

The background image shows a large industrial facility at night. The structure is composed of multiple levels of blue-painted steel frameworks, walkways, and pipes. Several tall, cylindrical smokestacks are visible, each emitting a plume of white smoke that rises into the dark sky. The scene is illuminated by bright, cool-toned lights, likely from the facility itself, creating a high-contrast, industrial atmosphere. The overall color palette is dominated by blues, greys, and the white of the smoke and lights.

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# The Ultimate Guide to Harsh Environment Ratings & Design

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## Introduction

The process of manufacturing, machining, and production in industrial applications is improved by sophisticated electronic controls and sensing components. This is possible only if the electronics survive the harsh environments used to manufacture materials like steel, chemicals, and petroleum products – inside hot, humid, and dirty conditions. System designs must endure these conditions that may also include destructively strong magnetic and electric fields.

Hostile conditions, if unchecked, will destroy electronic equipment over time. The list of potentially damaging conditions includes particulate ingress, physical impact, extreme temperature and temperature cycles, electrostatic discharge (ESD) and electromagnetic interference (EMI), and vibration. Standards, like the IP code (IEC 60529) and National Electrical Manufacturers Association (NEMA) ratings exist to quantify the extent to which a specific product can tolerate multiple harsh conditions.

The particular environmental conditions in which a product is used, influences its specifications. These specifications must be determined beforehand. However, components readily available today can be found at element14 and assembled to produce solutions to overcome such obstacles.

## Harsh Temperature Environment

High temperatures contribute to a harsh environment. Electronic devices must be kept cool for effective operational performance. Semiconductor thermal challenges must be solved.

### Automotive Temperature

The environment under the automobile hood is a hostile one.

- Positioning engine control units above the engine and transmission control units either on or in the transmission will spike the ambient temperature above 125 C.
- Exhaust gas sensors and combustion sensors (also known as cylinder pressure sensors) should function in elevated temperature environments fitted in harshest conditions. The control circuitry managing the sensors and actuators involves high-temperature electronics.

### Extreme High-Temperature

- Electronics, when used in elevated temperature environments, must have active or passive cooling to keep components within their respective operating temperature ranges. This is impractical in many situations, such as during downhole drilling operations. Electronic components employed in downhole applications should be able to function at temperatures exceeding 200°C and sometimes, in extremely cold conditions of -50°C reliably. Equipment failure results in rig downtime, which often turns out to be prohibitively expensive.

### Hazardous Temperature

- Temperature classes designate the equipment surface's maximum operating temperatures. It must not surpass the surrounding atmosphere's ignition temperature. The Ignition temperature is the needed minimum temperature, at normal atmospheric pressure in the absence of flame or a spark, to set on fire or cause any self-sustained combustion autonomously of the heated or heating element.
- Auto-ignition temperature is a characteristic of all flammable gases. The mix will ignite if a gas's flammable mixture is exposed to a component above auto-ignition temperature. Any selection of equipment thus implies the Temperature class is lower than the potentially explosive atmosphere's auto-ignition temperature of its installation location.
- If multiple diverse flammable materials are present within a specific area, the material that gives the lowest auto-ignition temperature determines overall area classification, and thus T-class.

### Semiconductor Thermal Challenges

Thermal issues crop up when electronic devices are kept in an air-tight industrial indoor environment. The devices dissipate heat, and rising temperatures will damage devices if improperly managed.

Temperature Classification	Maximum Surface Temperature, °C	Ignition Temperature of gas or vapour, °C
T1	450	>450
T2	300	>300
T3	200	>200
T4	135	>135
T5	100	>100
T6	85	>85

Figure 1: Permissible surface temperature and Temperature Class

Voltage regulators and power ICs use thermal shutdowns to prevent such a scenario. Continuation of the hostile environment will permanently destroy the IC. Even if the concerned IC does not reach thermal shutdown, longer-term reliability will suffer, leading to probable premature failure. The ICs should be used as per the recommended operating conditions stated in the datasheet. Manufacturers frequently use fans to up the airflow so that the best-operating conditions are maintained. An added complication is that industrial equipment is frequently isolated from the environment. This prevents cooling with the help of outside air. Heat is ferried away through thermal path ICs to a lower temperature point.

Choosing packages with super low thermal impedances helps to transfer heat away from the device. The addition of aluminum heat pipes or heat sinks to the concerned case offers a lower thermal impedance path to air. This reduces operating temperature, greatly improving its longer-term reliability.

## Ingress Protection (IP)

A sealed enclosure is used to prevent the ingress of water or dust. The sealed-off volume of space is used to safe-house electronics within harsh environments. The International Electrotechnical Commission (IEC) defined IEC 60529 as standard in this context. It designates the number of types and degrees of protection afforded by an enclosure to its electrical equipment. The IP code itself bears the form "IP XY," where the digits X and Y denote protection from particle ingress and water, respectively. The needs for each degree of protection are described in the standard, and also the procedures to test and confirm them.

They are commonly used for applications exposed to the elements, along with dust or moisture. Typical industries include marine, offshore oil and gas platforms, security, lighting, leisure, food processing, and more.

Rating	Water Protection	Dust Protection
IP65	Water at 12.5 liters per minute through 6.3mm nozzle from any direction	Total dust ingress protection
IP66	Water at 100 liters per minute through 12.5mm nozzle from any direction	Total dust ingress protection
IP67	Submersion into water upto 1 meter deep for amount of time specified by manufacturer	Total dust ingress protection
IP68	Permenent submersion beyond 1 meter into water of depth stated by manufacturer	Total dust ingress protection
IP69K*	Water at 80-100MPa (megapascal) and 14-16 Liters per minute from four angles while the device is rotated at 5RPM.	Total dust ingress protection

Figure 2: IP ratings

## NEMA Ratings

The National Electrical Manufacturers Association (NEMA) offers a popular protective enclosures standard similar to IP Code (IEC 60529). The NEMA 250 covers a wider expanse of harsh conditions than the IP code. It also includes ratings, both hazardous and nonhazardous, for indoor and outdoor locations. Such conditions include the ingress of foreign objects (like dust or fibers), water, and also corrosive agents, including various gases and atmospheres. The following table offers a concise description of each protection level, which NEMA mentions with a particular NEMA Enclosure Type Number. Underwriters Laboratories (UL) has accepted the NEMA Type designations. UL Publication 698, Standard for Industrial Control Equipment for Use in Hazardous Locations, propounds similar requirements. The Factory Mutual (FM) Research Corporation Approval Standard, Explosion-proof Electrical Equipment, Class Number 3615, puts forward performance tests and construction requirements. Such rating systems provide information that assists users in making informed product choices at the time of choosing effective enclosures suitable for hazardous locations.

Rating	Uses	Description
4 & 4X	General purpose weather-proof	Intended for use indoors or outdoors with protection from wash down environment and corrosion resistance.
6 & 6P	General purpose submersible	Intended for use indoors or outdoors with protection from occasional submersion.
7	Hazardous	Intended for indoor use in Class I, Groups A, B, C, and D environments per NFPA rating system.
8	Hazardous	Intended for indoor or outdoor use in Class I, Groups A, B, C, and D environments per NFPA rating system.
9	Hazardous	Intended for use indoor or outdoor use in Class II, Groups E, F and G environments per NFPA rating system.
12 & 12K	Industrial	Intended for use in industrial applications with protection from dust and non corrosive liquid drip.
13	Industrial	Intended for use in industrial applications with protection from dust, spraying water, oil and non corrosive liquid drip.

Figure 3: NEMA ratings

## Electromagnetic Considerations

Managing thermal issues associated with devices fitted inside an air-tight box is only one of many complications. The equipment's electromagnetic interference (EMI) and electromagnetic (EM) environment must be considered.

The EMI susceptibility, however, is not the sole failure-triggering mechanism of intense EM fields. Engineers must meet the challenge of Electrostatic damage mitigation. The power supplies are protected intrinsically from considerable voltage spikes by design. The input stages contain high-speed voltage monitors that clamp the input to avert overvoltage linked damage.

Wired connections offer a path to store the charge through wire capacitors. As the wire quickly drains the charge, super high voltages are observed at the cable's ends. This voltage can potentially destroy the equipment found at both sides of the wire if left unchecked. Spark gaps or arc tubes and electrostatic discharge (ESD) protection diodes are placed at the termination of the equipment cable, offering the charge a path to the ground. If this is not done, the path will run via the transceivers or cable drivers, thus destroying them. The other kind of EMI does not directly destroy ICs but shift the operating points. There can also be variations in drift from the specified limits.

EUT Application	Standard Organizations	
	Emission	Immunity
Commercial & Telecom	CISPR, FCC	IEC
Automotive	CISPR	ISO
Military & Aviation	MIL-STD-461 F & RTCA/DO-160 G	

#### EMC/EMI Standard as per Different EUT (Equipment under Testing) Application

CISPR-International Special Committee on Radio Interference Operating under IEC. Emission Standards

IEC- International Electrotechnical Commission (EU). Immunity standards

ISO-International Organization for Standardization

MIL-STD Military Standard from DOD

RTCA Radio Technical Commission for Aeronautics

FCC-Federal Communication Commission

## Vibration Isolation

Vibration cause many systems to fail. It is an important contributor to problems linked to the electronic equipment's operating environment. In a few industries like mil/aero and hostile industrial settings, resilience and vibration isolation can be a vital design consideration.

Military-grade electronics generally have a 20-year product life, and quality testing can be problematic. Accelerated stress testing methods like HALT (Highly Accelerated Life Test) and HASS (Highly Accelerated Stress Test) provide effective and practical solutions. These do more than a simple design verification testing as products to be tested stressed beyond their specifications. These determine both operational limits and destruct borders.

## Harsh Chemical Environment

Chemical environments (including heavy industrial environments) are atmospheres where densely concentrated chemicals (can be a solid, liquid, or solutions), highly corrosive gases or fumes touch the surface. Severity may widely vary, from mild concentrations in the yard areas to complete drench in chemicals. Aggressive chemicals negatively affect not only the measurement layer but also packaging. It is thus essential that all device aspects are considered during development. Several sensor types are found for chemical measurement, like electrochemical, chemFET, and optical types.

## Remote Sensing

The want to wirelessly transmit information is a common theme of many harsh conditions. Installation and cables can be expensive across longer distances. Wireless transmissions are placed on each sensor, or on the sensor cluster, to reduce overall installation cost while the necessary data continues to be collated.

## Transportation of Natural Resources

Transporting natural resources like natural gas to different locations need pipes snaking thousands of miles. Identification of issues linked with a long underground pipe can be tough, and digging up any area can be expensive. A broken pipe damages not only the natural environment but also the company's reputation. Such incidents also imply a breach of contract as delivery conditions remain unfulfilled.

Unique solutions are weaved to tackle such a hazardous situation. The systems monitor the resource flowing through the pipe, and compare occurred results from what was expected. Discrepancies due to leaks or blockages are identified. This needs a network infrastructure and sensors to gather and transfer information. The problem cause may also be traced to its roots.

## Hazardous Environment

Hazards are described as potential occurrence of fire and explosion in industrial environments. A hazardous area in this context refers to an area where any flammable vapor or gas is found in adequate quantities to create a 'potentially explosive atmosphere.'

### Hazardous Area Classification

Area classification requirements dictate the degree of hazard by describing the presence, nature, and extent of hazardous areas.

Hazardous areas are demarcated into zones based on an assessment of the frequency of occurrence of the explosive gas atmosphere and its duration.

- Zone 0 A particular area where an explosive gas atmosphere remains continuously or for longer periods
- Zone 1 The area where an explosive gas atmosphere will probably occur as part of a standard operation
- Zone 2 The area where an explosive gas atmosphere will probably not occur in normal operation. If it happens, it will do so only for short times.

For gases and dust, there are three zones

Gas	Dust	Hazardous Area characteristics
Zone 0	Zone 20	A hazardous atmosphere is highly likely to be present and may be present for long periods of time (>1000 hours per year) or even continuously
Zone 1	Zone 21	A hazardous atmosphere is possible but unlikely to be present and may be present for long periods of time (>10 <1000 hours per year)
Zone 2	Zone 22	A hazardous atmosphere is not likely to be present in normal operation or infrequently and for short periods of time (<10 hours per year)

Figure 4: Hazardous area characteristics

The Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) lays the link between the zones, and also the equipment that may be installed inside that zone. All equipment categories are explained through the ATEX equipment directive. The standards lay different protection concepts, along with further subdivisions applicable for few types of equipment as per temperature classification and gas group.

Different technical means are available when it comes to building equipment for different categories.

Zone 0	Zone 1	Zone 2
Category 1	Category 2	Category 3
'ia' intrinsically safe EN 50020, 2002	'd' - Flameproof enclosure EN 50018, 2000	Electrical Type 'n' - EN 50021, 1999 Non Electrical EN 13463-1, 2001
Ex - Special protection if specifically certified for Zone 0	'p' - Pressurised EN 50016, 2002	
	'q' - Powder filling EN 50017, 1998	
	'o' - Oil immersion EN 50015, 1998	
	'e' - Increased safety EN 50019, 2000	
	'ib' - Intrinsic safety EN 50020, 2002	
	'm' - Encapsulation EN 50028, 1987	
	's' - Special protection	

Figure 5: Building equipment suitability for different categories

## Protection Concept in Harsh Environment

All protection methods state a common rule. The parts vulnerable to a potentially harsh atmosphere must not reach unacceptable temperatures. Temperatures must be within the temperature class, which applies to the specific potentially explosive atmosphere. The defensive principles against the probability of explosion or ignition due to electrical equipment are elaborated in the following paragraphs.

Different kinds of equipment are employed in these zones to safeguard zero or reduced chances of explosions. Such equipment must be designed and manufactured as per specific construction guidance termed protection concepts. These concepts can be categorized into several principal methods. The latter is explained below, along with a brief description of some of the concepts.

Type of Protection Method	Equipment Code	Description	International Standard	Suitable for Zones
Intended to prevent a potential ignition arising	Ex e	Increased safety	IEC 60079-7	1, 2
	Ex nA	Type -n protection	IEC 60079-15	2
Intended to limit the ignition energy of the equipment	Ex ia	Intrinsic safety 'ia'	IEC 60079-11	0, 1, 2
	Ex ib	Intrinsic safety 'ib'	IEC 60079-11	1, 2
	Ex ic	Intrinsic safety 'ic'	IEC 60079-11	2
	Ex nL	Type -n protection	IEC 60079-15	2
Intended to prevent the explosive atmosphere contacting the ignition source	Ex p	Purge/pressurized protection	IEC 60079-2	1, 2
	Ex px	Purge/pressurized protection 'px'	IEC 60079-2	1, 2
	Ex py	Purge/pressurized protection 'py'	IEC 60079-2	1, 2
	Ex pz	Purge/pressurized protection 'pz'	IEC 60079-2	2
	Ex m	Encapsulation	IEC 60079-18	1, 2
	Ex ma	Encapsulation	IEC 60079-18	0, 1, 2
	Ex mb	Encapsulation	IEC 60079-18	1, 2
	Ex o	Oil immersion	IEC 60079-18	1, 2
Intended to prevent an ignition from escaping outside the equipment	Ex nR	Type -n protection	IEC 60079-15	2
	Ex d	Flameproof protection	IEC 60079-1	1, 2
	Ex q	Sand/powder (quartz) filling	IEC 60079-5	1, 2
Special	Ex nC	Type -n protection	IEC 60079-15	2
	Ex s	Special protection	See IEC 60079-0	0, 1, 2

Figure 6: Protection method with corresponding equipment code

## Intrinsic Safety

Intrinsic safety refers to a designed or engineered explosion protection method integral to that electrical circuit. The intrinsically safe systems restrict energy even when there are multiple failure conditions. Energy controlling apparatuses called intrinsically safe barriers are employed to restrict the energy which will be released if a component or wiring fails. The aim is to stop ignition.

## Tips for Intrinsic Safety Design:

### Battery Selection

Batteries must be sufficiently robust to survive anticipated environmental conditions. It must also minimize electrolyte leakage, which can happen during severe short-circuit environments.

### Voltage-Enhancing Circuits

Although voltage-enhancing and regulating circuits like charge pumps and switching regulators are useful in designing any efficient power supply, the circuits present challenges if not given sufficient voltage limitation using voltage limiters.

### Restrict Energy-Storing Components

Energy-storing parts like capacitors, inductors, and ferrite beads. They are also a challenge when it comes to complying with spark-ignition parameters. The available energy stored in them must be restricted so that there is not enough energy to result in the ignition of an explosive atmosphere. Encapsulation is used to shield circuits against any chances of spark ignition.

### Derate Protective Components

The Intrinsic safety standards dictate that the safety-critical components being used must not exceed two-thirds of their rated voltage, power, and current when subjected to a normal fault and operating conditions. This frequently needs the selection of components that are overrated for that specific application but not enough to fail to offer the needed protection.

### Conformal Coatings

These are essential to enhance the long-term performance and reliability of electronic assemblies. The product offer enhanced protection against dust, shock, vibration, chemicals, dirt, abrasion, fungus, moisture, and mechanical stress. Conformal coatings include one part UV curing formulations, one and two-part silicones, one and two-part epoxies, and a specialized, cost-effective latex system.

### Hermetic Sealing

These devices are fusion sealed within an envelope. Examples of fusion sealing are soldering, brazing, and welding. Glass is also fused to metal to seal against external atmosphere ingress. The electrical contact is generally sealed inside a glass tube.

### Potting or Encapsulation

Molding material encases the electrical energy source and stops any wayward spark from contacting the hazardous substance.

### Restricted Breathing

Gaskets are used to seal the enclosure.

### Sealing Gland

A Sealing Gland preserves an enclosure's incombustible properties at any cable entry hole. These are fitted where any "filled" cable gets used. Any cable, if it remains unfilled, should be used solely in reduced risk situations. A sealing gland offers an anchor, and a pressure seal to bar the cable being propelled out of the gland. It also seals the cable sheath to inhibit moisture access, as the presence of water vapor may corrode the armoring. This procedure must be given the highest importance as it will be the installation's weakest part if the fit is faulty.

### Barrier Gland

A Barrier gland must be fitted where a non-filled cable needs to be used. It is also used where a process fluid or an explosion must be stopped from moving through the cable. A Barrier gland, other than satisfying sealing gland requirements, cannot permit explosions to journey up the cable. Hardened epoxy resin is used to seal the cores to stop transmission through them.

### MIC Cable and Glands

The Mineral Insulated Copper Cable (MICC) is used in Ex d installation as the sheath affords sufficient mechanical protection. The MCC is a certified component device armed with a suitable compression ring. No distinct requirements are needed for the pot seal as it lies inside the Ex d enclosure.

### Unused Holes in Ex d Enclosures

Blanking plugs are used to fill unused holes in Ex d enclosures. These are supplied with the enclosure or proprietary component certified devices. Plugs are a part of the flame inhibition arrangement and thus must be fitted as per certifying authority requirements and manufacturer's instructions. It must not be fitted into a place where an adapter was used but must be sized for the enclosure's original hole.

### Use of 'grease'

The recommended partial protection against moisture inducing corrosion ingress and weatherproofing of joint surfaces is the application of 'a light smear of the non-setting compound.' Several greases were tested across multiple flameproof enclosures. The desired outcome is achieved through the use of suitable grease or a flexible non-setting compound in the flame path provided that the chemicals they come in contact with do not negatively affect them.