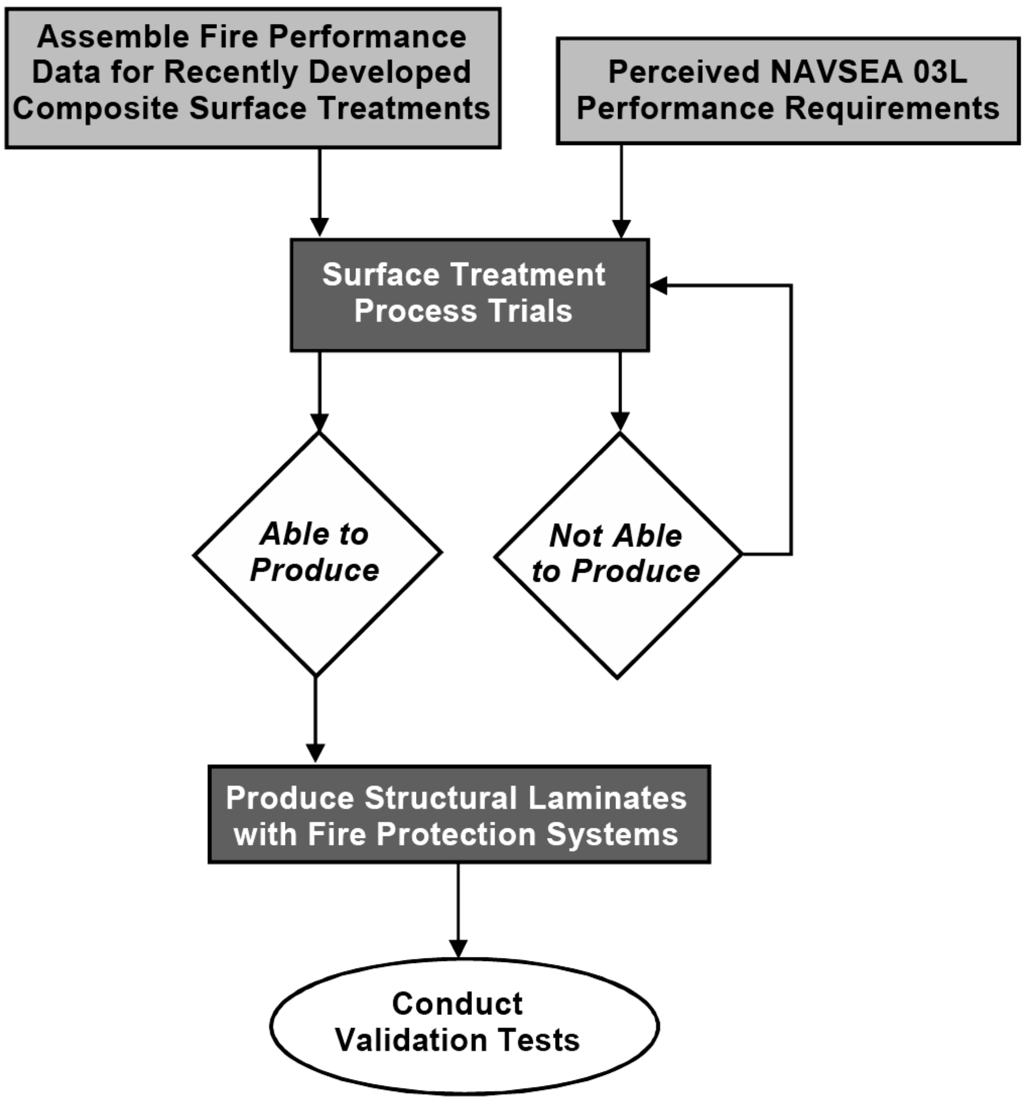
Tenability Criteria

Condition	Tenability Limit
Flashover	Upper-layer temperature greater than 500°C
Human Tolerance	
Temperature	Upper-layer temperature greater than 150°C
Smoke	Visibility less than 0.5 m
Toxicity	CO dosage of greater than 30,000 ppm min (e.g., 6,000 ppm for 5 minutes)
Interface Height	Less than 1.5 m from deck
Equipment Tolerance	
Malfunction	Upper-layer gas temperature greater than 50°C
Damage	Upper-layer gas temperature greater than 150°C

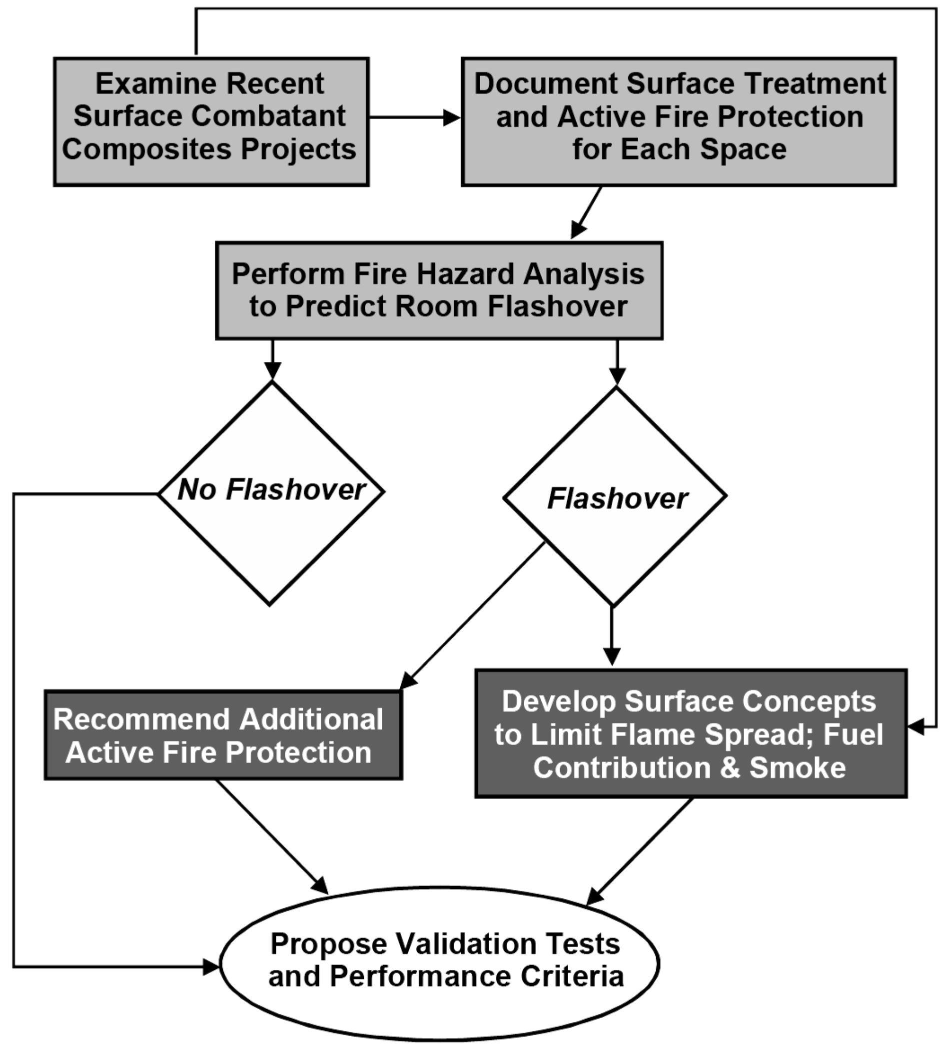
Usman Sorathia, NSWCD Code 643, Fire Protection and Sea Survival Branch, Fire Workshop 2001

Development of Fire Protection System

Qualify Structural Fire Protection

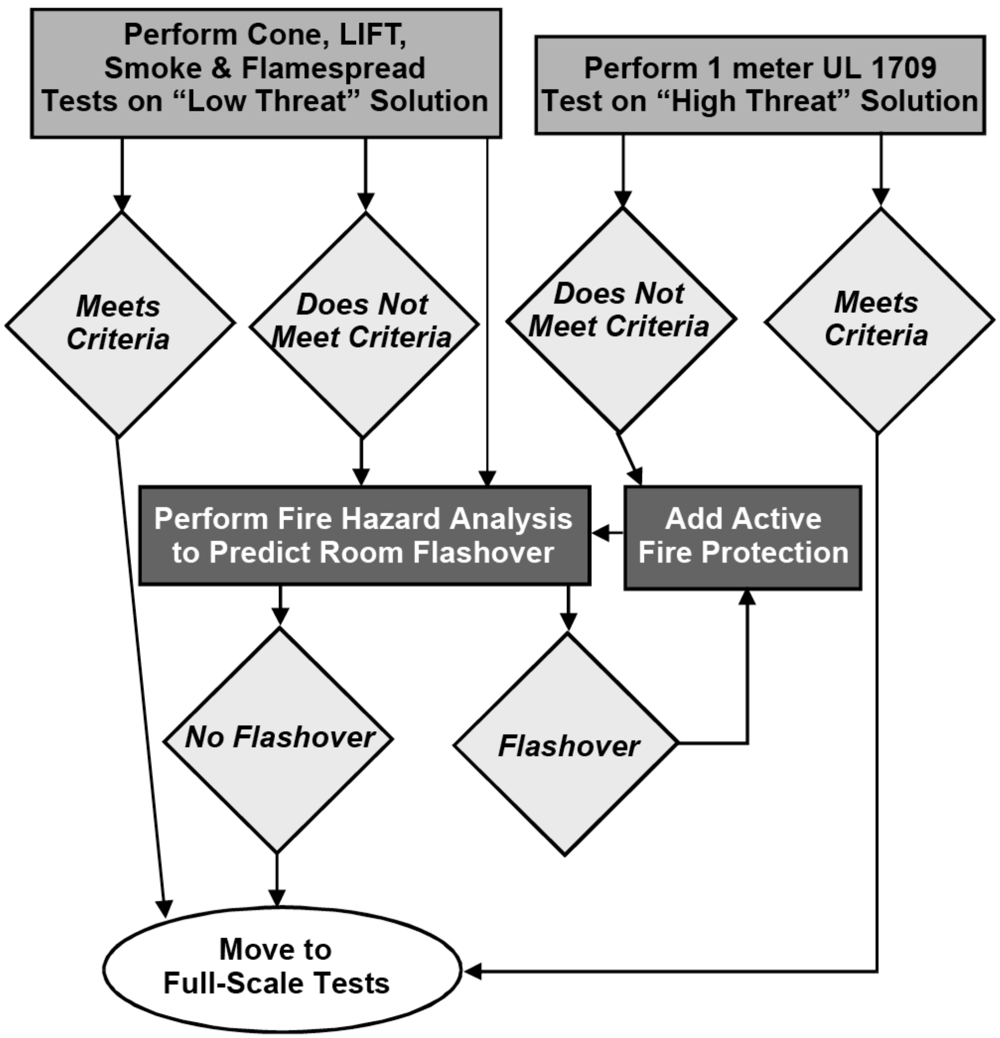


Develop Fire Performance Requirements

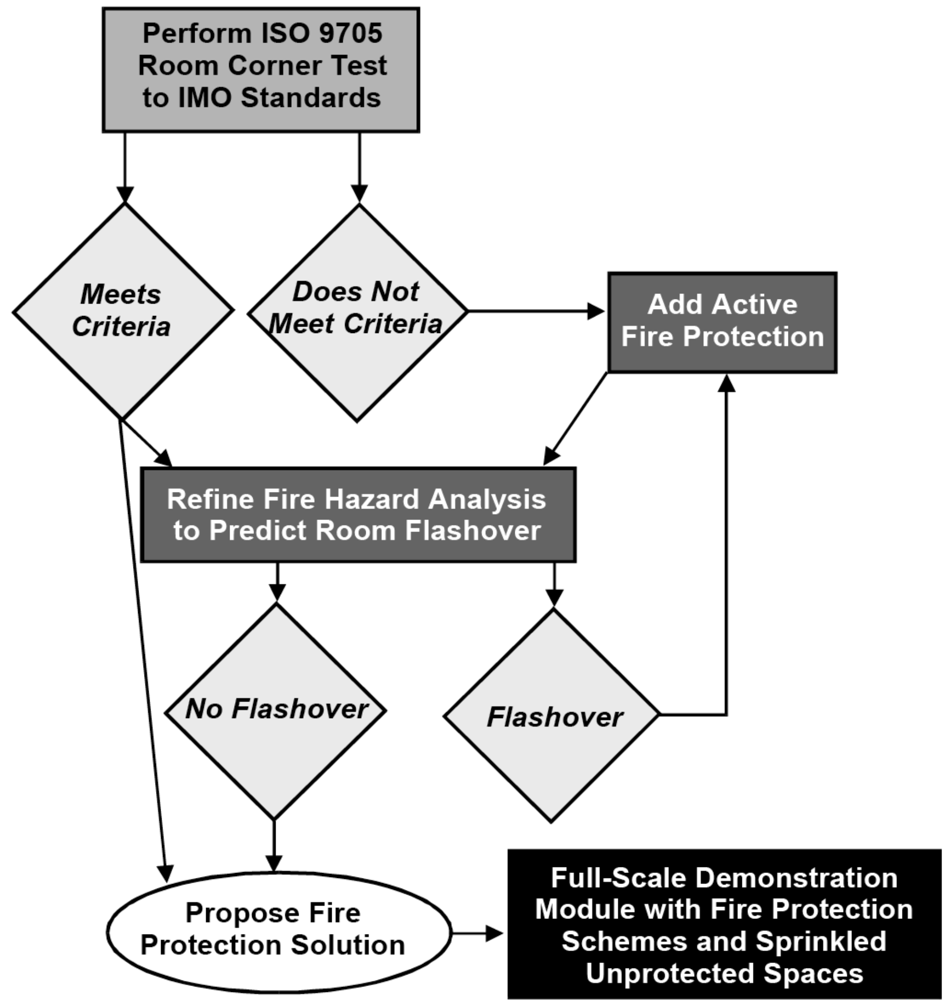


Fire Test Planning

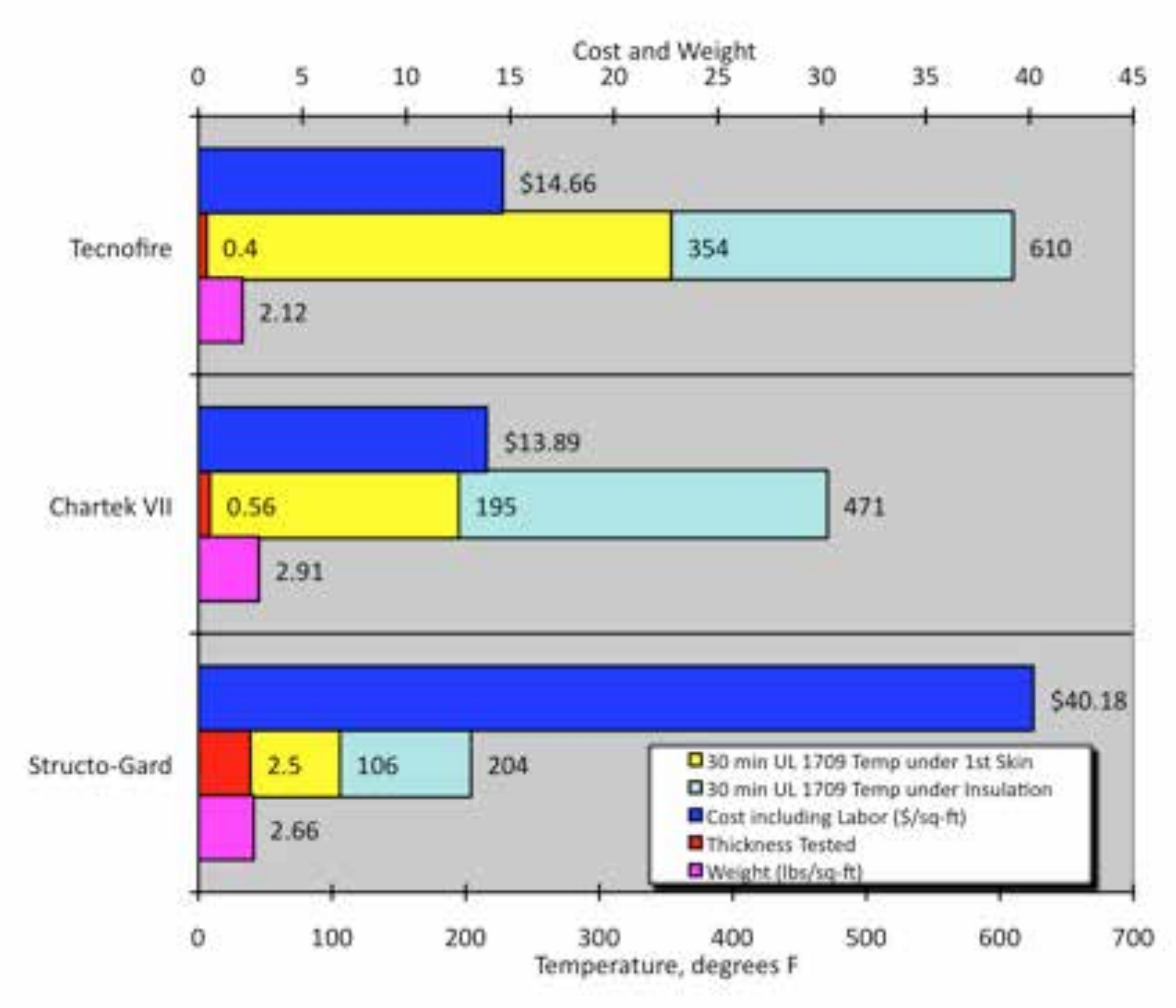
Small- and Intermediate-Scale Fire Tests

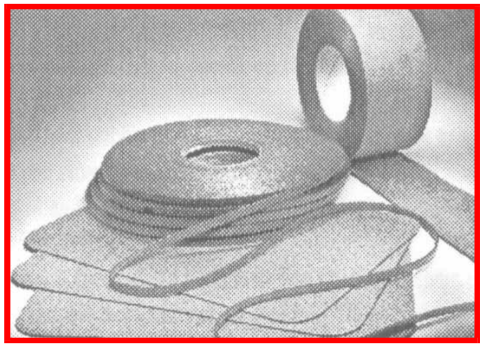


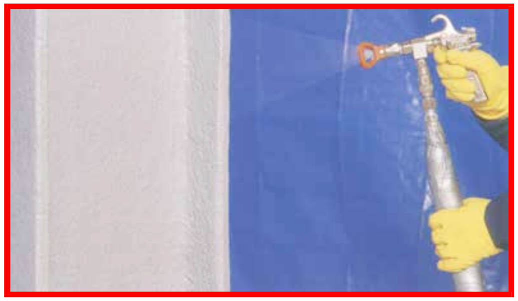
Full-Scale Fire Tests



Examine Fire Protection Alternatives

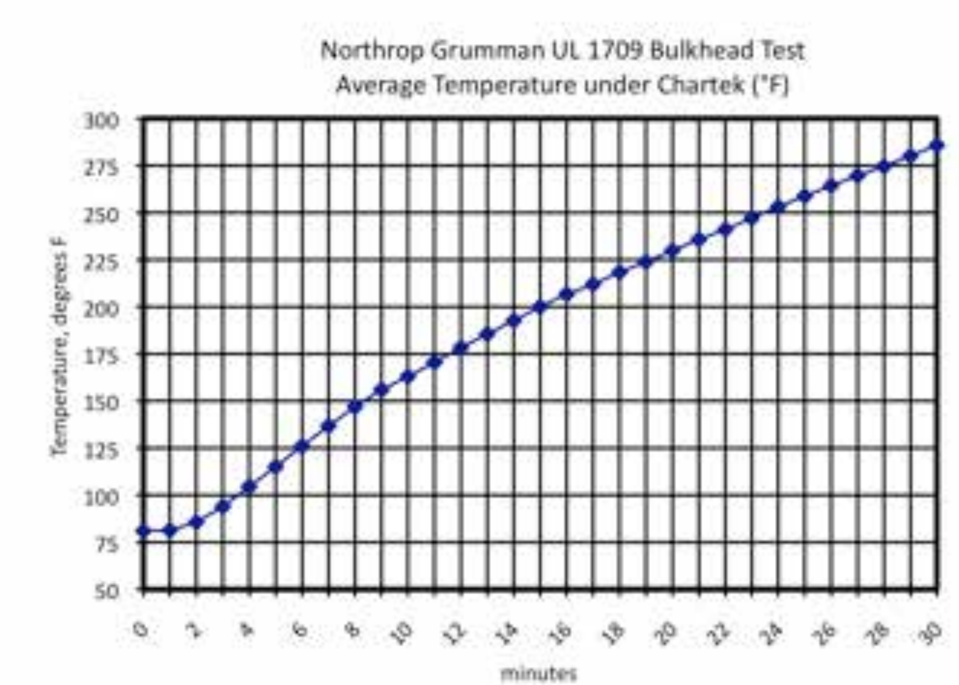




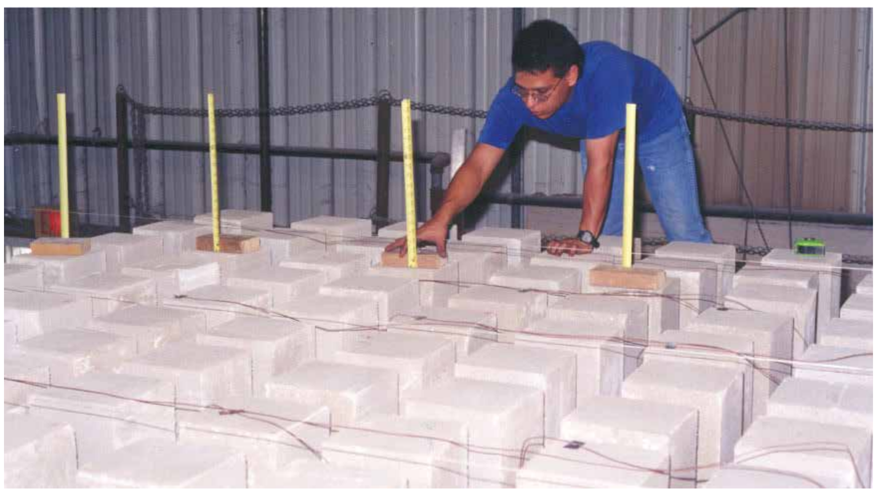


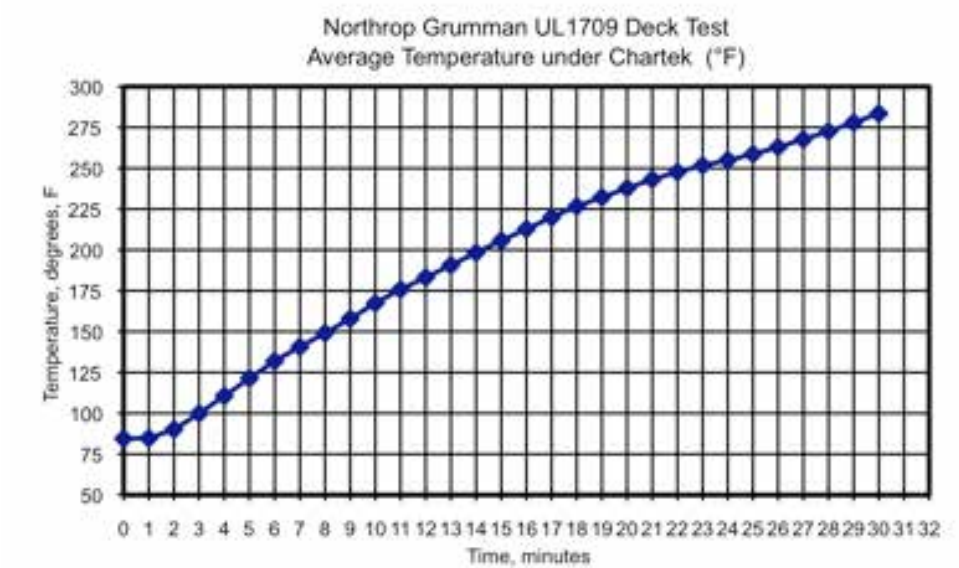
Full-Scale UL 1709 Testing

Bulkhead Before Test



Weights Placed on Deck Before Test

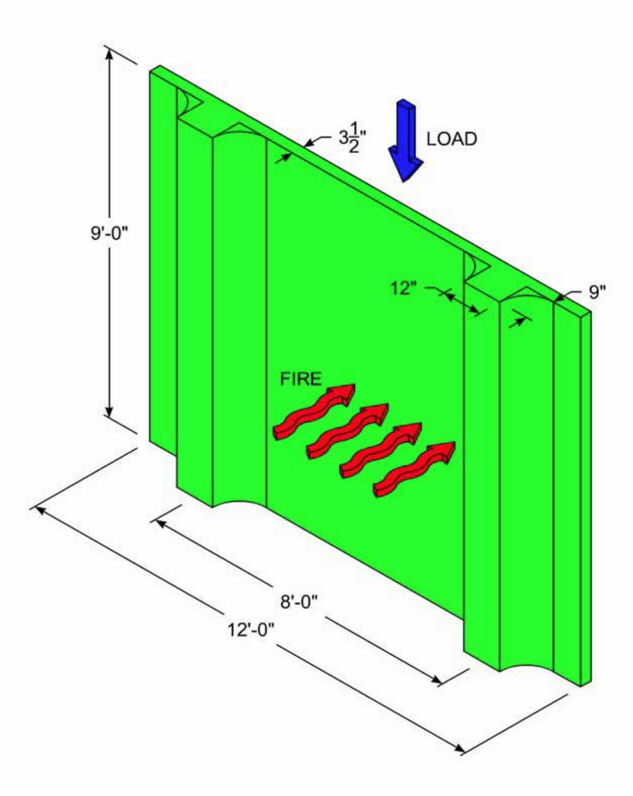




Structural Fire Protection

Carbon fiber sandwich panel with stiffeners

Sketch of a Bulkhead Test Specimen

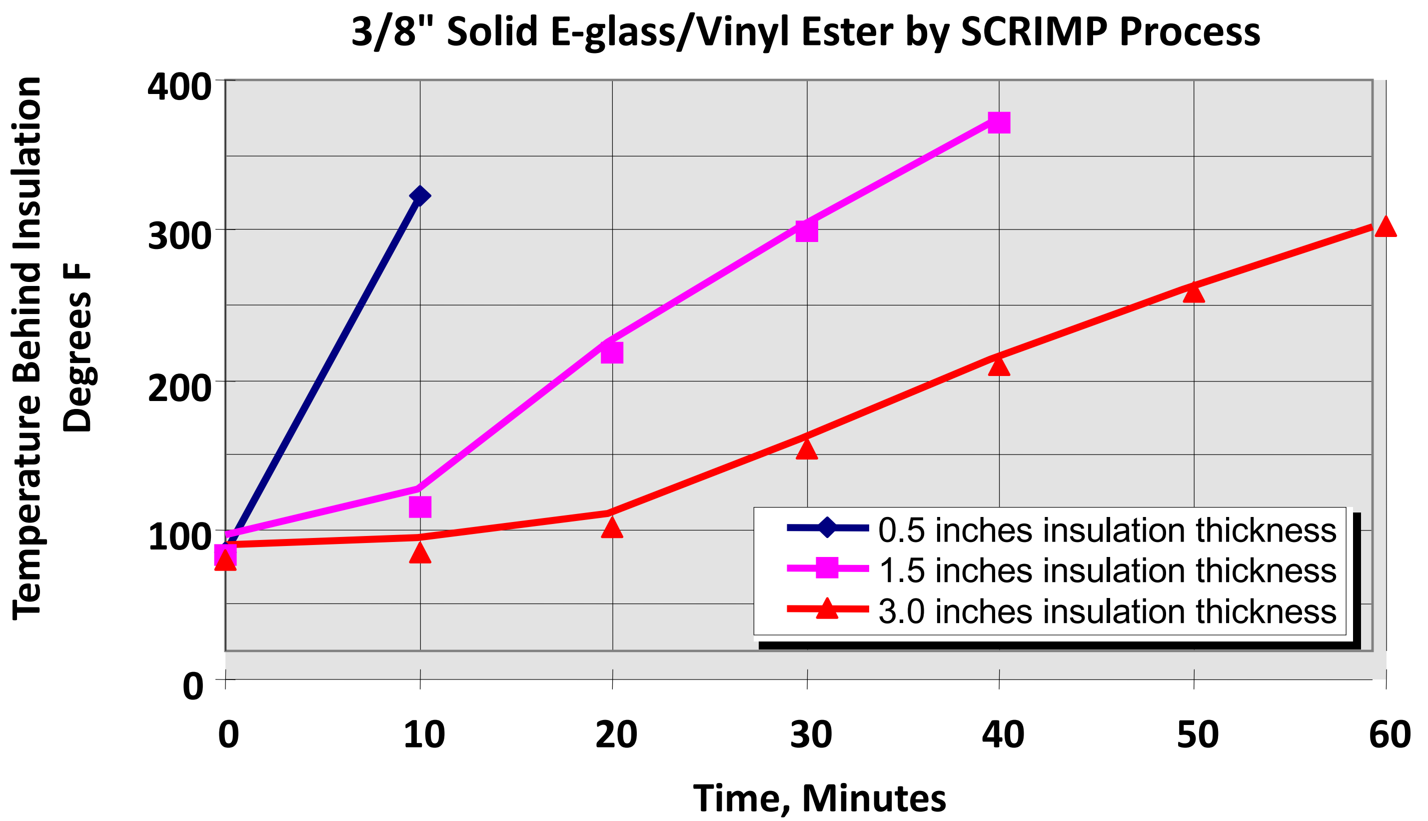


Structural fire protection attached prior to fire test

Johan Edvardsson, “Design and Production of Composites from the Ship-Industry point of view,” Lightweight Ship Conference, Karlskrona, May, 2008

Passive Structural Fire Protection

Structo Gard Insulation and E119 Fire Insult

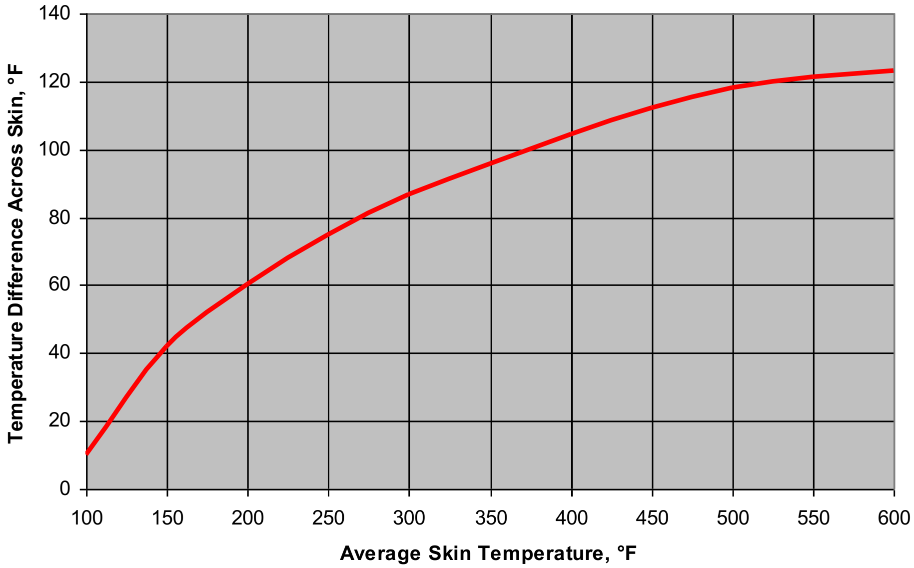


Conclusion: 2.5 inches of Structo Gard is required to keep composite under 200 deg F

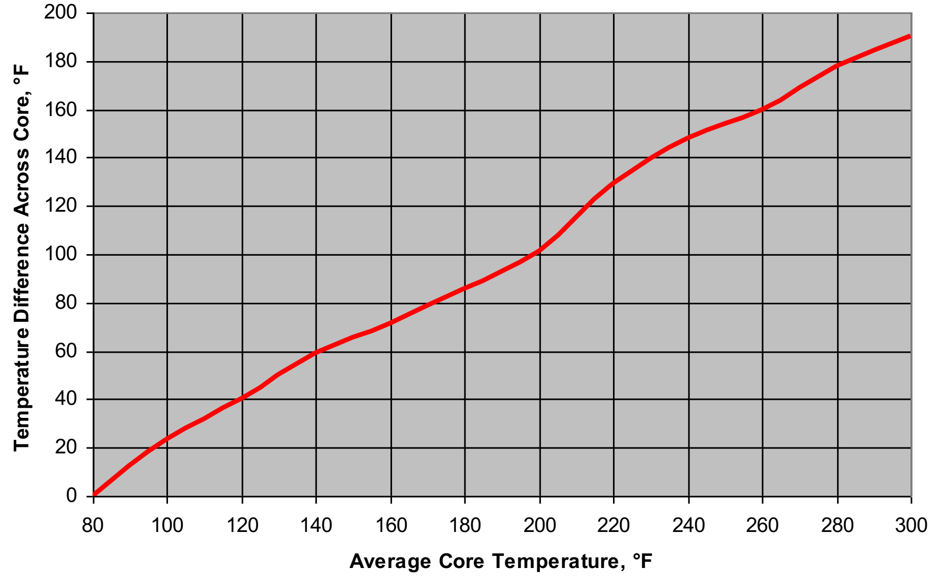
Rollhauser, C.M., "Development of a Fire Protection System for Vinyl Ester Composite Substrates," NSWCCD-TR-64-96/06

Thermo-Mechanical Performance

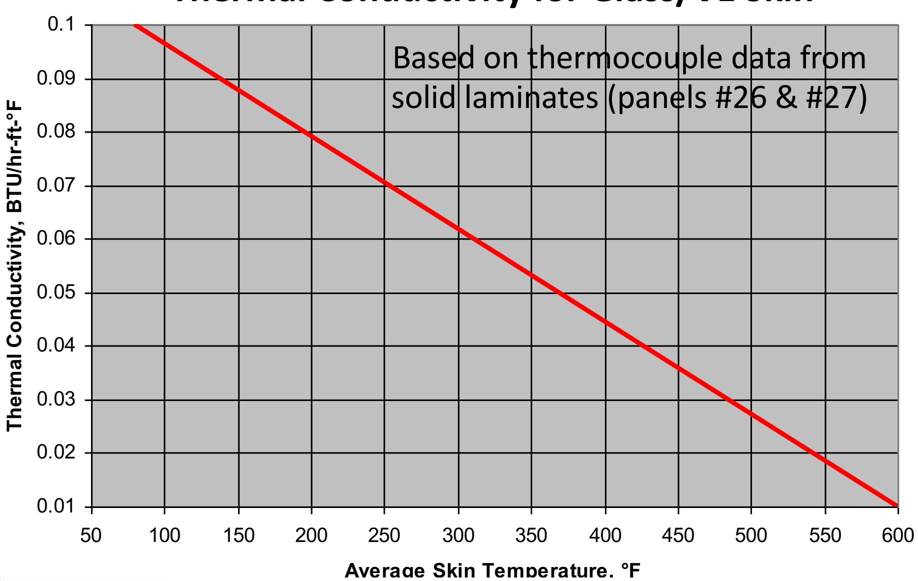
Temperature Difference Across 0.15-Inch Skin as a Function of Temperature



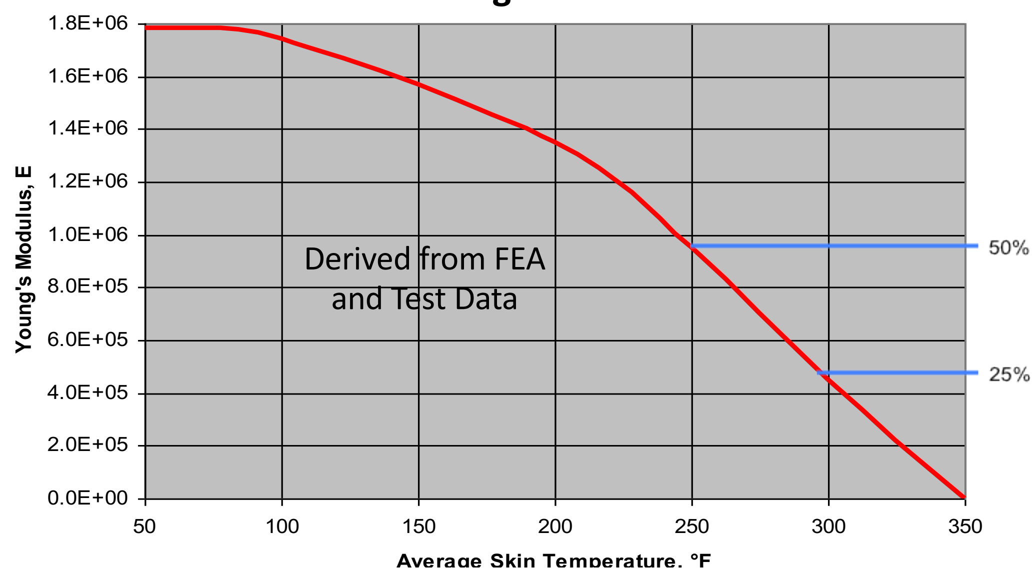
Temperature Difference Across 0.5-Inch Balsa Core as a Function of Temperature



Thermal Conductivity for Glass/VE Skin



Skin Young's Modulus vs °F

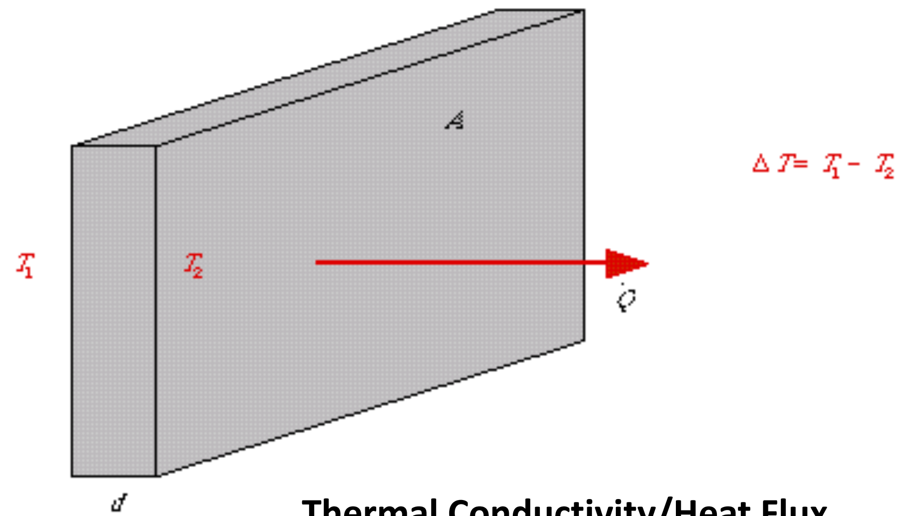


Thermal Conductivity

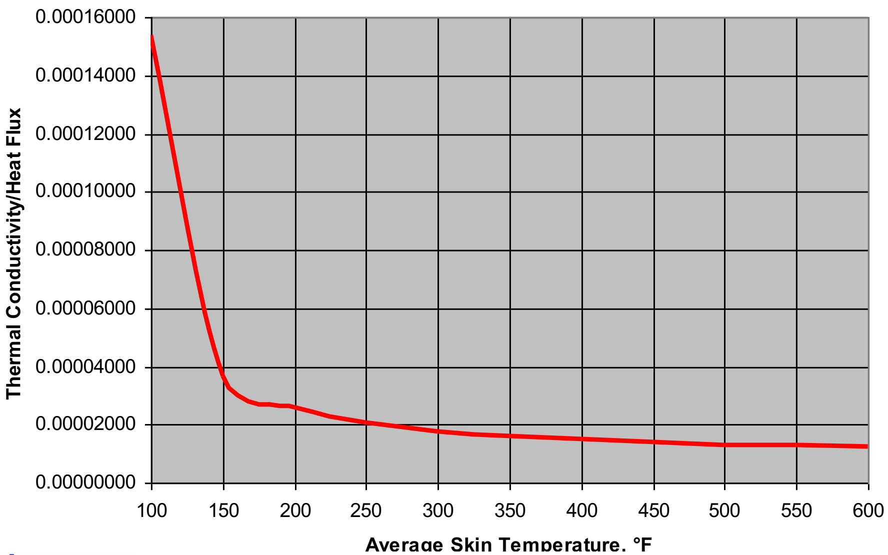
Heat conduction Q / Time = (Thermal conductivity) x (Area) x (T_{hot} - T_{cold})/Thickness

$$Q/t = (k*A*\Delta T)/d$$

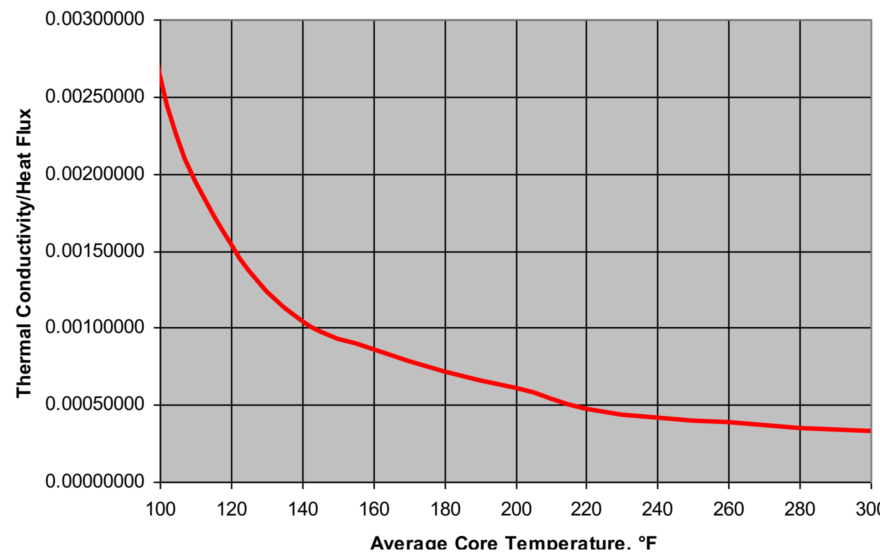
Q = heat transferred in time = t
k = thermal conductivity of the barrier
A = area
T = temperature
d = thickness of barrier



Thermal Conductivity/Heat Flux for Glass/VE Skin



Thermal Conductivity/Heat Flux for Balsa Core



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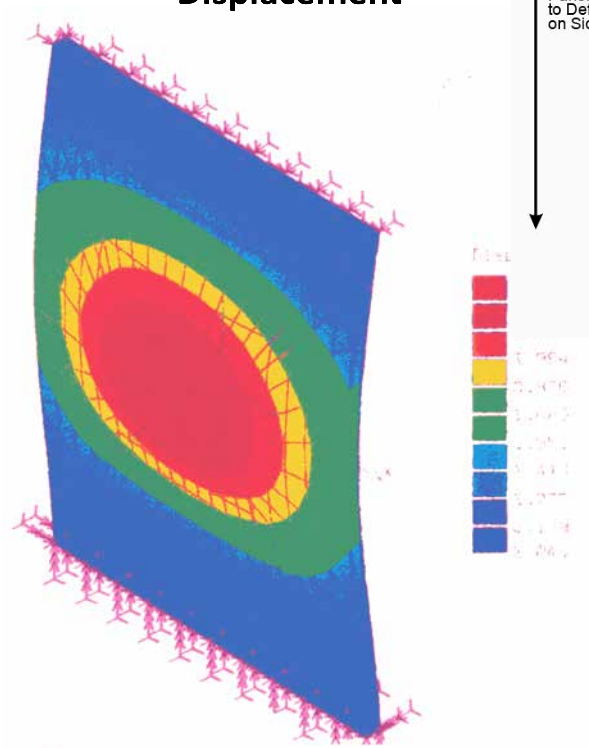
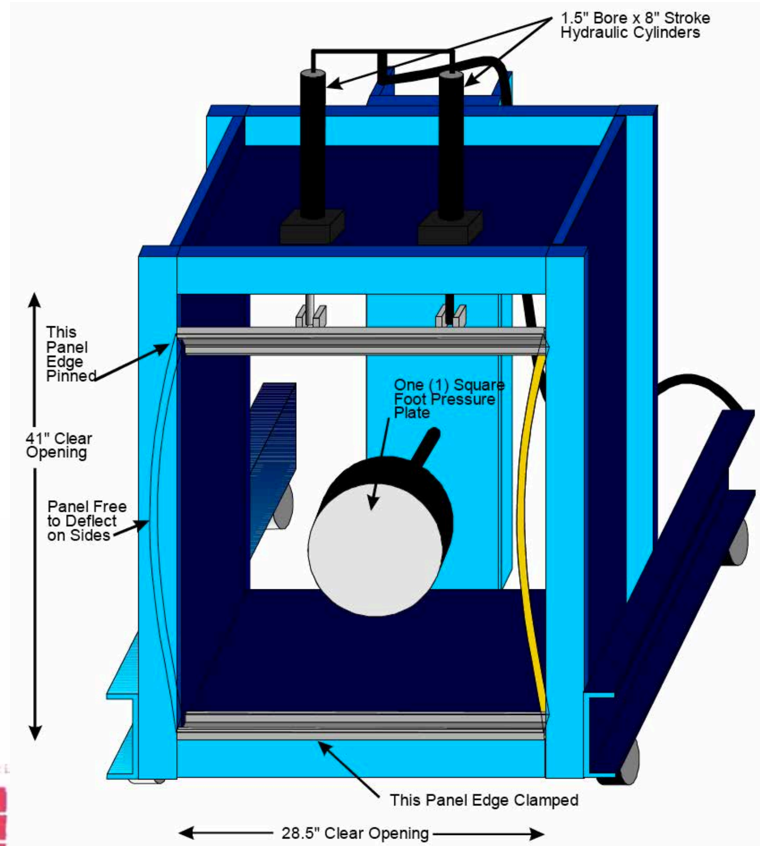
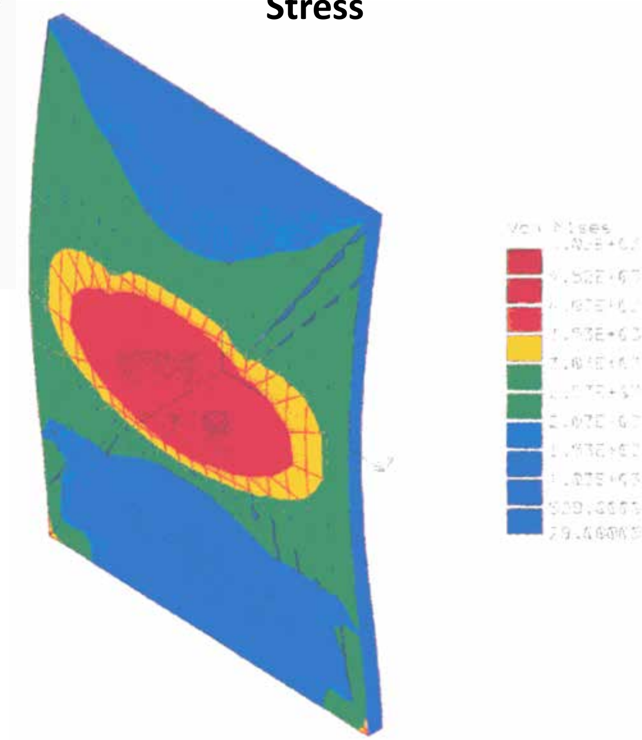
Thermo-Mechanical Testing

Displacement





Von Mises Stress



US Navy Submarine Fire Standard

MIL-STD-2031 (SH), *Fire and Toxicity Test Methods and Qualification Procedure for Composite Material Systems*

Fire Test/Characteristic		Requirement		Test Method
Oxygen-Temperature Index (%)	The minimum concentration of oxygen in a flowing oxygen nitrogen mixture capable of supporting flaming combustion of a material.		**Minimum**	ASTM D 2863 (modified)
		% oxygen @ 25°C	35	
		% oxygen @ 75°C	30	
		% oxygen @ 300°C	21	
Flame Spread Index	A number or classification indicating a comparative measure derived from observations made during the progress of the boundary of a zone of flame under defined test conditions.		**Maximum** 20	ASTM E 162
Ignitability (seconds)	The ease of ignition, as measured by the time to ignite in seconds, at a specified heat flux with a pilot flame.		**Minimum**	ASTM E 1354
		100 kW/m^2 Flux	60	
		75 kW/m^2 Flux	90	
		50 kW/m^2 Flux	150	
		25 kW/m^2 Flux	300	
Heat Release Rate (kW/m^2)	Heat produced by a material, expressed per unit of exposed area, per unit of time.		**Maximum**	ASTM E 1354
		100 kW/m^2 Flux		
		Peak	150	
		Average 300 secs	120	
		75 kW/m^2 Flux		
		Peak	100	
		Average 300 secs	100	
		50 kW/m^2 Flux		
		Peak	65	
		Average 300 secs	50	
		25 kW/m^2 Flux		
		Peak	50	
		Average 300 secs	50	
Smoke Obscuration	Reduction of light transmission by smoke as measured by light attenuation.		**Maximum**	ASTM E 662
		D_s during 300 secs	100	
		D_{max} occurrence	240 secs	

Russian Nuclear Submarine Fire

A shipyard worker set two fires on and near a nuclear submarine because he wanted to get off work

ORKLA Fire

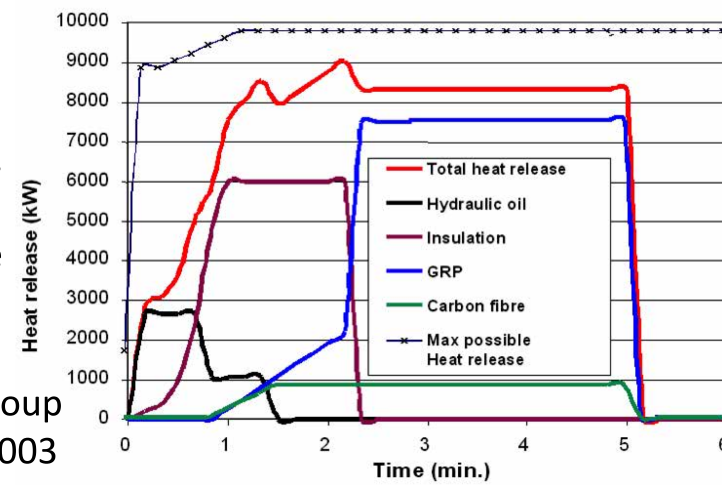
In November of 2002, a Norwegian minesweeper burned out of control after an "engine room fire" forced all 33 crew aboard to abandon ship. No one was seriously injured, but 11 sailors were treated for smoke inhalation. Seven sailors stayed on board to fight the blaze, but had to abandon ship after the fire flared up again. (initial report)

<u>Main basic causes</u>

1. *Lack of risk assessment when choosing design standard*. The lift fan room in itself was not considered a fire hazard by the project.
2. *Insufficient verification, inspection and monitoring.* The loss of firewater was the reason why the *Orkla* in reality was lost after only a few minutes.
3. *Inadequate trials and testing*. Adequate or relevant tests of among other things the fire water system were not carried out before the vessels were delivered from the shipyard.

"The fire on board the HNoMS *Orkla*," report from the Technical Expert Group submitted to The Norwegian Defence Logistics Organisation, September 2003

Heat release from the combustible materials in the lift fan room



Performance of Composite Materials in Fires

Parameter / Material	Flame Spread	Burn-Through Resistance	Structural Integrity	Smoke Production
Polyester Resin	Poor	Poor	Poor	Poor
Vinyl ester Resin	Fair	Fair	Fair	Fair
Epoxy Resin	Fair	Fair	Fair	Poor
Phenolic Resin	Excellent	Good	Good	Good
E-glass	Good	Excellent	Good	Excellent
Carbon Fiber	Good	Good	Excellent	Excellent
Kevlar®	Fair	Fair	Good	Good
Balsa Core	Good	Good	Excellent	Good
PVC Core	Fair	Fair	Good	Poor
Phenolic foam core	Good	Excellent	Good	Excellent

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Fire Performance Summary

- Fire characteristics of composite material systems are unique and require individual test methods
- Resin system overwhelmingly determines fire performance
- Small recreational boats currently have no structural fire protection regulations - sparks and fumes from gas engines biggest risk
- Megayachts need to be concerned with engine rooms, galleys, stairwells, and engine room ventilation systems
- Subchapter T Vessels must have ASTM E84 flame spread < 100; K Vessels can use fire hazard analysis or IMO High Speed Craft Code
- Naval structures must pass tougher 2000°F requirements
- Insulation blankets currently most effective method to provide structural fire protection