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WHITE PAPER: LOOKING DEEP INTO OPTICAL FLAME DETECTORS

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Introduction:

Optical flame detection is a developing component of the fire safety industry, emerging from the high risk, high value sectors of oil, gas, mining, chemical storage, and industrial painting/powder coating industries. Optical flame detectors fill in the role of fire detection where smoke detection and other more conventional methods are insufficient, such as those requiring: high speed (from seconds down to milliseconds- as opposed to minutes required by a smoke detector or fire sprinkler), high ceiling or in outdoor spaces, and where highly flammable materials are stored or processed. Optical flame detectors accomplish this by instead detecting flame/fire directly though the emission of light from the fire, and by a combination of spectral, temporal, and spatial analysis of flame/fire sources. In this paper, we will discuss several of the most common approaches to optical flame detection and their challenges in: false alarm discrimination, reliability in common and extreme conditions, and capability to detect at great distance.

Although there are hundreds of existing products in the market, each utilizing different configurations of sensors, windows, optical filters, electronic filters, and fire detection algorithms within their software, in the vast majority of cases their performance and behaviors can be categorized by their sensor types. Those being:

UV- Flame detection using only UV light emitted.

Multi IR- detection using 2 or 3 infrared detectors.(typically denoted as 2IR/3IR)

UV + IR- detection using a UV sensor in conjunction with IR sensors.(denoted at UVIR/UV2IR/UV3IR)

UV + Vis/Near band IR- using a UV sensor together with Visible light and/or near IR sensor (UVvis, UVNIR)

1. Defining the Performance of Optical Flame Detectors:

For a life safety device, the primary performance metric is reliability.
For Flame detection that is:

1-The ability to reliably detect fire when fire is present. Which can be tested to varying requirements (distance/weather/etc) but typically qualified by an ability to declare an alarm (switching the alarm relay) within 3 seconds. This will be expressed as the percent of test cases where an alarm is declared within the required seconds after exposure to fire, unless otherwise specified.(minimum 10 test cases, 3 detectors at a time.)

2- The ability to ignore other radiant light as false alarm sources (False positive). This will be expressed as a percentage of test cases where the alarm is declared in the presence of a false alarm source, after being exposed 5 feet from source for 10 minutes.(minimum 5 test cases, 3 detectors at a time)

3- The ability to detect fire despite the presence of a false alarm source (false negative). This test is conducted immediately after the false alarm test. After exposing each set of detectors to a common false alarm source, for 5 minutes prior, the device is exposed to a true fire source, allowing the false alarm source to continue through the duration of the test. The reliability is measured as a percent of test cases where the detector reported an alarm during the 3 seconds after exposure to a fire, as per normal function. The test is not conducted for scenarios where the false alarm has already triggered. This test was only conducted for some false alarm sources due to the hazard presented by conducting a live test in some of the false alarm scenarios. (minimum 10 test cases 3 detectors at a time)

4- The ability to recognize faulty optics/sensors (false negative). This is tested in several ways, and measured by the percent of test cases where the device senses a fault in the optics/sensors after completing 5 self-test cycles, and a full 24 hours of operation, with an electronic monitor recording the time till fault declaration. (minimum 3 test cases, 1 detector at a time)

The first test method is to block the window by orienting the optics facing vertically, and applying 10 seconds of spray from an airbrush with a wide opening nozzle containing dust, dirt, salt and mineral oil. To ensure consistency across tests, the same verification is also done instead placing a polyethylene film laminating a layer of dust and salt, which is measured via light meter to absorb roughly 50% of visible light transmission, atop the lenses.

The second method is to replace the sensors with resistors of the same value, or by replacing them with faulty or out of specification sensors of the same type, depending on availability. This test is to ensure that not only the optical path but also the electronic diagnostics function to warn the user if the device is unable to sense a fire when it is needed to.

1.1 Flame Detector Performance Chart by Category:

DETECTION OF FIRE

SENSOR TYPE	40 m (131ft) 30%RH2	40 m (131ft) 95%RH2	65 m (213ft) 30%RH2	65 m (213ft) 95%RH2	90 m (295ft) 30% RH2	40 m (131ft) @85C in 15secs	40 m (131ft) w/ Sunglare3	40 m (131ft) with Modulated Blackbody	40 m (131ft) w/ shimmer reflections	40 m (131ft) w/ brushed motor /generator
UV	100%	100%	20%	20%	10%	100%	100%	100%	100%	false alarm
UV (HS) 1	100%	100%	100%	100%	100%	100%	100%	100%	100%	false alarm
2IR	100%	70%	0%	0%	0%	10%	50%	false alarm	false alarm	100%
3IR	100%	80%	0%	0%	0%	10%	60%	false alarm	false alarm	100%
3IR(HS) 1	100%	100%	90%	10%	0%	50%	20%	0%	false alarm	100%
UV+ VIS/NIR	100%	100%	0%	0%	0%	50%	90%	90%	60%	100%
UV2IR	100%	100%	50%	0%	0%	10%	100%	80%	100%	100%
UV3IR	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

(HS)1- some devices are set to a high sensitivity mode/specialized versions to maximize detection range.
RH2 -measured at ~30C, 1atm. Absolute humidity, (kg/m3): 0.009, 0. 030 respectively.
Sunglare3- Device pointed towards sun during test. (25 degrees from horizon and flame

1.2 The Unexpected Common-ness of False Alarm Sources:

False Alarms are a topic usually avoided in the sale's pitch of a device, but it is something customers and engineers must absolutely take seriously. Different approaches have resulted in varying strengths and weaknesses.

UV only devices are susceptible to UV sources, such as electric brushed motors/generators, halogen lights, even neon and fluorescent lights which have worn through the UV protective inner layer of the bulb. Some devices can claim "immunity" to welding and other sources of extreme UV output, but again fail if the welding or UV source is sufficiently far away that it appears in line with the UV output of a fire. Older generation flame sensors using the "paperclip style" sensors are also prone to false alarm due to vibration alone, and can even be permanently damaged during regular shipping. With only one dimension to the sensing capability, UV only devices are notoriously false alarm susceptible, albeit often the most affordable option.

IR2 and IR3 devices in recent years have sought to improve on this by identifying flame by its spectral characteristics. When a carbon containing fuel combusts, the hot CO2 emits very strongly in the mid-infrared around a narrow peak centered at 4.3um, and when a hydrocarbon or other hydrogen containing compound burns in a way that releases water vapor there is a broad peak centered at 2.8um. IR only detectors often contrast one of these peaks to a reference off-peak band to single out fire based on the ratio.

This however is not fool-proof, as any hot object, including most non-LED lighting, emits in these wavelengths to some degree- as does the sun, exhaust pipes, smoke stacks, combustion engines, electric engines that are running hot, even human beings. These detectors of course do not alarm to people normally. IR2/IR3 detectors, at least in the recent generations, have focused on the frequency, ratio and flux of incoming light to rule out false alarms. Flames unlike other sources tend to fluctuate around 4-8Hz, and are not precisely periodic as artificial sources, such as motors and lights, but this too is not always enough.

When there is sufficient background heat and noise, IR2/IR3 detectors can often fail to alarm in the presence of fire, since the ratios of incoming light are all washed out, this sort of false negative is one of the major drawbacks to an IR only device, although less so for a 3IR device than a 2IR one. In some cases, sufficiently random slow fluctuations of light can put them into alarm as well, this kind of false positive is dramatically less likely with an IR3 device than an IR2. Industry insiders often use warm hands waving in front of the device to test the worthiness of the device. To discriminate against this, the sensors must be able to detect both low and high frequency light flux. Here, sensor selection is key. More on this in page ***8.***

The "best of both worlds" is best achieved through a combination of UV and mid-IR. Notable contenders are UV + Visible, and UV+ Near infrared, which are dramatically more cost effective to build. In these devices, strong Near IR, non-fire band Mid-IR, and the absence of UV are rejecters of false alarms. It is extremely rare for both UV and 4.3um light to be present while non-fire emission bands are not—unless it is a real fire. Detectors using UV and 2IR are sufficient for 90% of applications. However, for the same reasons the 3IR is superior to 2IR, UV3IR is superior to UV2IR.

1.3 False Alarm Immunity

FALSE ALARM IMMUNITY

SENSOR TYPE	MODULATED BLACK BODY (SEE NOTES)	HALOGEN LIGHT FLICKER	SODIUM-VAPOR LIGHT FLICKER	WELDING	ELECTRIC BRUSHED MOTOR/ GENERATOR	LIGHT SHIMMER OVER WATER	HOT SMOKE STACK	VEHICLE EXHAUST	SUNRISE CRESTING HORIZON
UV	100%	10%	10%	0%	0%	100%	90%	100%	100%
UV (HS) 1	100%	0%	10%	0%	0%	100%	70%	100%	100%
2 IR	10%	0%	70%	100%	100%	20%	20%	70%	80%
3IR	90%	80%	80%	90%	100%	90%	80%	90%	90%
3IR(HS) 1	30%	50%	60%	90%	100%	80%	60%	80%	90%
UV+ VIS/NIR	100%	80%	80%	90%	100%	100%	70%	100%	100%
UV2IR	100%	100%	100%	90%	100%	100%	90%	100%	100%
UV3IR	100%	100%	100%	100%	100%	100%	100%	100%	100%

1.4 Other features to consider

Enclosure material: Depending on the environment detectors can come in aluminum or steel, with various paints and coatings. For maritime use, stainless steel 316 is recommended for its high chemical resistance. Additionally, powder coating over this can add an extra layer of defense. However, it should be noted that for a powder coating to adhere, the surface must be rough with iron exposed. And thus if the powder coating is damaged, the underlying surface can become a nucleating point for corrosion which causes further lift-off of coating material. Alternatively, a nitric acid washed part, polished to mirror shine presents a hard chromium oxide super smooth surface, which if scratched, does not propagate the point of corrosion. This is especially useful in environments where aromatic organic compounds are present in oil sprays, which slowly dissolve some powder coatings.

Wiring compartment Design: While working in the field, certain facilities require that no electronic components be ever exposed to the environment. This again splits the detectors up into categories. If installing a device that does not have separate and explosion proof electronics compartment from the wiring compartment. Some facilities may have to be shut down to de-escalate the hazard level during installation. This could mean thousands or even millions of lost revenue, and thus in many applications becomes a required feature. Additionally, it is important to consider the mechanical ease of use by the installer. Especially considering the size of hands, wearing of thick gloves, and the situation where installers must work high above the ground precariously balancing atop a ladder. Easy wiring access is again an imperative feature often overlooked in detector design.

Conduit gland positions: continuing with ease of use design features, it is also useful to note that many facilities will want to save on wiring costs by daisy chaining devices as well as using conduit pipes to carry other wires besides those used for the device. For this reason, multiple entry points are often a feature in detectors. Keeping those conduit glands lined up in a way that allows wires to be drawn though easily is a small but useful design feature for installers.

Accessories: In addition, special use cases may require the use of accessories. In a remote location, a solar panel and battery for off grid use may be useful. When there is an intentional flame present, such as with flare stacks or furnaces, a shroud to modify the field of view can be useful, and in extreme heat, such as in the desert, a weather shield can reduce the device operating temperature from the ambient by as much as 10°C. It is important to have a flexible set of accessory and mounting options for the future development of any product, which allow the enhancement and modification of a products capabilities, without having to replace it.

2. Type of sensors: Their reliability as determined by their physical and optical properties

2.1 Vibration and UV sensors

UV detectors, despite their false alarms, are often the most cost-effective flame detector because of their simplicity of design and low component cost. This makes them very attractive solutions for cabinets, closed indoor rooms with seemingly no false alarm sources. This however can sometimes be a source of endless nuisance alarms, if the detector is placed in an environment with high vibrations, such as an engine room, or compressor station. Here, the problem lies with the sensor selection. Not all UV sensors are vulnerable to vibration, but the fact is that most are, because most UV devices utilize the “paperclip” style UV sensor, which is the useful sensor for this application. Pictured below, this type of sensor is made up if a plate of nickel tack welded to a long wire and another wire bent to a spiral set at a parallel plane just a small distance apart from the plate. These two wires are then charged up to several hundred volts of potential between them. When a UV photon collides with gas between the plates, or with the plate itself through photoelectric effect, an electron can be dislodged which depending on where it is carries some chance to be drawn toward the opposite electrode with sufficient force to cause an avalanching breakdown, and spark between the two electrodes. This process is highly dependent on the distance between the electrodes. Too far and the gap cannot be bridged and the avalanching fails to discharge in a detectable way. Too short, and there is no light needed to cause the spark and the UV detector goes into a false alarm.

"8-Posted Grid"	"Dome & Hook"	"Paperclip" UV detector
The most expensive of the sensors because of its difficulty of manufacturing and small production quantity. It is extremely resistant to vibration while nearly twice as sensitive, due to its very large active area. but only has a 120° angle of acceptance on one axis (170° on the other.) Although, optics usually restrict it to <120° anyway. This configuration puts a grid and a plate, supported at all corners by 4 posts each. This design makes it extremely difficult to change the distance between the electrodes, and thus prevents false alarms from vibration. This is the most "no-compromise" option for flame detection.	This design creates a small active area and is thus unable to count photons as effectively. It's benefit is that it is far less susceptible to false alarm, since any vibrations can only pull the two closest points of the electrodes (the hook and the dome) away from each other. But during that time it becomes less able to sense UV light, decreasing its effective range when exposed to dramatic vibration.	The cheapest of the UV sensors. This design has a moderate active area (directly between the looping electrode and the plate) but a 180° angle of acceptance. Although this is usually restricted by the other optics of the enclosure. Its slender and long electrodes however make this design highly susceptible to false alarm from vibration, as the electrodes can self-discharge when they swing closer together. (false positive).

In the case of the "paperclip" style sensor, even shipping has been acknowledged as a problem. By shipping from supplier to detector manufacturer using ½" foam packaging, manufacturers can expect as high as 16% fallout, and a few more again from shipping from manufacturer to end use customer (as high as 1.5%). With many of tested devices going into alarm when put through a vibration test (standard: IEC60068-2-6, 10-2000hz ,10g, 1 octave per minute), and shock half-sine test (100g pulse, 6ms). With exposure to vibration in the long term (such as in an engine room) ultimately resulting in metal fatigue of the electrodes and making many UV only detectors using the "paperclip" style sensors wholly unsuitable for those applications.

For reference, the "paperclip" style sensor is approximately half the price of the hook and dome sensor, and less than 1/3rd that of the 8-posted grid type sensor. So it is understandable why it is so common, despite its shortcomings. For the best UV sensor performance and reliability, it is objectively best to utilize the more robust 8-posted grid type sensor.

2.3 Infrared Sensors

Infrared sensors get a bit trickier. False alarms here can be the result of random noise, which by slim chance emulate the signatures of a fire, or uneven lighting across sensors in a way which emulates the ratios expected from a fire. The latter of which can be avoided by filtering only for signals which appear in all sensors simultaneously, and then determining if the ratios thereafter are in the correct ratio, but this only works well with highly responsive sensors. Shorter range detectors often look for the weaker 2.8um band because the lens and sensors are far cheaper. These can be distinguished by their quartz glass, rather than sapphire lens, and suffer more in the tradeoff between range and false alarm resistance, since the 2.8m emission peak is more broad and less intense, a broad filter is necessary to capture sufficient light, which makes the fire signature to background heat ratio less dramatic, and thus easier for random noise to fool into false alarm , or prevent a device from going into alarm in case of a real fire.

Longer range detectors often look for the stronger 4.3um signal, but here too sensor selection is key. There are several ways to make use cheaper lower performance sensors. Mid-infrared sensors which detect beyond 3um are already generally quite expensive. However, lower cost sensors such as Pyroelectric, and PbS sensors suffer significant performance loss at higher operating temperatures. It is also important to note that PbSe has a much wider dynamic range of sensitivity than other sensors, which is important to prevent signal-washout from pointing towards hot objects, or the sunrise. The development of high sensitivity PbSe has also been pivotal in the development of the next generation flame detectors. In the past few years, the cutting edge of Mid IR technology has brought to market PbSe sensors which are nearly thrice the sensitivity from just a decade ago, positioning it as the new top-of-the line technology. Working closely with the material scientists of the sensor development team, it's been possible to design a sensor specifically for fire detection applications. Using those optimized sensors has allowed for a new design which overcomes one of the greatest drawbacks to IR detection- humidity. As much as 2/3rds of the 4.3um fire emission peak can be masked by water vapor over long ranges in high humidity conditions. Some devices have their effective range reduced by as much as 50% from their listed range, simply due to high humidity.

These new PbSe sensors, with their dramatically greater performance, allow a device to maintain an effective range well within the applicational needs of most use cases while overcoming one of the biggest problems of IR flame detection. Delivering effective flame detection, even in less than ideal conditions.

2.4 Field of View, Range, and False Alarms

Range and field of view are the two most obvious metrics for device performance but it is often the contention that quality and performance are not reflected in this. It is important to note that there are very important caveats to the fine print when reporting these metrics. Front facing IR sensors will have less signal from off axis light sources, simply by the effective cross-sectional area. Reported range can be either the maximum range on axis and in ideal conditions, with no false alarm sources present, or it can be at the maximum off-angle specification, with a radiating black body, high humidity, and staring at the sun. The decision to specify a detector's range in optimistic conditions, versus a guarantee that at the worst, it will perform to a minimum, are more representative of the design philosophies than performance in many cases.

In some cases, it is possible to see to extreme distances, but only in high sensitivity settings which lowers the threshold for alarm declaration to just above the random noise, exposing the device to false alarms. Decreasing this threshold by half, is of course by far easier than doubling the signal captured. And in some use cases where false alarm sources are scarce, it is acceptable to decrease the noise-floor to signal ratio needed to trigger an alarm to only a factor of 2 to extend the range of a detector. In most field applications, however, there is a strong priority on false alarm immunity, and thus it is best practice to set this noise-floor to signal ratio to at least a factor of 4. These types of decisions dramatically alter the range of the device but are the deciding factor between a device which is false alarm immune 99.5% of the time to one that is immune 99.95% of the time. As with any battle against random external factors, the final percent towards absolute immunity is exponentially more difficult, and thus usually ignored in favor of more favorable specifications.

3.1 UV and Infrared sources

All high-end life safety devices are required to not only be able to report danger, but also report their ability to detect danger. If a device's optics, or sensors fail, it is important to be able to sense when this happens and signal the user to service the device as soon as possible. This added layer of safety is often not the selling point of a device, but contributes greatly to a device's primary strengths and weaknesses. In the case of UV detectors, a UV source must be utilized to trigger a response to periodically test the device's capabilities. Likewise, an IR detector must use an IR source, although this is much simpler since IR can be given off by a simple incandescent light. Common UV sources such as arc discharge type lamps are unfortunately far less reliable than the UV sensors they are intended to test.

Arc Lamps require high voltage sources, and to lower the firing voltage, thermionic emission coatings are often used, but eventually wear out and crack from heat shock. Gas discharge and arc lamps also have a great deal of difficulty in extreme cold. To offset this, it is common that radioactive gas isotopes (usually of a noble gas) be used in the lamps to keep it primed for quick firing, and gives the added benefit of being able to fire at lower temperatures. However, due to the presence of these isotopes can add a hidden cost, in the form of end-of-life disposal fees (which is usually rolled into the cost of the device without the consumer knowing), and it is generally advisable to avoid using radioactive materials in a device whenever possible.

Stepping back from these kinds of complicated solutions however, most people don't know that even regular incandescent bulbs emit UVC sufficient for self test. More importantly, the manufacturing lines for small incandescent bulbs is by far more developed than those for arc lamps which require special licenses to handle radioactive gas, and are often hand made. The tricky bit has been that Glass additives for to block UV have been so long used, many have forgotten about it. In certain niche applications however, light bulbs for old car indicators, typically already hidden behind plastic, these additives were not included, allowing them to emit UV freely. These bulbs were for maximum lifespan, often lasting longer than the cars they were made for, usually listed at 100,000+ hours, compared to miniaturized arc lamps which fail around 10,000 to 20,000 hours. Incandescent lamps require no hazardous gas fillings and they warm themselves up in low temperatures. They are extremely small and cost efficient by comparison to arc lamps, even when made custom. Custom incandescent lights, made with thick filaments, and UV transparent glass, is ultimately the most reliable method, and redundancy can be easily achieved by adding additional test lamps. Redundancy here means that even in the unlikely event the lamp fails, the device is not considered at risk of blindness. It can let the user know it needs serviced at their convenience while continuing to be fully operational. A level of reliability not usually afforded when the test lamp is as costly as a sensor.

3.2 Optics test and OPTI-radar™

In addition to checking the sensors, the device is also meant to check the clarity of the optical path. Since it is perfectly possible for the device to be functional. But the view outside to be blocked by oil, dirt, dust, ice, and quite commonly, bugs.

This leads to a notable feature most detectors have in common, a little stub sticking into the field of view. That stub, usually polished metal on the underside, is a reflector. To test the optics path of the sensors, a reflector is used in conjunction with the self-test lamp to test both simultaneously. This usually also results in a slight irregularity in the cone of view, as it blocks the sensors from seeing past the reflector, but that in itself isn't usually a problem.
One minor problem with reflectors is that it can block light unevenly. Especially problematic with IR only devices, light from a false alarm source can be partially blocked from one sensor, but not another resulting in inaccurate data. This can, although rarely, result in false alarms and false negatives.

The second, more pressing problem is that tying together the optics test and the sensor test makes both appear as a fail-dangerous point of failure. The optics test can fail for all sorts of reasons. Rusty reflectors, bugs making a home under the reflector, dust and liquid tend to gather in that gap first, and even act as a latching on point for frost. The reflectors are a susceptible point of failure, where there isn't an immediate danger, but the device has no way of telling. For the device, it only knows it can't see the reflector, and thus assumes itself blind. Alternatively, the reflector method only really tests for whether or not the sensor can see the reflector, this doesn't rule out the possibility that the sensors view of the outside is blocked, while the view of the reflector is clear. It is also possible for the detectors ability to be diminished through attenuation, but not blocking, and in that case, the detector would have no way of knowing its range had been reduced as long as it passed the optics test.

To circumvent these problems, it is also possible to check the entire window, measure its transparency as a percent, and detect solid objects, and do so all separately from the sensor test- notifying the user that the window needs cleaning, without having to declare itself blind.

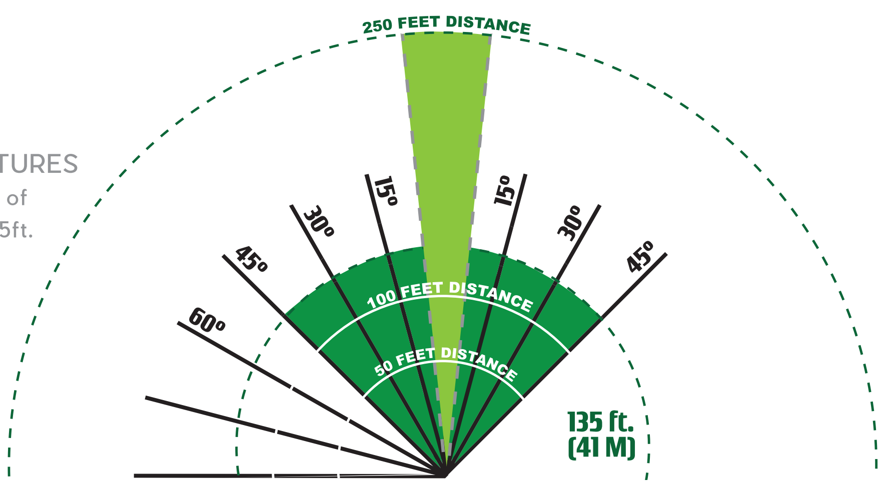
OPTI-radar™ is a patented method whereby an infrared proximity sensor is configured to look through the glass using encoded pulses to check for any change in transparency, whether by oil film, or solid object. This provides real time monitoring, in a way that allows the device to continue operating even if there is some obscuration. The device in this case can be configured to report optics transparency via communication lines, but only declare a fault when there is a solid object, or impact on the performance goes below the specifications of the device. This can even be customized to a customer's desired level, in the case of environments where window obscuration is regular and unavoidable. Allowing the user to clean and maintain the optics at their own convenience. This eliminated many of the nuisance faults, while providing a higher level of confidence in the device's sensing capabilities.

4. Detectors Inc Tech Summary

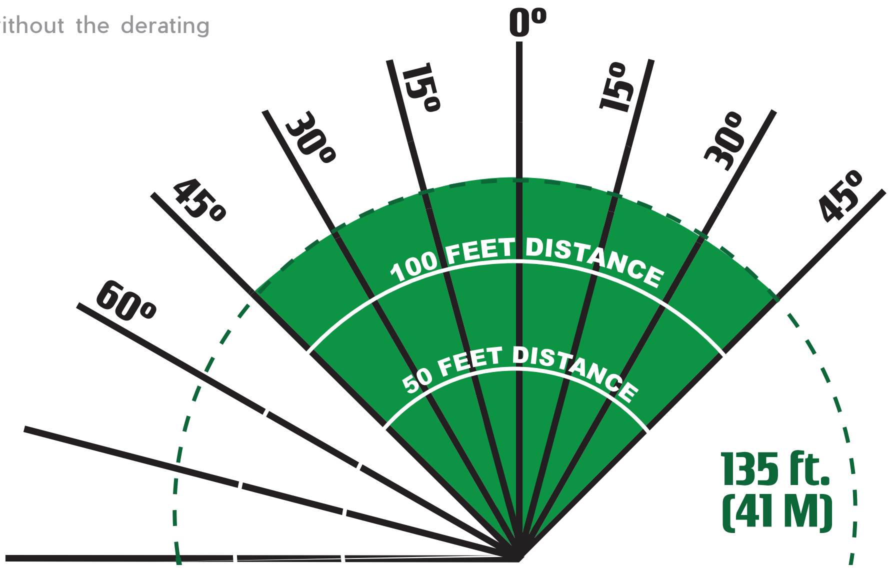
Detectors Inc puts together over a hundred years of industry experience to bring together the best of fire detection technology into one. Combining the most robust techniques, the most reliable parts, and the latest material science developments into our products; Detectors Inc has positioned itself as a company that stands apart in performance, and philosophy. We don't do cost savings measures at the cost of performance. We don't design for obsolescence, we state only specifications we can be confident with.

Detectors Inc. UV3IR detectors utilize the latest generation of PbSe high speed mid IR sensors. They incorporate a unique filter design which allows the device to overcome the challenge of humidity, and random noise discrimination. High speed signal filtering at both analog and digital levels allow the device to be the most false alarm immune product brought to market. The UV sensor used overcomes the problems faced by other UV sensors and is more responsive while virtually immune to vibration induced false alarm or false negative. The conduit port orientation allows for easy daisy chaining/passthrough of wiring and detachable terminal blocks allow for easy installation. The Self test lamps are effective at low temperature, without the use of radioactive isotopes, and have an effective lifespan on the order of 5 times greater than the arc lamp/ gas discharge alternative. The device also includes an additional lamp for added redundancy. The removal of reflectors from the design eliminates one of the most common failure points in field use of flame detectors. The OPTI-radarTM further enhances its self test confidence by providing real time monitoring of not only FOV blockage, but also signal attenuation, again reducing maintenance frequency.

DIFFERENT FIELD OF VIEW PICTURES
This one includes the 150ft normal line of sight, and the intentional derating to 135ft.



Alternatively there is the version without the derating



And the 3D cone of view