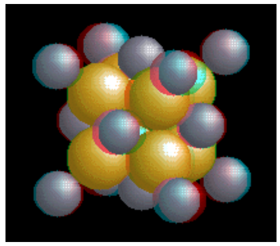
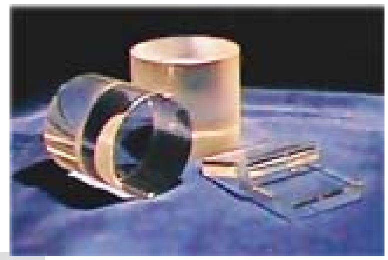

Infra Red Inspection Window Materials
The Way Forward:

9th November 2005

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Infra Red Windows Overview

WHY DO WE NEED INFRA RED WINDOWS?

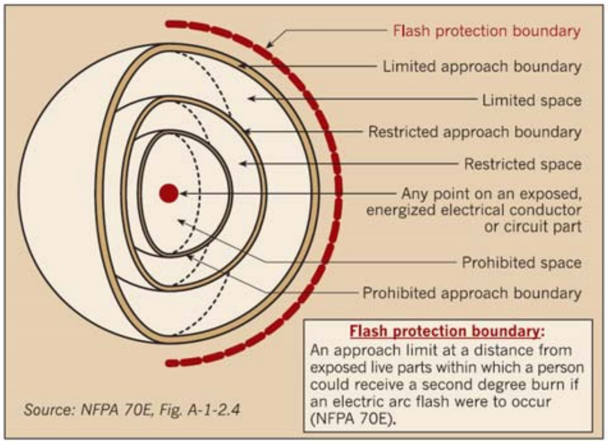
Infra Red cameras are based on digital camera technology and therefore require a direct-line-of-site to record an accurate image. Surveys are hampered by cabinet designs that obscure the target components being imaged and thermographers are put at risk by having to open cabinets or doors in an attempt to gain access to the internal components that they wish to image, even the most comprehensive risk assessments and method statements cannot avoid the obvious risks involved.

The use of Infrared Inspection ports is becoming more common place, in fact electrical panel manufacturers are now fitting Infrared inspection ports, grills, mesh screens, etc. in an attempt to make their panels infrared friendly.
Infra Red (IR) Thermography is the fastest growing predictive maintenance technology in the world today. The number of IR Equipment manufacturers has increased significantly over the last 5 years and just recently FLUKE has brought out 2 manufacturers to bring out its own range of IR cameras.

With this enhanced level of interest the IR market has become very competitive , which has had the effect of forcing manufacturers to reduce the price of their existing higher end IR cameras, and also to produce a range of entry level cameras that suit maintenance budgets (typically £5,000 - £7,000).

The largest market for IR Technologies is the US, where IR has been used for the last 20 years in the maintenance industry. However the US market has a regulation called the NFPA 70E which restricts access to live components by defining a series of boundaries relating to electrical safety when working on energized electrical equipment, these are:

- **Prohibited Approach Boundary**
- **Restricted Approach Boundary**
- **Limited Approach Boundary**
- **Flash Protection Boundary**



Source: NFPA 70E, Fig. A-1-2.4

Flash Protection Boundary.

The flash protection boundaries define the safe working distances in which any tradesman can operate from an energized component. Thermographers must be fully conversant with these regulations, especially if they intend to remove covers to allow access for a live inspection to be completed. Also the NFPA 70E regulations stipulate that unless the thermographer is a certified electrician and fully conversant and qualified on the equipment that he is inspecting they will need to be accompanied, thus increasing the manpower requirement for the inspection.

Voltage Flash Protection Boundary	
Up to 750 V	3 Feet
750 to 2 kV	4 Feet
2 kV to 15 kV	16 Feet
15 kV to 36 kV	19 Feet
Over 26 kV	Must be Calculated

Note:

- Arc flash does not happen without a trigger, it nearly always begins due to a "change of state" that causes even a momentary connection between phases
- 99% of the time this Arc Flash incidents are Caused by intervention/someone contacting components, etc… spontaneous arc flashed very rarely occur…
- Electrical circuits must be energized and loaded for effective IR inspections
- Higher Voltage = More Critical and greater hazard
- Some Organizations prohibit inspections of energized higher voltage equipment
- **IR windows are the alternative to doing nothing!**

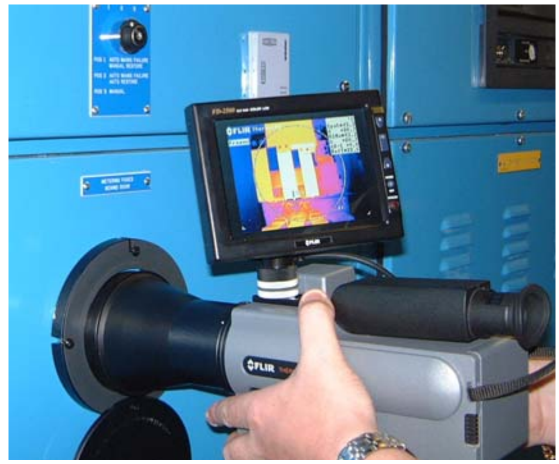
IR Windows remove the risks and costs associated with live inspections.

Their use in a thermographic inspection program removes 99% of the triggers of Arc Flash incidents whilst improving electrical safety by allowing safe, regular Infra Red inspections of energized and loaded electrical switchgear.

WHAT IS AN INFRA RED WINDOW?

A window is used to separate two environments of different pressure, temperature, etc., while allowing light at a specified wavelength to pass between the two.

An IR window should therefore have the necessary characteristics for the IR Equipment being used and fulfill the strength, rigidity and environmental requirements for the type of equipment in which it is fitted.



An IR window sounds more complicated than it really is, and although there are several types of window available on the market today, there is nothing stopping the thermographer from designing a window for use in any particular inspection that they may wish to complete.

An IR viewing window is basically an optic material that allows IR Energy to pass through it and a holder / body; thermographers may even decide not to use a crystal as the energized component that you are interested in is some distance from the cover and a protective grill can be used in place of the crystal, you however must ensure that the grill is IP2X certified, that is that the grill size must offer protection against foreign objects with diameters larger than 12mm. This method can significantly reduce the capital expenditure required and also has the additional benefits of allowing ultra sound inspections of the electrical switchgear as well as thermographic inspections.

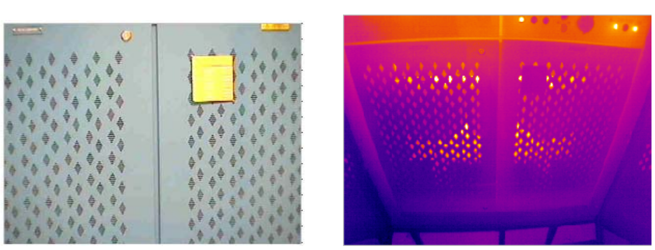
The optics holder design depends upon a number of parameters, the field of view, equipment lens and window size are all functions of the design and must meet all the parameters that the thermographer require before a holder is manufactured, also a protective cover should be included in the design as crystals are very expensive and in some cases extremely fragile.

ALTERNATIVES TO IR WINDOWS

There will be times when we will not be able to implement the use of IR windows and need therefore need to look at other methods to facilitate a direct temperature measurement.

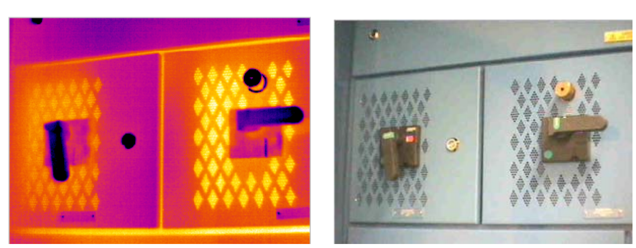
Screens and modified panel designs.

Some panel manufacturers have thought of this and included diamond lite covers, these are covers that have a series of holes drilled or punched into the cover and allow the thermographers to see the components inside the panel and take direct temperature measurements, the main issue with this type of panel is that it is very difficult to identify precisely where the high temperatures are, only that there is a high temperature, this however is better than indirect temperatures taken from the covers.



Transformer Covers

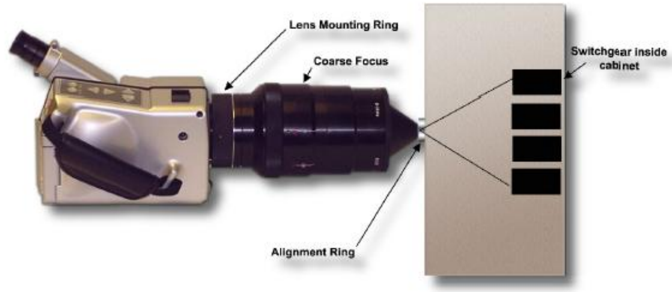
Panel Isolator Switches

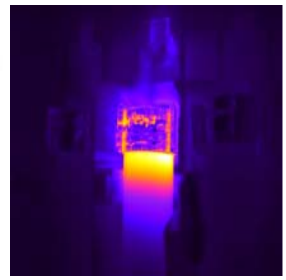


Specialist Lens Alternative.

There are also special lenses available that allow for images to be taken through a small hole drilled into the panel, the end of the lens has a small diameter (approx 16mm) and a wide FOV, the featured example “Spyglass” has a 53°H x 40°V (66° Diagonal) FOV and a focus range of 4” to 45”. This allows for components to be easily seen and does not have a detrimental effect on the structural integrity of the panel being inspected. The main downfall is that this lens is expensive and is only of use in sites where this type of IR window is fitted.

Spyglass Lens





CHARACTERISTICS OF MATERIALS

From the table below (Table 1) it can be seen that the materials vary considerably in material properties and points to other areas that have to be considered such as:

Environmental Considerations:
Is the window for indoor or outdoor use? Will it be submitted to severe environmental conditions? Such as:

- UV Exposure
- Humidity
- Rain
- Snow
- sea water
- acids or alkalis
- extreme temperatures
- Etc.....

Operational Considerations:
Some materials are less robust than others, the Knoop hardness number indicate the resistance to local penetration. Rugged materials such as Sapphire (Al2O3) have a high number; fragile materials like Barium Fluoride have a low number. Therefore operators must give serious consideration to the operating environments in which they intend to use IR windows as choosing the wrong material would be a very costly exercise!!

Material	Chemical Symbol	Wavelength µm	Reflection (Two Surfaces)	Knoop Hardness	Soluble in H2O
Calcium Fluoride	*CaF2*	*0.13 – 10*	*5%*	*158*	*Yes*
Sapphire	*Al2O3*	*0.15 – 5.5*	*14%*	*2000*	*No*
IR Polymer	*N/A*	*0.15 – 22*	*21%*	*N/A*	*No*
Germanium	*Ge*	*1.8 – 23*	*53%*	*780*	*No*
Zinc Selenide	*ZnSe*	*0.5 – 22*	*29%*	*120*	*No*
Barium Fluoride	*BaF2*	*0.15 – 12.5*	*7%*	*82*	*yes*

Table 1. IR material Properties comparison table.

Note

Manufacturers place too much importance on providing IR window material with a very high infrared transmittance value; more consideration must be given to the environmental and operational conditions in which the window will be used.

An IR window must be functional for the life of the panel in which it is fitted, therefore never trade off mechanical properties for higher infrared transmission rates, you don't need them, you do however want a window that lasts.

Listed below are the physical and chemical properties of Calcium Fluoride (CaF2) and Barium Fluoride (BaF2). These are currently the materials most used as infra red window optics.

As you can clearly see these materials are very fragile and neither is expected to withstand any kind of impact, and both materials are subject to thermal shock and BaF2 is the more sensitive of the two.

Both BaF2 and CaF2 are hygroscopic. However, in theory, we do think that either material could be left in some humid environments for a couple of years or more before any effect could be perceived. A protective coating may extend that time but as to how much exactly there is no evidence to even formulate a real guess. There may be none at all. At the same time, we know that submitting them to moisture is not good either of course, and long term substrate failure will occur.

In an industrial environment, we would not recommend BaF2 or CaF2 due to the fact of their fragility and sensitivity to energy impact.

Physical	**CaF2**	**BaF2**
Density	3.18 gm/cc	4.89 gm/cc
Melting Point	1360°C	1280°C
Thermal Conductivity	9.71$Wm^{-1}°K^{-1}$	11.72$Wm^{-1}°K^{-1}$
Thermal Expansion	18.85 x 10^{-6}/°C	18.1 x 10^{-6}/°C
Hardness	Knoop 158.3	Knoop 82
Specific Heat Capacity	854 J $Kgm^{-1}°K^{-1}$	410 J $Kgm^{-1}K^{-1}$
Dielectric Constant	6.76 at 1MHz	7.33 at 1MHz
Young's Modulus (E)	75.8 GPa	53.07 GPa
Shear Modulus (G)	33.77 GPa	25.4 GPa
Bulk Modulus (K)	82.71 GPa	56.4 GPa
Elastic Coefficients	C11 = 164 C12 = 53 C44 = 33.7	C11 = 89.2 C12 = 40.0 C44 = 25.4
Apparent Elastic Limit	36.54 MPa	26.9 MPa
Poisson Ratio	0.26	0.343

Chemical		
Solubility	0.0017gm/100gm water at 20°C	0.17g/100g water at 23°C
Molecular Weight	78.08	175.36
Class/Structure	Cubic (111) cleavage	Cubic CaF2, Fm3m, (111) cleavage

Explanation of Terminology Used for the Properties of Lens Materials:

THERMAL

Values are given for the thermal linear expansion, thermal conductivity, specific thermal capacity, thermal stability and fusion temperature of melting points.

Thermal linear expansion α_t deg C^{-1} characterizes the relative change in length of the sample at a change in temperature of one deg C. It is determined by the formula

$$\alpha_t = 1 / L \times dl / dt$$

Where **L** is the length of the sample and **t** is the temperature.

Average values of the thermal linear expansion coefficient are presented within the given temperature ranges. For optically uniaxial Magnesium Fluoride and Sapphire crystals, thermal linear expansion coefficients are given for directions parallel to and at right angles to the optical axis.

Thermal conductivity, W / (m•deg C), characterizes the capacity of the material to transmit heat and is determined by the amount of thermal energy that has gone through a unit area in a unit time at a unit temperature gradient. For Magnesium Fluoride and Sapphire crystals, thermal conductivity values are given in directions parallel to and at right angles to the optical axis.

Specific heat capacity, J / (kg•deg C), characterizes the energy necessary for heating the material and is determined by the amount of heat needed for warming the material by one degree. Data are presented for specific heat capacity at constant pressure.

Thermal stability, deg C, characterizes the capacity of the material to resist sharp temperature changes without destruction. The measure of thermal stability is the maximum difference in temperature in an abrupt change of the latter, which the sample can withstand without destruction.

Melting points are given in deg C.

MECHANICAL

Density, g/cm^3 is determined by the ratio between the mass of the sample and its volume. Reference data are presented for densities at room temperature and at normal pressure.

Moh hardness is a relative scale showing the capacity of a material to resist being scratched by another material. Reference values are presented for hardness according to the conditional Moh scale, in which 10 standard minerals are arranged in the order of increasing hardness (Talc, Moh=1 to Diamond, Moh=10).

Vickers micro hardness, Pa, is characterized by the resistance of the surface of the material to impression by the indentor in the form of a four-faced diamond pyramid at indentor load of 1Newton. Reference microhardness values are presented for optical uniaxial crystals of Magnesium Fluoride and Sapphire in directions parallel to and perpendicular to the optical axis.

Elastic properties are characterized by the ***constants of elastic compliance*** and by the technical elasticity characteristics: the ***Young modulus, Pa***, the ***shear modulus, Pa,*** and the ***Poisson ratio*** (coefficient of transversal deformation). The constants of elastic compliance are the proportionality coefficients between the stress and deformation components. The elastic properties depend on the crystallographic directions in which the stress and deformation are applied.
For cubic crystals, constants of elastic compliance S11, S12, S44 are given. This makes it possible to carry out transformation of Young's modulus and of the shear modulus in any arbitrary system of coordinates. It is also possible to obtain maximum and minimum values of the Young modulus and the shear modulus corresponding to the crystallographic directions <100> and <111>, as well as the Poisson Ratio.

For optically uniaxial Magnesium Fluoride and Sapphire crystals, six constants of elastic compliance are given, as well as values of the Young modulus and of the shear modulus for directions and faces parallel to and at right angles to the optical axis. Values of the Poisson Ratio are given for two possible positions. The first is used if the stress is directed parallel to the optical axis, and the deformation of the material under effect of this stress is considered in the direction of the plane perpendicular to the optical axis. The second is used if the stress is directed at right angles to the optical axis (in the case of a magnesium fluoride crystal in the direction at right angles to the face<100>). The deformation of the material under action of this stress, being different, is considered in two planes, positioned parallel and at right angles to the optical axis of the crystal. For polycrystalline materials isotropic Young modulus, shear modulus and Poisson ratio are given without regard to the possible effect of texture formation of the material.

CHEMICAL

The chemical properties of the crystalline materials are characterized by ***molecular weight*** and ***solubility***. The solubility of the material is inversely related to its resistivity against the action of aggressive media: water, acids and organic compounds.

CALCULATION OF WINDOW THICKNESS

Fragility increases proportionally to the ratio of the diameter to thickness. If thickness stays the same, as the diameter increases so does the fragility factor.

Minimum thickness of a window required to with-stand a pressure difference may be calculated by the following:

$$Th = \sqrt{\frac{1.1(P)(DIA)^2}{MR}}$$

Th = thickness, inches
DIA = unsupported diameter, inches
P = pressure difference, psi
MR = modulus of rupture, psi

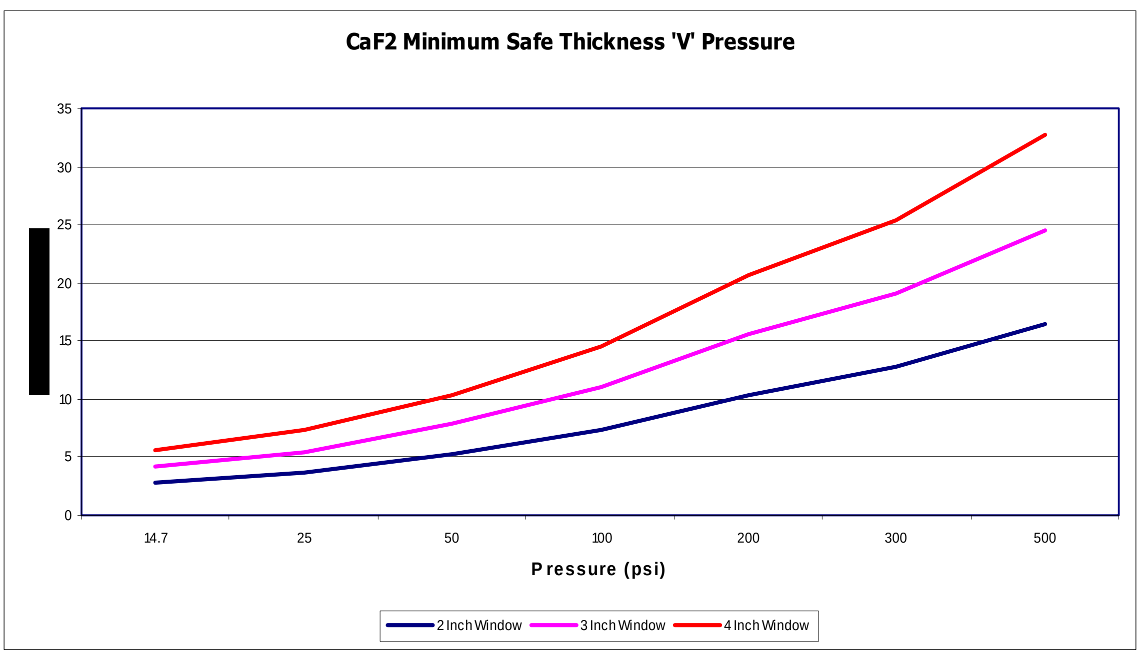
Pressure at 1 atm = 14.7 psi = 101.324 kPa

Modulus of rupture (MR, psi) of commonly used IR Crystals:

BaF_2	**3,900**
CaF_2	**5,300**
ZnSe	**8,000**
Ge	**10,500**
Sapphire	**65,000**

CaF2 window Minimum Thickness Requirement

Pressure Differential *(psi)*	IR Window Diameter *(inch)*	Minimum Required Window Thickness *(inch)*	*(mm)*
14.7	2.0	0.110	2.8
25.0	2.0	0.144	3.7
50.0	2.0	0.204	5.2
100.0	2.0	0.288	7.3
200.0	2.0	0.407	10.3
300.0	2.0	0.499	12.7
500.0	2.0	0.644	16.4
14.7	3.0	0.166	4.2
25.0	3.0	0.216	5.5
50.0	3.0	0.306	7.8
100.0	3.0	0.432	11.0
200.0	3.0	0.611	15.5
300.0	3.0	0.749	19.0
500.0	3.0	0.966	24.5
14.7	4.0	0.221	5.6
25.0	4.0	0.288	7.3
50.0	4.0	0.407	10.3
100.0	4.0	0.576	14.6
200.0	4.0	0.815	20.7
300.0	4.0	0.998	25.4
500.0	4.0	1.289	32.7



NOTE:

The minimum thickness of a CaF2 crystal to resist 1 atmosphere (14.7 psi) to be:
2 inch window = 2.8 mm 3 inch window = 4.2 mm 4 inch window = 5.6 mm

25 psi is the safety point where arc protected switchgear pressure relief devices are designed to work.
The minimum thickness of a CaF2 crystal at this point needs to be:
2 inch window = 3.7 mm 3 inch window = 5.5 mm 4 inch window = 7.3 mm

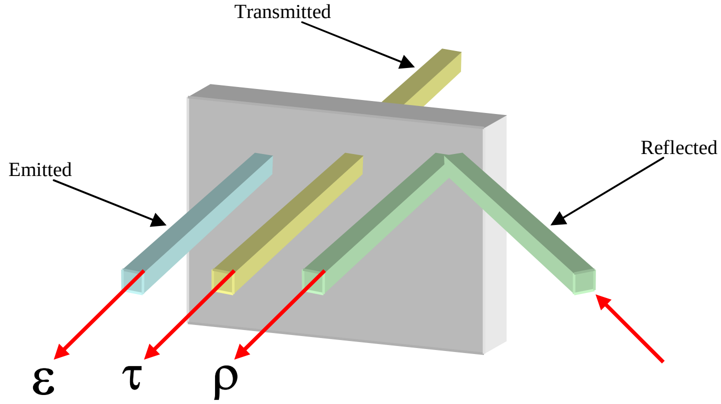
TRANSMISSION RATES

The ideal IR window is one that would allow all the infrared radiation to pass through it with zero losses, unfortunately with the materials available presently we cannot achieve the perfect transmission rate of 100%, we can get very close i.e. coated Zinc Selenide has a peak IR transmission rate of 99%.

Kirchhoff's Law states "the sum of the radiation leaving the surface of an object = 1"

We therefore have to try to keep emitance and reflectance values as low as possible to achieve as high a transmittance value as possible. This is achieved in a number of ways such as coating materials with an anti reflectance coating to reduce reflectance and choosing the correct material for the IR wavelength suitable for your camera. However a high transmission rate is not the most important property of an Infrared window, in fact there are many other issues that can have a very detrimental effect on the results gathered through infrared windows.

Kirchhoff's Law



$$\varepsilon + \tau + \rho = 1$$

The graph below demonstrates the transmission rates of the chosen materials and where they fall into the LW and SW infrared wavelengths, it can be seen that it is imperative that full consideration is given to the type of equipment being used as some materials will be unsuitable for use with a LW camera as is the case for Sapphire Al_2O_3, and SW cameras such as Germanium Ge.
Some materials are however suitable for use with both LW and SW cameras i.e. coated Zinc Selenide ZnSe, though these materials tend to be more expensive for that reason, and consideration must be given to the budget available as well as the technical and physical requirements of the required IR window.

Note
When deciding on the transmission rates of IR materials ensure that the supplier quotes against a known wavelength, our research has shown that in the PDM field the majority of LW thermography at approx 9 µm and SW at approx 4 µm, thus as a benchmark you should ask for the IR transmission at these wavelengths.

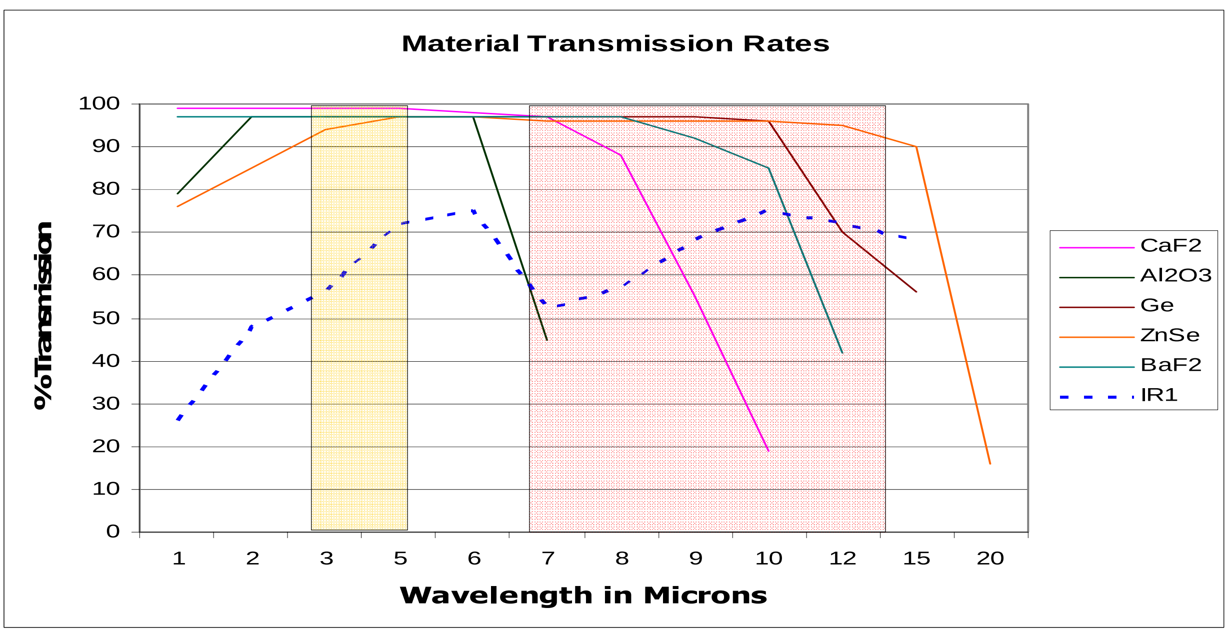


Chart 1. IR Material Transmission comparison chart.

The most important thing to remember regarding IR transmission rates is that you must know what the transmission rate and wavelength that your IR window is operating in. It is irrelevant to the measurement whether it is 99% or 50%, as the camera / software will calculate the temperature based on the transmission rate that you put into the calculation, therefore you must be confident that the transmission rate is correct.

The transmission V Temperature chart shows how calculated temperature readings change when you vary the transmission rates. The transmission rates were changed from 99% to 50% using the same image. This gave a difference of 11.8 °C.
The significant thing to note other than the temperature difference, is that the calculated temperature increases when the transmission rate decreases, therefore if your transmission rate is too high the calculated temperature is too low!, this will cause real problems if you are using temperature as the means of categorising faults or scheduling maintenance.

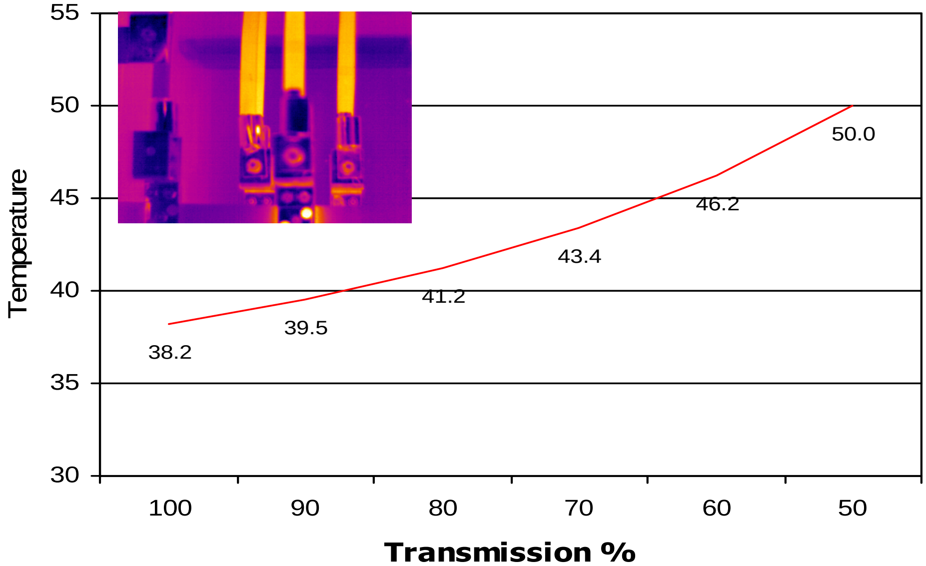


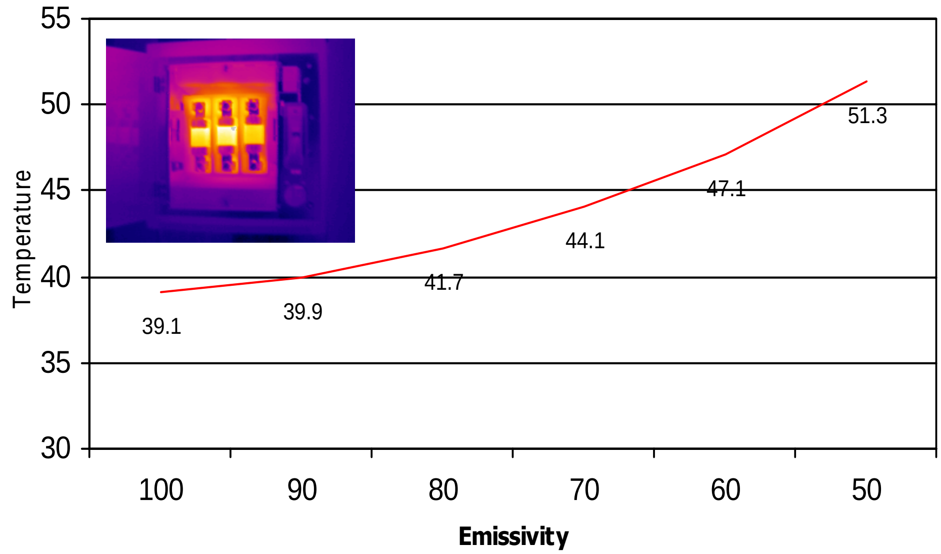
Chart 2. Transmission V Temperature chart.

EMISSIVITY OR EMITTANCE

The emissivity of an object is the ratio of radiant energy emitted by that object divided by the radiant energy which a blackbody would emit at that same temperature. If the emittance is the same at all wavelengths, the object is called a gray body. Some industrial materials change their emissivity with temperature and sometimes with other variables also. Emissivity always equals absorption and it also equals 1 minus the sum of reflectance and transmittance (E = A= 1 - T - R).

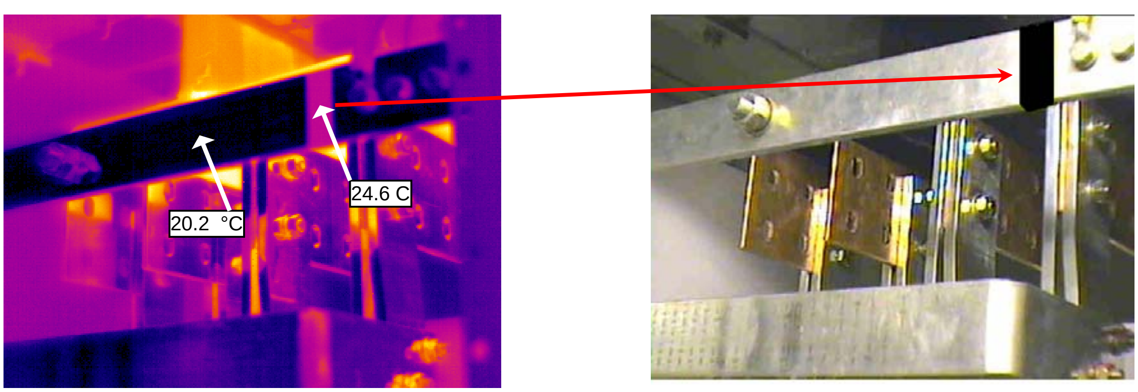
Electrical cabinets, etc are full of different materials of varying emissivity, they can range from .95 to 0.15 and as stated these values can change with age and temperature. The graph below shows, as with transmission, how calculated temperatures can be adversely affected if you get them wrong and, as with transmission, if your emissivity is too high the temperature is too low! Therefore it is imperative that the thermographer knows the emissivity of the target components within the panel, another method used by thermographers is to cover or coat all targets with a material of a known emissivity, i.e. electrical tape, bar-b-q paint, etc.

The graph below shows how calculated temperature readings change when you vary the emissivity rates. The emissivity rates were changed from 99% to 50% using the same image. This gave a difference of 12.2 °C



Note

Worse case scenario would be to get the emissivity and the transmission totally wrong, in the example shown above in chart 3, the temperature with emissivity and transmission set to 0.95 is 39.1 °C, if you now change both the emissivity and transmission settings to 0.50 the calculated temperature now changes to 73.6 °C an increase of 34.5 °C, almost twice the original apparent temperature, again just as with transmission, this will cause real problems if you are using temperature as the means of categorising repairs or scheduling maintenance.



Field of View

The window diameter needed is a function of the lens field of view and the distance from the window to the component in which the thermographer needs to see. Traditionally the total field of view is calculated by multiplying two times the distance by the tangent of one half the angle.

This illustration shows the area inside a cabinet that can be viewed through a 100mm IR window with an 82° FOV lens. A typical cabinet for an MCC panel is 20" deep, therefore:

D = 2d x 0.87
D = 40 x 0.87 = 34.8"
D = 2.9 Feet
D = 8.41 square feet

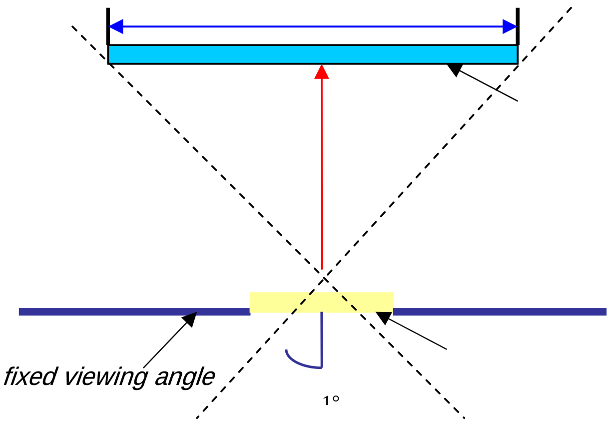


Figure 1. Standard Field of View calculation with fixed viewing angle

The calculations from figure 1 show that using an 82° FOV lens in a fixed plain that up to 8.41 square feet can be seen inside the panel, however during an inspection a thermographer does not hold a camera at a fixed angle and can manipulate a camera to various angles whilst looking through an IR window, therefore the field of view is substantially increased. We recommend that the camera angle of incidence where possible never exceeds 30 degrees from a perpendicular target which equates to increasing the FOV by up to approx 3 times although we recommend that if you need to work to extreme angles that you consider using wider angled lenses if possible.

Figure 2 below shows how the FOV is increased by multiplying the calculated FOV figure by up to 3 times.

Equal to two times cabinet depth or target distance

D = 40 x 0.87 x 2 = 69.6"
D = 5.8 Feet
D = 33.64 square feet

Equal to three times cabinet depth or target distance

D = 40 x 0.87 x 3 = 104.4"
D = 8.7 Feet
D = 75.69 square feet

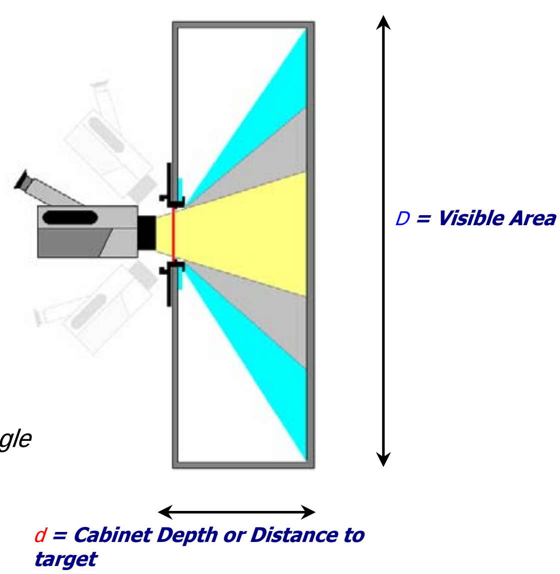


Figure 2. Standard Field of View calculation with no fixed viewing angle

Although these figures may look impressive, the operator must be aware that it is impractical to use a multiplication factor in excess of 3, as correlating the images to their actual positions within the panels, etc can cause problems and give poor results due to extreme angles, internal obstructions, etc. It is therefore advised that a maximum multiplication factor of 3 is used to maintain the image integrity and identifying any fault locations.

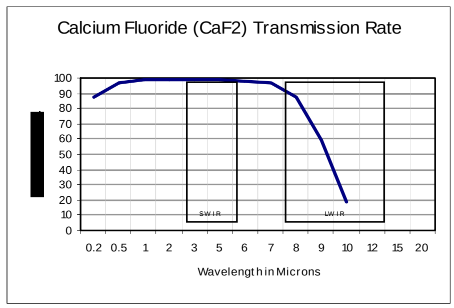
USING IR WINDOWS

An important point to remember when using IR windows is to identify the window with a unique number; this will be invaluable especially when you have multiple windows on electrical panels, etc. It is also advisable to identify the type and wavelength of the crystal.

The most essential data to record is the transmission rate of the crystal and also the emissivity of the component or components that you are measuring through the IR window, the most effective way of using IR windows is to, where possible, prepare all components that are inspected so as they have the same emissivity with electrical tape, paint etc, thus all components being inspected will have the same transmission rate and emissivity readings, consequently the results gathered will be more accurate.

It should be noted that there may be multiple targets through the IR window, these need to be recorded on the ID label, the most common method of locating the targets required is by using the clock face method, i.e. Bus Bar connections at 4 O'clock, etc. This data can all be placed on labels, examples of which are shown in figure 4.

LOCATION: MCC1 North Plant Room
IR WINDOW NO: No 2
LENS MATERIAL: IR Polymer
TRANSMISSION: SW 55% LW 68%
NOTES:
BUS BAR CONNECTIONS: 3 O'CLOCK: E = 0.95
BUS BAR CONNECTIONS: 8 O'CLOCK: E = 0.95



Location:
IR Window No:
Material: CaF2
Transmission: 55%
Notes

Figure 4: Samples of IR window ID labels

Instructions for Use:

Each IR window should be provided with the instructions for use, this will help inexperienced or new operators to use the equipment safely and within the design parameters laid down by the manufacturer and certification bodies.

An example of an instruction label is below; you can also use these labels to give contact telephone numbers, websites, etc…

IRISS VP100 INSTRUCTIONS FOR USE

UNDO ALL FOUR PROTECTIVE COVER LOCKING SCREWS TWO COMPLETE TURNS, AND SLIDE TOGGLE BOLTS AWAY FROM THE COVER.
ROTATE COVER ANTI-CLOCKWISE.
TAKE THERMOGRAPHIC IMAGE (REMEMBER TO RECORD DATA FROM IR WINDOW: LOCATION, TRANSMISSION RATE, ETC).
ROTATE COVER CLOCKWISE TO LOCATE COVER IN CLOSED POSITION.
SLIDE TOGGLE BOLTS INTO LOCATION GROOVES AND FULLY TIGHTEN ALL FOUR LOCKING SCREWS.

TEL: 1-800-555-1234 FAX: 1-800-555-4567 WEB: WWW.INFO@1111.COM

The use of information labels is a simple addition to assist a thermographer and give them all of the information that they require for the inspection with each individual inspection window.

Infra Red Windows
The Way Forward

CURRENT REGULATIONS

Currently there are no regulations specifically for Infra Red Inspection Windows.

All testing is completed to the current regulations that are in place for Viewing Panes, these are unfortunately inadequate for IR windows. The regulations need to take into consideration that IR window manufacturers must provide information to the thermographers who use them as well as complying with the construction regulation requirements for the switchgear in which they are fitted.

An IR window in itself is a simple device that is required to meet the construction requirements of the switchgear to which they are fitted; however as an IR device it is part of a far more complex inspection methodology, and the users of IR windows need precise easy to use information to ensure that the results gathered through them is as accurate as possible.

UL currently certify IR windows as viewing panes under the standards 508 & 508A, up to now they have been tested as a closed component with the flammability and impact testing only required to be completed on the window bodies (optics holders & covers). This standard has recently been revisited to test the actual optical materials being used, however, as this standard is still for viewing panes the crystals are at present exempt (if over 1.4 mm) and the impact and flammability requirement is only required on polyermeric materials. This standard is for switchgear up to 1.5 kV.

A very worrying fact regarding the current testing regime that UL has in place for IR windows is that they treat IR crystals as GLASS, this would be OK if the manufacturers of IR windows using crystal had to meet the minimum standards for thickness V pressure (as stipulated by the "Modulus of Rupture" see page 9) nevertheless they are exempt from this requirement because the regulations for viewing panes state that glass over 1.4mm is exempt from any form of impact testing!!, Flammability testing, etc… This is an area that requires immediate rectification as crystal can not take any form of impact and we are therefore producing IR windows with no structural integrity.

Above 1.5 kV IR window manufacturers can certify to IEEE requirements for Viewing Panes (IEEE standard C37.20.2, specifically the specification required for section A.3.6.) the standard which specifies that a transparent material covering an observation opening and forming a part of the enclosure should be reliably secured in such a manner that it cannot be readily displaced in service and should meet the following requirements:

Viewing panes should not shatter, crack, or become dislodged when both sides of the viewing panes in turn are subjected to:

- A force of 445 N (100 lbf) should be exerted perpendicular to the surface in which the viewing pane is mounted. This force should be distributed evenly over an area of 0.010 m2 (16 in2) (as nearly square as possible and as near the geometric center of the viewing pane as possible). If the viewing pane has an area less than 0.010 m2 (16 in2), the force should be evenly distributed over the entire viewing area. The 445 N (100 lbf) should be sustained for a period of 1 min.
- The viewing pane should be subjected to an impact of 3.4 J (2.5 ft-lbf) using a steel ball weighing approximately 0.54 kg (1.18 lb) and measuring approximately 50 mm (2 in) in diameter.

The IEEE test is competed at ambient temperature and is required for metal clad switchgear up to 36 kV and station switchgear up to 72 kV.

Other test that are completed on IR windows are to test the windows sealing ability, this standard is to ascertain the windows IP rating Type Rating or NEMA rating.

A word of warning about "NEMA" ratings:

UL uses the NEMA rating system. HOWEVER, a "NEMA" rating is a self declared rating as opposed to a UL "TYPE" rating which we obviously have to test, to verify the performance.
If a NEMA rating is marked on a UL Listed device we would ***require*** that the corresponding tests be conducted to verify that rating is met.

Environmental Type Ratings

Type	Intended use and description
1	Indoor use primarily to provide a degree of protection against limited amounts of falling dirt.
2	Indoor use primarily to provide a degree of protection against limited amounts of falling water and dirt.
3	Outdoor use primarily to provide a degree of protection against rain, sleet, wind blown dust and damage from external ice formation.
3R	Outdoor use primarily to provide a degree of protection against rain, sleet, and damage from external ice formation.
3S	Outdoor use primarily to provide a degree of protection against rain, sleet, windblown dust and to provide for operation of external mechanisms when ice laden.
4	Indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water and damage from external ice formation.
4X	Indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.
5	Indoor use primarily to provide a degree of protection against settling airborne dust, falling dirt, and dripping noncorrosive liquids.
6	Indoor or outdoor use primarily to provide a degree of protection against hose-directed water, and the entry of water during occasional temporary submersion at a limited depth and damage from external ice formation.
6P	Indoor or outdoor use primarily to provide a degree of protection against hose-directed water, the entry of water during prolonged submersion at a limited depth and damage from external ice formation.
12, 12K	Indoor use primarily to provide a degree of protection against circulating dust, falling dirt, and dripping noncorrosive liquids.
13	Indoor use primarily to provide a degree of protection against dust, spraying of water, oil, and noncorrosive coolant.

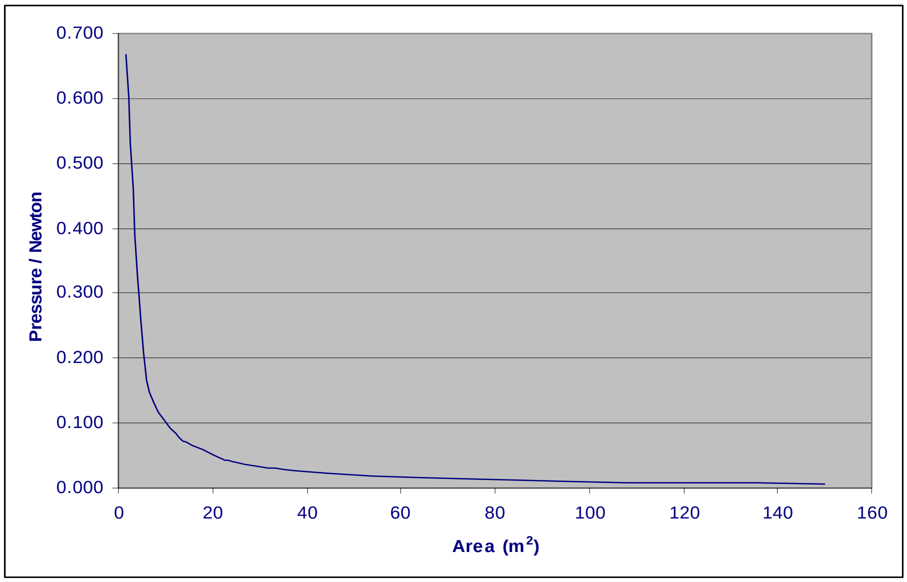
WHY CAN IR WINDOWS NEVER CARRY A GENERIC ARC RATING?

Electrical Switchgear comes in infinite shapes and sizes and as such the surface areas and volumetric elements of the cabinets are different with each model, type and rating.
Each cabinet is subject to the testing that is laid down by the certification bodies such as UL, IEEE, etc… This test is completed on the cabinet assemblies and when the testing is completed the compliance is awarded to the assembly, and not the components that make up the assembly.

A simple way of viewing this is to calculate the force that would be experienced on the surface of an electrical cabinet whilst undergoing an arc flash explosion test. The pressure exerted on a surface by a given force is determined by using the area over which that force acts. The formula to be used is;

$$P = F/A$$

This is a generic chart that shows how the area is related to the pressure.



Where:
P: Pressure in N/ m^2
F: Force in Newton's
A: Area in m^2

Note:
For the purposes of these calculations we are assuming that an Arc Flash explosion causes a uniform increase in pressure across the entire inside area of the chamber.
However you should note that pressure also increases with temperature and so in an explosion where temperature increases this would make these cases even more extreme, especially in smaller chambers.

Therefore for a given force x the pressure is inversely proportional to the area and hence as the area over which the force acts decreases the pressure will increase, this relationship can be seen in graph above. This shows that if the force or explosion remains constant but the chamber and hence the area gets smaller the pressure on each part of the chamber goes up according to the relationship shown.

Example:
The following four electrical cabinets have the following dimensions:

1x1x1 = Internal Surface Area **6m2**
3x1x1 = Internal Surface Area **14m2**
3x2x1 = Internal Surface Area **22m2**
3x3x1 = Internal Surface Area **30m2**

This shows that the internal surface of the1x1x1 cabinet is 5 times smaller than the 3x3x1 cabinet and would in the event of an arc incident of the same magnitude be subjected to 5 times more surface pressure than the 3x3x1 cabinet.

Electrical cabinet designs and dimensions are infinite and we therefore **CAN NOT** or **MUST NOT** use the data from one cabinet design to another design unless they are identical in every way.

This is the reason why components can never carry a generic arc rating and must be subjected to industry standard tests to confirm that they conform to the minimum required level of mechanical strength and environmental properties for the electrical cabinets and assemblies into which they are going to be fitted.

IR TRANSMITTIVE MATERIALS SUITABILITY:

As stated the vast majority of IR windows are using either Calcium Fluoride or Barium Fluoride crystals that are normally 2 – 3mm thick depending on construction and are normally provided in either 2, 3 or 4 inch diameters.

As previously stated and demonstrated these materials are not suitable for use in IR windows in industrial applications for the following reasons:

- CaF2 and BaF2 are not considered to be useful beyond 9 micron wavelength with BaF2 having a little better transmission after 9 micron
- Hygroscopic
- Barium Fluoride is a restricted material which carries a harmful classification
- Neither can take any form of impact
- Both have a high co-efficient of thermal expansion and will suffer long term substrate failure if submitted to transient temperatures.
- Fragile
- Sensitive to Energy Impact (Vibration & Noise)
- Sensitive to Thermal Shock
- Both have a low "Modulus of Rupture" to fragile to maintain pressure ratings.

- **CaF2 & BaF2 WILL FAIL EVENTUALLY (Test data confirms their weaknesses)**

The most suitable crystal for use in IR windows is Germanium with an Anti-Reflective coating on the inside and hard carbon on the outer side. Ge performs as well as Zinc Selenide in this circumstance and is a lot less expensive. Ultimately, the best combination is ZnSe with an Anti-Reflective coating one side and hard carbon on the other. This is however rarely used due to pricing versus performance overall.

The most suitable material for industrial applications is Infra Red Transmitive Polymer is has a transmission rate of 68% at 9 microns which out performs the traditional calcium fluoride window and is flexible therefore is not as susceptible to thermal shock and fracture due to impact. This material recently passed the IEEE Impact test and survived with no issues. It is rated to a working temperature of 325 °C (although we state a maximum temperature of 100 °C for IR Window use)

With regards to the material durability the manufacturer testing shows that:

- It offers the least absorption loss in the 8 to 14 µm region of any of the IR polymer materials.
- Excellent transmission rates through both the LW & SW IR wavelengths, easily out performing CaF2 at 9 microns: CaF2 = 55% IR1 Lens Assembly = 68%
- Impact tested to IEEE standard C37.20.2, for viewing panes.
- Impact Tested to UL UL746c, section 56 in the GM Tech IR 1 Lens Assembly
- Flammability rating of 5V in the GM Tech IR 1 Lens Assembly
- Waterproof
- Resistant to Light Acids & Alkalis
- ultraviolet stabilized,
- It has a lifetime of many years in full sun. We have yet to establish an exact lifetime, though material which has been on the roof for two years (In a rooftop testing facility in the full Texas sun) shows no significant UV degradation in either infrared transmittance or physical properties. We also know of at least one instance of a PIR lens array in a passive infrared motion detector that has been used outdoors in Texas for approximately 15 years without a noticeable decrease in performance. (this is on material that is unprotected with full exposure to the elements, our IR1 lenses are totally enclosed within the IR window body)
- **LOW COST** makes it easily affordable and therefore increases the likelihood of implementation.

PROPOSED REQUIREMENTS FOR IR WINDOW ASSEMBLIES:

UL & IEEE test requirements for viewing panes are very thorough and fine for using as a benchmark for the framework of the test requirements for IR windows, we must however realize that there are very few IR transmitive materials available to IR window manufacturers and as such full consideration needs to be given to this fact when attempting to set the minimum requirements to fulfill the safety requirements.

IR Windows are a risk management device, they allow IR inspections to be completed live safely with no interruption to process, and as such will allow for more inspections to be completed and reduce the risk of equipment failure through routine monitoring and predictive engineering techniques.

The following are a recommended minimum requirement for an IR window:

NOTE: IR Windows should not crack, shatter or dislodge during any of the proposed impact or load testing.

1. **All IR windows should undergo an impact testing to a UL746c, section 56**
   - After conditioning at 0° C for 3 hours, an impact of 5 foot-pounds is applied front and rear of the window

2. **All IR windows should undergo a front and rear load test as per IEEE standard C37.20.2, specifically the specification required for section A.3.6.**
   - A force of 445 N (100 lbf) should be exerted perpendicular to the surface in which the viewing pane is mounted. This force should be distributed evenly over an area of 0.010 M^2 (16 in^2) as nearly square as possible and as near the geometric center of the viewing pane as possible. If the viewing pane has an area less than 0.010 M^2 (16 in^2), the force should be evenly distributed over the entire viewing area. The 445 N (100 lbf) should be sustained for a period of 1 min on the front and rear of the window.

3. **All IR windows in switchgear above 1.5 kV should be able to pass a 5 Inch flammability test.**

4. **All IR windows should have fixed covers (i.e. the cover should not be able to be removed by removing a screw, etc...)**

5. **All IR windows should fail safe.**
   - In the event of a failure of the lens the maximum opening within the panel should not exceed the requirement for IP2X

6. **All IR windows should be able to maintain a minimum of 25 psi.**
   - As per the "modulus of Rupture"

7. **All IR windows should be tested for functionality to ensure that they are suitable for the task and perform as specified by the manufacturer**

8. **UL should test the IR transmitive materials during the regular 3 month inspections at the manufacturers for actual IR transmission rates.**

9. **Where IR windows use grills, or inspection orifices they must comply with IP2X (13mm 0.5") and clients must be made aware of the safe dialectric clearances for the type of switchgear that they intend to install the window into. IEEE C37.20.2 table A.3 has minimum distances from live components and it is recommended that these be considered as a standard for grills / inspection orifices.**

Rated Maximum Voltage kV	Clearance	
	In	cm
4.76	5.5	14
8.25	6.5	17
15.0	8.0	20
27.0	12.0	30
38.0	15.0	36

PROPOSED REQUIREMENTS FOR IR WINDOW MANUFACTURERS:

IR window manufacturers have a duty of care to their clients to provide them with all the relevant details regarding the IR window materials that they are using and as such should as a minimum requ9irement provide the following information:

1. **Industry standard needs to be set for quoting transmission rates of IR materials, manufacturers must be made to come into line and not try to use IR transmission as a means of confusing the customer in an attempt to gain market advantage. We therefore suggest that the transmission rates of materials are quoted against:**

   Short Wave IR wavelength = 4 Microns
   Longwave IR wavelength = 9 Microns

2. **IR windows must be provided with instructions for use labels**

3. **IR Windows must be provided with a label system that identifies the material in the window and the IR wavelength in LW & SW IR.**

4. **IR Window manufacturers must provide MSDS on all substances in the assembly as per current regulations**

5. **All IR window manufacturers are to cease manufacture with Barium Fluoride due to its restricted and hazardous status.**