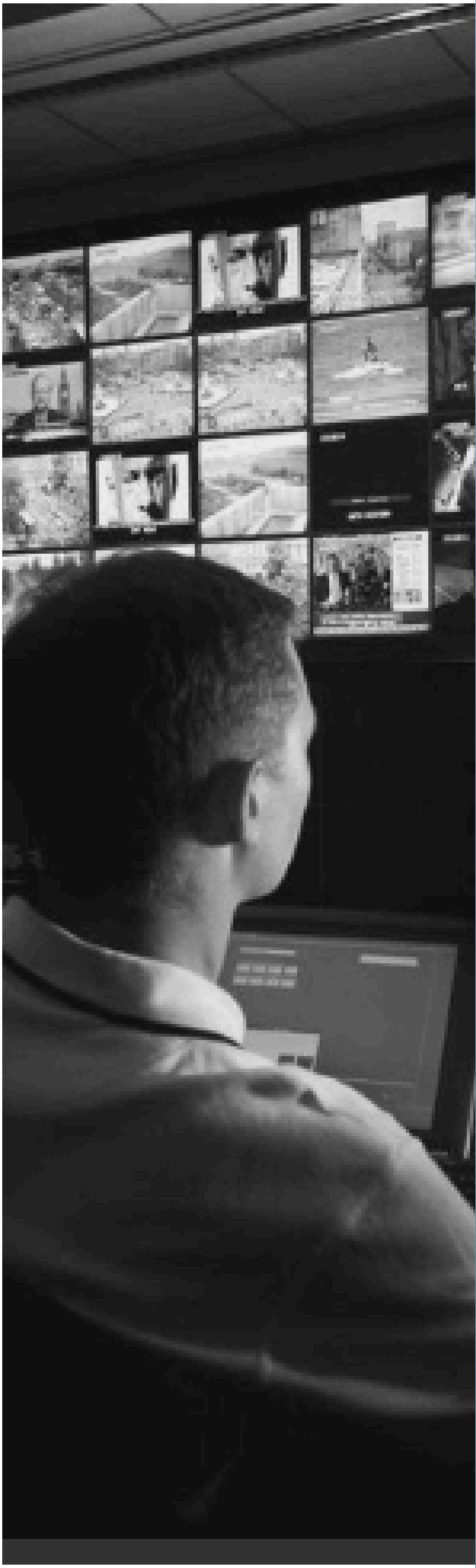


QuantumLABS
Dynamic Location Monitoring

LiDAR

Safety Standards and Exposure Limits

https://q-labs.ai/

1800 026 026

info@q-labs.ai

Level 2, 151 Rathdowne Street, Carlton,
VIC 3053, Melbourne, Australia

LIDAR SAFETY STANDARDS AND EXPOSURE LIMITS

LiDAR (Light Detection and Ranging) systems use laser beams to measure distances, which raises important safety considerations. Laser safety is classified into different classes based on potential harm to eyes or skin, and regulatory standards define exposure limits to ensure safety.

Scientific research supports that properly designed Class 1 LiDARs pose no adverse health effects. The research in this document shows that the Class 1 laser used by QuantumLABS is safe for its intended purpose.

This report reviews **the safety standards and exposure limits for LiDAR technology, focusing especially on Class 1 LiDAR** (considered eye-safe), and examines guidelines from leading regulatory bodies (IEC, ANSI, FDA, ISO), maximum permissible exposure levels, differences between laser classes, industry-specific requirements, and findings from scientific studies on LiDAR exposure.

Laser Safety Regulations

Laser products are subject to international and national safety standards that classify lasers by their ability to cause injury.

The primary international standard is **IEC 60825-1**, which defines laser classes and requirements for safety. In the United States, **ANSI Z136.1** (through the Laser Institute of America) provides guidance on laser use, and the **FDA** (via 21 CFR 1040.10) regulates laser products.

Notably, the FDA has largely harmonized with IEC standards; manufacturers can self-certify to either the FDA or IEC classification (the FDA announced in 2019 it would accept IEC classifications).

Other bodies like **OSHA** (occupational safety) typically defer to ANSI and FDA standards.

Canada and other countries likewise adopt IEC 60825-1 (e.g. CSA E60825-1 in Canada) with minor deviations.

Across these frameworks, compliance with IEC 60825-1 generally means compliance with local regulations.

Laser Classification

Lasers are categorized into classes (1, 1M, 2, 2M, 3R, 3B, 4) based on the Accessible Emission Limit (AEL) relative to the Maximum Permissible Exposure (MPE) for human eyes and skin.

Lower classes are safer by design, while higher classes pose greater hazard. Key classes include:

- **Class 1:** Considered inherently safe under all reasonably foreseeable conditions of operation. A Class 1 laser cannot emit radiation above the MPE for eyes or skin during normal use, meaning even direct viewing with optical instruments does not exceed safe exposure. Class 1 lasers or products pose no need for special control measures.

- **Class 1M:** Lasers emitting in 302.5–4000 nm that are safe for unaided viewing (like Class 1) but may be hazardous if the beam is viewed with optical magnifiers (binoculars, telescopes). Essentially, Class 1M meets Class 1 safety for naked-eye exposure but not when the beam is concentrated by optics.

- **Class 2:** Low-power visible lasers (400–700 nm) that emit up to the Class 2 AEL. They are considered safe for accidental viewing because the human blink reflex (<0.25 s aversion response) limits exposure. However, intentional staring into the beam can be dangerous. Any non-visible emission from a Class 2 laser must stay below Class 1 limits.

- **Class 2M:** Visible lasers that are safe for unaided viewing (like Class 2) but hazardous with optical aids (similar concept to Class 1M).

- **Class 3R:** “Reduced risk” lasers that exceed Class 1 (or Class 2 for visible) limits but by no more than a factor of 5. Direct eye exposure is potentially dangerous but risk is lower than higher classes. For example, Class 3R visible lasers can be up to ~5 mW. Minimal controls may be needed.

- **Class 3B:** Lasers that are hazardous upon direct or specular-reflection viewing. Even brief exposure to the direct beam can cause eye injury. Diffuse reflections (scattered light from matte surfaces) are usually not harmful for Class 3B. Power outputs are typically 5 mW to 500 mW for visible lasers.

- **Class 4:** High-power lasers (> Class 3B limits, typically >500 mW continuous or high pulse energy) which are dangerous to eyes and skin even from diffuse reflections. They can cause serious injuries and are also fire hazards. Class 4 lasers demand strict control measures (enclosures, interlocks, safety eyewear).

Laser Classification

Laser eye injury hazard increases with higher class/power. Lower-class lasers (Class 1, 1M, 2) are “low” risk, while Class 3B and 4 can cause immediate eye injury at close range. (This chart illustrates relative hazard for visible lasers; Class 1 lasers pose essentially no eye hazard even for accidental exposure.)

Regulatory standards require manufacturers to label lasers with the appropriate class and incorporate safety features.

For example, **IEC 60825-1** mandates protective housings and interlocks such that no accessible laser radiation exceeds Class 1 levels unless intended for use.

In other words, products containing higher-power internal lasers must be engineered as **Class 1 laser products** (fully enclosed or emission-limited) to be safe to users.

Many consumer and industrial laser devices achieve Class 1 by engineering controls (enclosures, beam diffusers, etc.) even if the internal laser is higher class.

In the context of LiDAR, the goal is to meet Class 1 so that the sensor is eye-safe in all normal usage scenarios.

Safety Assessment Criteria for Class 1 LiDAR

Class 1 LiDAR sensors are designed such that their emitted laser pulses do not exceed the Class 1 AEL at any point where a person could be exposed.

This means the intensity and duration of pulses are constrained so that even a worst-case exposure remains below the injury threshold for eyes and skin.

According to IEC 60825-1, a Class 1 laser is "safe under reasonably foreseeable use, including the use of optical instruments for intrabeam viewing."

In practical terms, a person could directly look into a Class 1 LiDAR beam (intentionally or accidentally) and not sustain eye damage. While this is not recommended behavior, the safety classification ensures that even inadvertent exposure (within the specified limits) is not harmful.

Opsys-Technology's LiDAR Systems: Opsys Tech (an automotive LiDAR manufacturer) explicitly designs its pure solid-state LiDARs to meet Class 1 eye safety.

Their scanning microflash LiDAR operates "under the FDA Class 1 eye-safety limit" while still achieving long range.

Opsys accomplishes this by using techniques such as spreading the beam across many small segments of the field of view and using multiple low-power beams (from VCSEL arrays) that rapidly scan.

By dividing the field into thousands of tiny segments, the instantaneous power in any given direction remains below Class 1 limits, even though the total system power can be higher.

This approach maximizes range and resolution but keeps the exposure per eye-length segment very low.

Opsys Tech's datasheets confirm their LiDARs are "Class 1 Eye-Safe per IEC/EN 60825-1", meaning they have been tested and certified not to exceed Class 1 emission limits in any operating condition.

Other LiDAR manufacturers follow similar safety criteria. **Velodyne,** a pioneer in automotive LiDAR, uses 905 nm diode lasers and ensures all its units are Class 1.

Velodyne notes that its ~2 mW laser beams are continuously scanning, so any individual's eye would only be illuminated for about 1 millisecond as the beam sweeps by – far too brief to cause harm at those power levels.

By keeping the beam moving and limiting power, Velodyne's 905 nm LiDARs are "classed as Class 1, incapable of causing eye damage under any conditions" of normal use.

Likewise, companies using 1550 nm lasers (like **Luminar**) also design their LiDARs to meet Class 1 standards despite the higher power possible at that wavelength.

Meeting Class 1 is often a mandatory requirement for LiDAR intended for use around the general public, since it obviates the need for special eye protection or exclusion zones.

Safety Assessment Criteria

To certify a LiDAR as Class 1, manufacturers perform a laser hazard analysis per IEC/ANSI standards. They calculate the Accessible Emission Limit (AEL) – the maximum accessible output allowed for Class 1 – taking into account worst-case conditions (highest power, longest exposure, beam focusing by the eye).

The device must not exceed this AEL for any exposure duration from 0.25 seconds (the nominal human aversion response time) up to continuous viewing, depending on how the laser operates.

For pulsed LiDAR (typical in automotive), pulse energy and repetition frequency are evaluated against MPE for both single-pulse and repetitive exposures. Often the **Nominal Ocular Hazard Distance (NOHD)** is calculated – the distance beyond which the beam is safe for eye exposure.

A Class 1 product effectively has an NOHD of 0 m (no hazard at any distance), or a very small NOHD confined within the device's aperture.

For example, one study showed an experimental "flash" and "blade" scanning LiDAR design achieving a 200 m range with an NOHD of only ~0.2 m or less – meaning the beam becomes eye-safe just a few centimeters from the aperture.

Such designs use beam divergence or housing such that the intensity drops below MPE almost immediately outside the device.

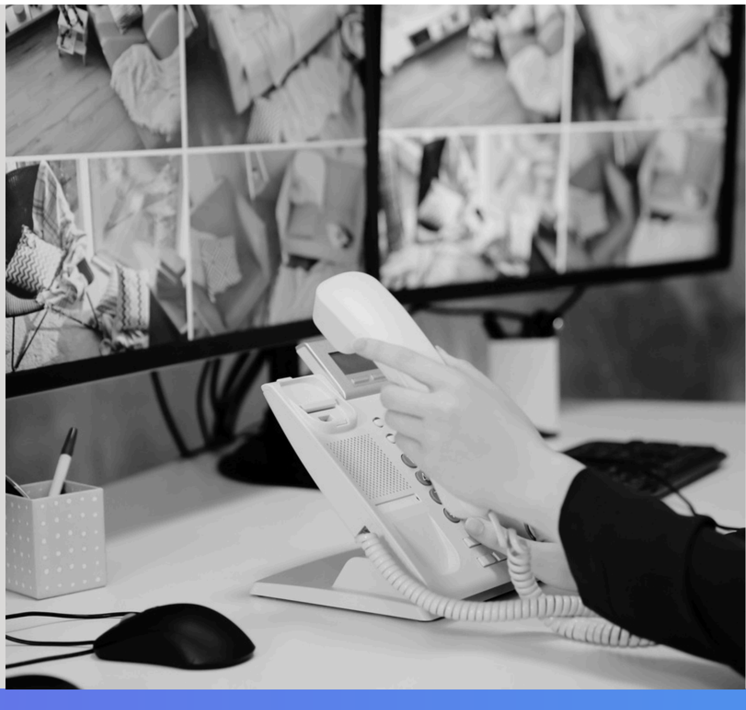
A critical part of the safety assessment is considering optical instruments. Class 1 criteria now require safety even when the beam is viewed through binoculars or other magnifiers. (unlike Class 1M).

LiDAR beams are typically collimated (parallel) for long range, which means a distant observer's eye could, in theory, focus a lot of the beam's power onto the retina. Manufacturers ensure that either the beam divergence, pulse limitations, or other factors keep even magnified exposure below the injury threshold.

In summary, **Class 1 LiDAR safety criteria** involve: limiting laser output (power, energy per pulse, pulse duration, repetition rate), maximizing beam divergence or scan motion to dilute exposure, and designing fail-safes so that no single point or pulse train can cause harm.

These criteria are validated by testing under IEC 60825-1 procedures.

Any LiDAR product released for consumer or general-use environments will undergo this certification to ensure it can carry the "Class 1 Laser Product" label.



Maximum Permissible Exposure (MPE) for Eye and Skin

Maximum Permissible Exposure (MPE) is the key metric underlying laser safety limits.

MPE is defined as “the maximum level of laser radiation the human eye or skin can be exposed to without hazardous effects or biological changes.”

In other words, it’s the threshold of safe exposure; any exposure at or below the MPE is considered non-injurious, while exposure above the MPE could cause damage if sustained.

MPE values are determined by extensive biological research on laser-tissue interactions and include safety margins.

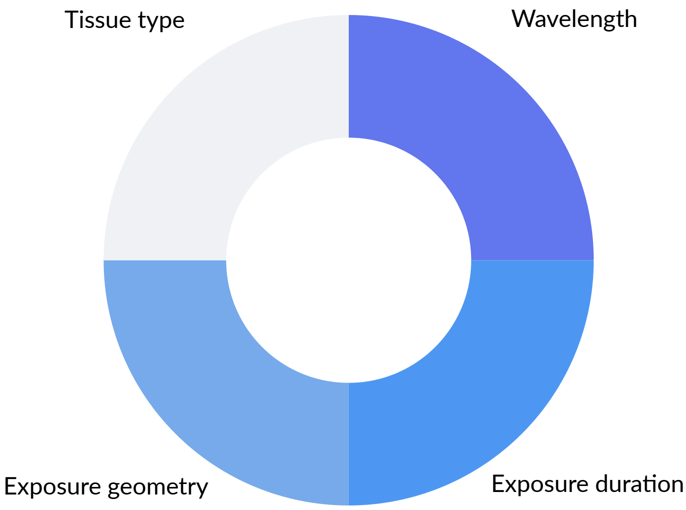
MPE values are determined by extensive biological research on laser-tissue interactions and include safety margins.

The eye is usually the critical organ for laser safety because it is far more sensitive to light injury than the skin.

The focusing effect of the eye’s lens concentrates light on the retina for certain wavelength ranges, drastically lowering the energy needed to cause retinal damage compared to what would cause skin injury.

As OSHA notes, “the human eye is almost always more vulnerable to injury than human skin.”

Several factors determine the MPE for a given laser



Laser Safety Standards Overview

Laser safety standards are primarily driven by eye-safety Maximum Permissible Exposure (MPE).

If a laser is safe for the eye, it will generally be safe for the skin, with exceptions for high-power ultraviolet or infrared lasers that could cause skin burns at extremely high intensities.

Eye MPE: The Eye's Sensitivity Varies with Wavelength

Visible and Near-Infrared (400–1400 nm):

This range, including common LiDAR wavelengths around 905 nm and 1064 nm, can penetrate the retina.

The MPE here is low because even a small amount of energy focused on the retina can cause damage.

- ***Example Exposure:***

For a typical exposure of 0.25 s at 905 nm, the MPE for a point source is in the order of microjoules/cm^2 or a few milliwatts/cm^2 entering the pupil. Class 2 visible lasers (up to 1 mW continuous) are considered on the borderline of safe for momentary viewing. Class 1 limits are even lower for these wavelengths.

Infrared beyond 1400 nm (e.g., 1550 nm):

The cornea and lens absorb these longer IR wavelengths, so very little reaches the retina.

The risk of retinal damage is negligible for wavelengths like 1550 nm, allowing higher power exposure without harm to the retina.

However, the energy gets absorbed in the eye's front, which could heat the cornea or lens. Intense exposure could cause corneal burns or cataracts.

Laser Safety at 1550 nm

<u>The retinal MPE at 1550 nm is much higher compared to 905 nm, making it "eye-safe" in terms of higher power usage without damaging the retina.</u>

However, powerful lasers at 1550 nm can still damage the eye's surface (cornea or lens). The MPE for corneal damage is higher at 1550 nm than for retinal damage at 905 nm.

Key Takeaway:

"Eye-safe" does not mean unlimited power at 1550 nm. Even at 1550 nm, high-powered lasers can still cause damage to the eye's surface. The power limits remain under Class 1.

Laser Safety Standards Overview

Skin MPE: Skin is More Resistant to Laser Damage than the Eye

- The skin can absorb and dissipate much higher energy levels before sustaining damage compared to the eye.
- For most LiDAR wavelengths (near-IR), the skin's outer layers can dissipate energy without causing burns or lesions.
- Class 1 Eye Safety = Skin Safety: If a LiDAR is Class 1 for eye safety, it will almost certainly be safe for skin under reasonable exposure.

Skin Hazards:

- Become a concern mostly for high-power Class 4 lasers or ultraviolet lasers that can cause burns or even cancer risk with prolonged exposure.

Standards:

- IEC and ANSI standards ensure exposure below eye MPE will automatically protect the skin in most cases. Therefore, LiDAR safety evaluations focus on eye MPE as the limiting factor.

Exposure Duration and Pulsed Lasers

- **MPE is a curve** depending on exposure time. For short exposures (sub-millisecond pulses), tissue can tolerate a brief energy spike better than continuous exposure.
- **Repetitive Pulses (e.g., LiDAR)**: Standards apply a multiple-pulse correction, ensuring the cumulative effect of a pulse train does not exceed MPE.
- Manufacturers must calculate MPE for their specific pulse duration and repetition rate. For instance, a LiDAR emitting 10 ns pulses at 100 kHz will have a scaled-down MPE to avoid cumulative effects on the retina.

In Summary:

Class 1 limits are tied to MPE: A Class 1 laser ensures that even in worst-case scenarios (e.g., staring into the beam), the exposure will not exceed the MPE for eye or skin safety.

This provides a large safety margin. Real-world LiDAR exposure to an individual is typically far below that worst case, since the beam is scanning and a person is unlikely to align their eye perfectly at close range for an extended time. Even so, the safety classification guarantees protection even in that contrived scenario.

Differences Between LiDAR Laser Classes

- **Class 1 vs Class 1M**:

Class 1M lasers are safe to the unaided eye but could be dangerous with magnifying optics (like telescopes or binoculars).

- **Class 2 LiDAR:**

Only applies to visible lasers. LiDAR typically uses infrared, so visible-wavelength LiDARs are rare.

- **Class 3R LiDAR:**

Allows slightly higher emissions than Class 1, but direct eye exposure can be harmful if sustained.

- **Class 3B LiDAR:**

Significantly exceeds safe eye exposure limits and can cause immediate eye damage. Not sold for general public use.

- **Class 4 LiDAR:**

High-power lasers capable of causing eye or skin burns and igniting materials. Used in specialized contexts like military or scientific research.

Class 1 LiDAR: The Gold Standard

Class 1 is the most commonly used for LiDAR in public-facing applications, including commercial, automotive, and industrial use. It ensures complete safety under normal operating conditions.

LiDAR in Different Industries

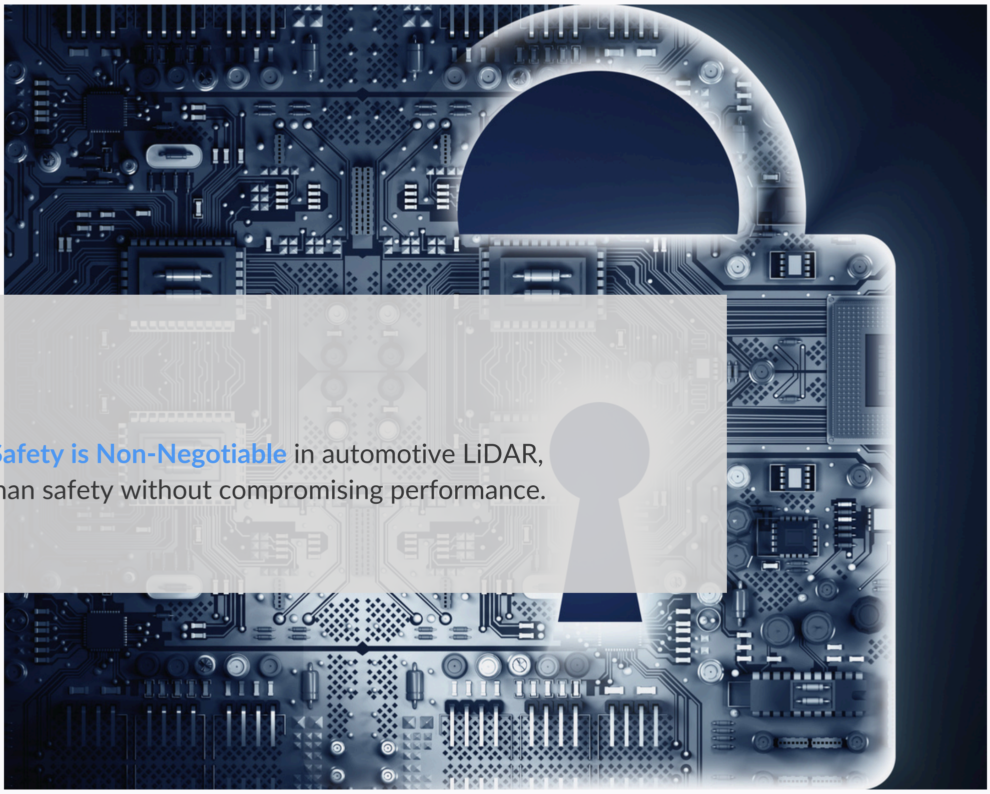
Automotive LiDAR Safety

In the automotive sector, LiDAR sensors are used in driver assistance and autonomous driving to detect obstacles and map the environment.

Automotive LiDAR must be Class 1 eye-safe as these sensors operate in public spaces where pedestrians, drivers, or cyclists could be exposed.

Regulatory authorities implicitly require eye safety—European vehicle safety standards and U.S. FMVSS regulations would not permit vehicles that could harm bystanders' eyes.

As a result, all major automotive LiDAR products (Opsys, Velodyne, Luminar, Innoviz, Ouster) are Class 1, making this a non-negotiable design constraint for automakers and suppliers.



Key Insight:

- **Class 1 Eye Safety is Non-Negotiable** in automotive LiDAR, ensuring human safety without compromising performance.

LiDAR in Different Industries

Automotive LiDAR Safety (Cont...)

Achieving Class 1 Eye Safety in Automotive LiDAR

Long-range LiDAR (200m+) is essential for highway speeds, making Class 1 compliance challenging. Engineers use the following solutions:

- **905 nm vs. 1550 nm Lasers:**
  - Early automotive LiDARs used 905 nm lasers, which reach the retina, but strict eye-safe limits severely cap power per pulse, limiting range to ~100m.
  - 1550 nm fiber lasers allow higher pulse energy without exceeding Class 1 because the eye's front optics absorb the beam.
  - Studies show 1550 nm LiDARs can emit ~40x more power than 905 nm for the same eye safety limit (LS Lidar), or send out ~17x more photons (Luminar), enabling 200m+ range.
  - Trade-offs include higher costs (requiring InGaAs detectors) and greater atmospheric attenuation, but many consider 1550 nm superior for high-performance LiDAR.
- **Beam Scanning & Multiplexing:**
  - Automotive LiDARs often split the laser into multiple beams or rapidly scan a single beam to spread energy over time.
  - A scanning LiDAR's beam never dwells on one point (or eye) for more than a fraction of a second, keeping average exposure below MPE.
  - Some systems use VCSEL arrays, where each low-power beam is individually eye-safe, but together they provide a strong reflected signal.
- **Fail-safes:**
  - Fail-safe mechanisms prevent dangerous laser output if a component fails.
  - Watchdog circuits shut down lasers if scanning stops (to prevent a stationary high-intensity beam) or power spikes above limits.

LiDAR in Different Industries

Automotive LiDAR Safety (Cont...)

Compliance & Emerging Concerns

- Automotive LiDARs follow IEC 60825-1 for classification.
- Other standards (ISO 17387, AEC-Q tests) focus on reliability but still require Class 1 certification.
- UNECE regulations effectively mandate IEC 60825-1 compliance for any laser-emitting vehicle part.
- Automakers verify Class 1 labeling and test reports before integrating LiDAR sensors.

Potential Secondary Hazards:

- High-powered IR LiDAR could damage CMOS/CCD camera sensors, even if human eyes are safe.
- Silicon cameras (sensitive to 905–1550 nm) could be saturated or overheated by strong IR pulses, affecting autonomous vision systems.
- Manufacturers like Luminar mitigate this by confining emissions to specific wavelength bands.

LiDAR in Different Industries

Robotics and Industrial LiDAR Safety

LiDAR is widely used in robotics and industrial automation – for example, in autonomous mobile robots (AMRs) in warehouses, in industrial safety scanners (presence detection), and in service robots.

In these contexts, lasers operate around people in factories, hospitals, or public spaces, so safety requirements are stringent.

Industrial LiDAR sensors are virtually always Class 1 as well.

A prominent example is the safety laser scanners made by SICK and Hokuyo, used to create virtual safety fences around machinery. These devices (often using 905 nm pulsed lasers) are Class 1 so that workers can be in their vicinity without risk. SICK's product specifications explicitly state "Laser Class 1 (IEC 60825-1:2014)" for their LiDAR sensors.

This means the emitted beams are eye-safe even for long-term exposure.

Such scanners typically have a fan-shaped scan (270° field) that sweeps many times per second – like automotive LiDAR, the beam's motion ensures no static high exposure.

Additionally, they tend to have fairly large beam divergence (to cover area), which further reduces intensity at any given point.

Robotics applications might also use LiDAR for perception (e.g., a robot vacuum or drone's LiDAR).

These too must be Class 1 if there is any chance of human presence. A home robot or drone cannot have a hazardous laser for consumers.

LiDAR in Different Industries

Robotics and Industrial LiDAR Safety (Cont...)

Indeed, even consumer devices like the latest iPhone and iPad have a tiny LiDAR (infrared laser for depth sensing) which is Class 1 and certified safe under IEC 60825-1 – the user manual will note the device is a "Class 1 Laser Product". This shows how ubiquitous and expected Class 1 safety is.

In industrial settings, there are additional standards that come into play for functional safety (making sure the sensor reliably detects people, etc.), such as IEC 61496 for electro-sensitive protective equipment, or ISO 13849 for safety functions.

These relate more to performance than laser radiation, but they assume the laser itself is not harming people.

In other words, a safety scanner that's supposed to protect people obviously cannot have a dangerous beam itself – so Class 1 is a baseline. Training for industrial laser users (if higher classes are used in closed setups) often references ANSI Z136 and requires a Laser Safety Officer for Class 3B/4. But Class 1 LiDAR can be deployed freely without special training, which is another incentive to keep power low.

LiDAR in Different Industries

Aerospace and Specialized Applications

LiDAR is also used in aerospace – for example, in aircraft altimeters, terrain mapping from planes, obstacle detection on helicopters/drones, and even satellite-based laser systems (like NASA's laser altimeters for planetary mapping).

The safety approach here depends on the operational scenario:

Aircraft-mounted LiDAR:

The FAA has published guidance (Advisory Circular AC 20-183) on installing lasers on aircraft.

It recognizes that laser devices (like LiDAR) could be anywhere from Class 1 to Class 4, and it provides a framework for safety assessment.

A key concern is any laser that emits externally from an aircraft (downward or in any direction that could hit observers or other aircraft).

Even if airborne, one must ensure that the beam at ground level or intersecting another aircraft is eye-safe.

Often, high-altitude mapping LiDARs rely on distance to diffuse the beam. For instance, a powerful laser that is Class 4 at aperture may, after spreading over a 1000 m path, produce an energy density below the Class 1 MPE at ground – thus not hazardous to people on the ground.

However, during takeoff or if someone were to approach the device, there could be risk.

Operators manage this by restricting use to when aircraft are at altitude and by procedural controls.

Some airborne LiDAR systems also use 1550 nm to mitigate retinal risk for anyone seeing the beam from below.

LiDAR in Different Industries

Aerospace and Specialized Applications (Cont...)

Aircraft-mounted LiDAR:

In space applications (like altimeters used on satellites), the beams typically do not pose a human hazard because they are either aimed at planetary surfaces with no people or the distance is so great that by the time the beam could reach a human, it's extremely diffused.

Satellite LiDAR can be quite high energy (they often are Class 4 by output to get returns from orbit), but these operate in a domain where human exposure is virtually impossible.

Nonetheless, agencies like NASA still analyze worst-cases (e.g., could the beam hit an airplane or a person in orbit, etc.) and ensure risk is negligible.

Satellite or Space LiDAR

The military uses laser rangefinders and LiDAR-like designators which sometimes are not Class 1 because they prioritize performance.

These are used by trained personnel with safety protocols (for example, rangefinder lasers may be Class 3B but soldiers are trained not to expose eyes to them and often use protective eyewear in training exercises).

<u>In civilian aerospace, however, if lasers are used in an aircraft intended for general airspace, regulators would expect Class 1 or robust controls.</u>

The European Union Aviation Safety Agency (EASA) and FAA coordinate on these issues; for instance, EASA's guidance considers both visible and IR lasers from aircraft and emphasizes not creating eye or sensor hazards to others.

LiDAR in Different Industries

Aerospace and Specialized Applications (Cont...)

In summary, aerospace applications can sometimes step outside the strict Class 1 regime due to the operational distances involved, but they then require careful analysis and operational constraints.

Whenever lasers (like LiDAR) are used in airspace where third parties could be exposed, authorities will require evidence that either the laser is Class 1 or that conditions ensure people cannot be overexposed (for example, a GPS-synchronized system that inhibits firing if the aircraft is below a certain altitude or above populated areas).

Class 1 is still preferred whenever feasible, as it simplifies deployment.

Research and Scientific Evaluations of LiDAR Exposure Effects

Ensuring Safety Through Scientific Precision

The safety standards for lasers (IEC, ANSI) are grounded in decades of scientific research on how laser radiation affects biological tissues.

Numerous studies, often involving animal eyes or ocular tissue models, have determined damage thresholds for retina, cornea, and skin at various wavelengths and pulse durations.

These thresholds, with safety factors applied, become the MPEs and class limits. Here we summarize some relevant scientific insights into LiDAR-related exposure.

Panel Retinal vs Corneal Damage (1550 nm "Eye-Safe" Debate)

Scientific literature reinforces that the retina is the most sensitive part of the eye for wavelengths that reach it.

For 905 nm (near-IR) lasers, the retina is the primary concern. For 1550 nm lasers, the retina is effectively spared, but the cornea can be injured at high energies.

A research program at Johns Hopkins APL examined corneal injury from IR lasers around 1.5 µm. They pointed out that calling 1550 nm "eye-safe" is somewhat misleading – while it avoids retinal damage, "painful and visually disabling corneal injuries are possible from over-exposure to these wavelengths," even though it requires higher power than a retinal injury at shorter wavelengths.

In other words, 1550 nm is safer but not absolutely safe. Their experiments determined thermal damage thresholds for corneal tissue, helping inform the MPE.

The result is that standards allow more laser power at 1550 nm, but still with an upper limit to protect the cornea and lens.

Scanning Effects

One reason scanning LiDARs are safer is the concept of duty factor on the eye. Studies have shown that if a laser beam moves rapidly, the exposure at any one retinal location is reduced.

A continuous 2 mW beam pointed steadily at the eye might be a problem, but the same beam scanning yields much lower deposited energy per retinal image.

Velodyne's safety rationale (sweeping beam) is supported by analysis that a beam crossing the eye in 1 ms deposits only a tiny fraction of the energy needed to cause damage.

Researchers modeling scanning patterns have confirmed that dynamic exposures effectively raise the damage threshold compared to static exposures since the eye (or target) is not stationary relative to the beam.

Research and Scientific Evaluations of LiDAR Exposure Effects

Cumulative Exposure

Another consideration is repeated exposure over long periods. In environments with many LiDAR-equipped vehicles (for instance, in the future with ubiquitous self-driving cars), people could be bathed in low-level IR pulses frequently.

While each exposure is below MPE, scientists have considered whether chronic exposure has any effects. So far, there is no evidence of cumulative injury from chronic Class 1 IR laser exposure – MPE levels are set with wide margins for even repetitive daily exposure.

Lasers do not cause ionizing damage (like X-rays), and sub-threshold exposures allow the tissue to dissipate heat without damage. Studies on laser safety sometimes expose animal eyes to repeated pulses at just below MPE to validate that no injury occurs at the cellular level, which underpins confidence in the standards.

Camera Sensor Damage

A somewhat tangential but interesting finding (not about human safety, but device safety) is that certain camera sensors can be affected by high-power IR lasers. In one reported incident, an attendee at a trade show had a camera burned out by a 1550 nm automotive LiDAR – the intense pulses caused irreversible spots on the imaging chip.

This led to investigations which found that nonlinear effects (two-photon absorption) in silicon can allow even “invisible” 1550 nm to deposit energy on the sensor.

Luminar and others have since tested their LiDAR against camera chips and often include warnings not to point them at cameras at close range for extended time. While this isn’t a direct human hazard, it’s part of the broader safety and interoperability assessment in the industry.

Peer-Reviewed Evaluations

Peer-Reviewed Evaluations A 2022 paper by Dai et al. looked at automotive LiDAR requirements including laser safety. It compared different LiDAR architectures (scanning, flash, etc.) and noted how safety constraints limit performance.

For example, flash LiDAR (illuminating a whole scene at once) spreads power but can suffer range limitations; scanning can achieve longer range but must reduce pulse rate or power to stay eye-safe.

The study quantified how using a “blade” (line scanning) approach had a very short NOHD (safe distance), implying a promising design for safe long-range LiDAR.

Conclusion

Scientific research supports that properly designed Class 1 LiDARs pose no adverse health effects.

The exposure levels are far below what would cause even minor retinal or corneal changes.
As a safety margin, the standards are conservative – often the real injury threshold is 2–10 times higher than the MPE, and Class 1 devices stay comfortably under the MPE.

Continuous review by organizations like ICNIRP (International Commission on Non-Ionizing Radiation Protection) and ANSI bioeffects committees ensures that if any new findings emerged (for instance, a subtle effect of long-term low-level IR exposure), the exposure limits would be updated.

To date, no such effects have been demonstrated; Class 1 exposure is considered truly safe.
In conclusion, LiDAR technology can be used safely by adhering to established laser safety standards.

Regulatory guidelines from IEC, ANSI, FDA, etc., provide a robust framework to classify and limit laser emissions.

Class 1 LiDARs – which encompass virtually all automotive and commercial systems – are eye-safe under all normal conditions, meaning they do not exceed the MPE for eye or skin.

The differences between laser classes highlight why Class 1 is universally targeted: higher classes would introduce unacceptable risk in most applications. Industry-specific requirements (whether in cars, robots, or aircraft) uniformly emphasize preventing any harmful exposure to humans.

Thanks to extensive scientific research on laser-tissue interactions, we have high confidence in the exposure limits that define “safe” levels.

When LiDAR systems are engineered to stay within those limits, they offer their sensing benefits without compromising human health or safety.

Sources

International Electrotechnical Commission (IEC) 60825-1 standard definitions of laser classes
rli.com

Laser safety regulatory framework (ANSI Z136.1, FDA 21 CFR 1040.10) and harmonization with IEC standards
laserax.com

Definition of Maximum Permissible Exposure (MPE) for eye and skin
lasersafetyindustries.com

and OSHA guidance on eye and face vulnerability
osha.gov

Opsys Tech and Velodyne Class 1 LiDAR design approaches and statements on eye safety
autovision-news.com
laserfocusworld.com

LaserFocusWorld analysis on 905 nm vs 1550 nm LiDAR eye safety considerations
laserfocusworld.com

Research on infrared (1550 nm) laser eye effects indicating corneal injury thresholds (JHU/APL)
secwww.jhuapl.edu

Industry (Velodyne, Luminar) compliance with Class 1 eye safety and power scaling strategies
laserfocusworld.com

Automotive LiDAR requirements study discussing eye-safe design trade-offs
mdpi.com

Rockwell Laser Industries resource on laser classifications and safety concepts.
rli.com