



WHITE  
PAPER



Expertise Applied | Answers Delivered

Nehad El-Sherif, P. Eng.  
Technical Product Specialist  
Littelfuse Inc.

# PREVENTING ELECTROCUTIONS AND INJURY WITH INDUSTRIAL GFCI<sub>s</sub>

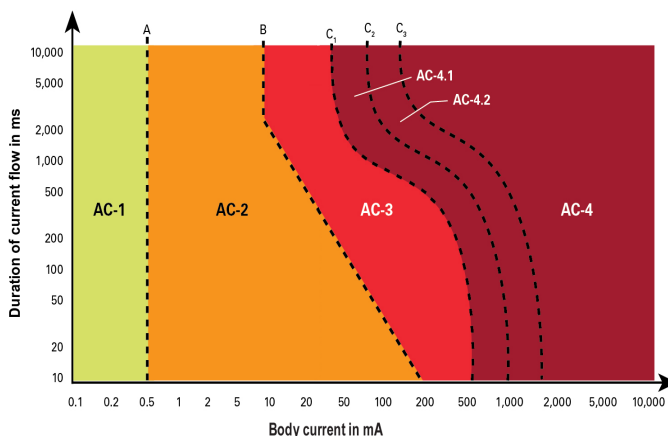
## Introduction

Hundreds of people in the United States are killed by electricity every year, and several times that number are shocked or burned. Most of the industrial cases are caused by contact with overhead electrical lines (which are usually fatal), but there were 66,748 nonfatal electrical industrial in the U.S. between 1992 and 2010 that required time off from work.

Electric current can travel through the human body in several ways: it can go from hand to foot (touching a live conductor, for example, while standing on a grounded surface); from hand to hand, and from foot to foot (stepping on a live conductor). A heavy current passing through the body can cause burns or other injury, but even a much smaller current is dangerous if it passes through the heart: it can take only 50 mA of current through the chest to cause ventricular fibrillation, in which the heart, its internal control system disrupted, ceases to beat normally and instead quivers or writhes uncontrollably. If the fibrillation continues for more than a few minutes without immediate medical intervention the victim will die.

(Figure 1) shows the effects of different levels of current flowing through the body as a function of time. Currents in region AC-1 (up to Line A at 0.5 mA) are harmless and usually not even felt. Currents in region AC-2 (up to Line B) can be felt but still may not do any harm, depending on how long they last. Currents in regions AC-3 can cause involuntary muscular movements (including self-injury from striking objects, or the inability to let go) and, if they continue for more than two seconds, breathing difficulty. Currents in regions AC-4 can cause heart fibrillation, stopped breathing, and severe burns. The longer the current lasts the greater the injury.

**Figure 1.**  
The effects of different levels of the AC Current flowing through the body.



## Methods of Preventing Shock

Every worker is taught the elements of electrical safety, and the normal precautions to take: Turn off power before working on electrical equipment, use lockout/tagout procedures, keep water away from electrical equipment, wear protective gear like rubber-soled shoes and nonconductive gloves when working on live equipment, get proper training, and make sure proper procedures are being followed.

Proper design and maintenance of equipment also contributes to electrical safety; on the design side, double insulation on equipment (which in some cases is required by the NEC) can help quite a bit. On the user side, making sure ground conductors are intact and connected and that all electrical equipment is in proper condition are common-sense measures.

What about the design of the electrical system itself? Some people may have heard, for example, that something called high-resistance grounding (HRG) can prevent problems from shorts to ground. Would that help to reduce the danger of shock?

No, it won't. In an HRG system the neutral point of the three-phase electrical supply is not connected to ground directly (which is the normal arrangement), but through a high-value resistor. The idea is that if one of the hot phases shorts to ground the system will continue to operate, with the fault current limited to a low value by the grounding resistor. HRG systems can keep an electrical system operating in spite of a ground fault, and they can help reduce the danger from arc flash, but they do nothing for shock hazard. The current the grounding resistor will permit is many times what it takes to kill a person, so touching a live conductor can still be fatal.

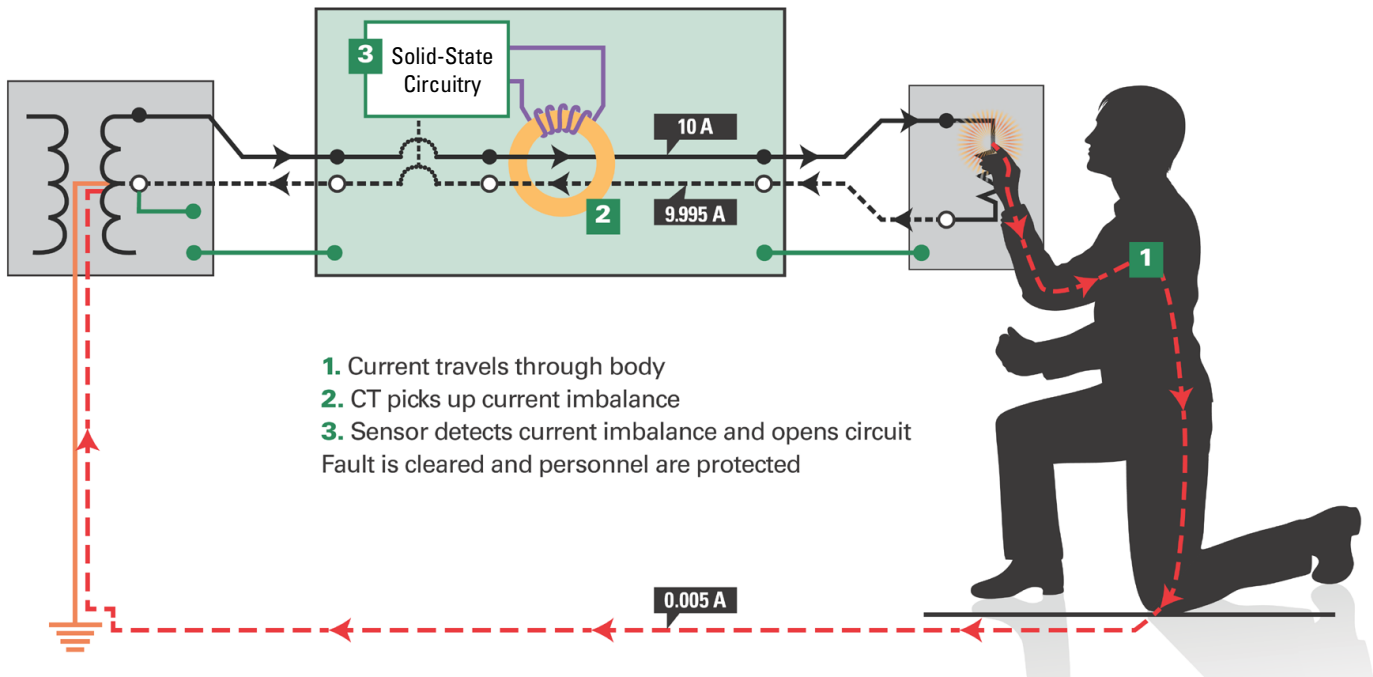
## GFCI is the Answer

There is one device that will prevent death or injury from electric shock: Ground-Fault Circuit-Interrupters (GFCI). GFCI actually detects if current — even just a little bit of current — is flowing where it should not and shuts off the power. Touching a live conductor that is protected by a GFCI will still cause a shock, but the GFCI will open the circuit before it becomes lethal.

## How a GFCI Works

A single-phase GFCI (the simplest example) contains a toroidal current transformer (CT) through which the hot (phase) and neutral (return) lines pass, plus a sense winding (Figure 2). The sense winding feeds a triggering circuit that is connected to a power contactor. If there is no leakage to ground (through bad insulation or a person) the currents in the hot and neutral lines will be equal and cancel each other out in the CT. But if there is leakage (some current going

**Figure 2.**  
Operation of a single-phase GFCI.



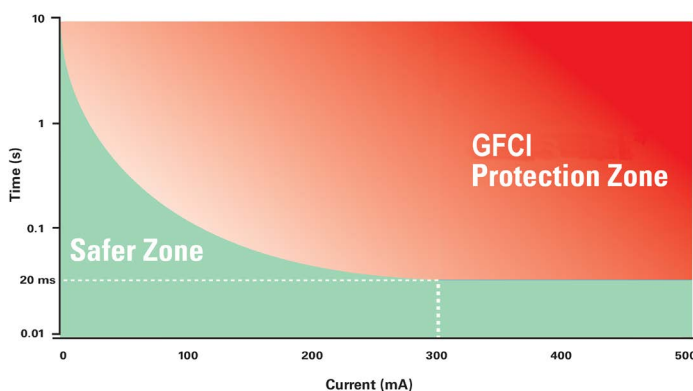
out on the hot conductor does not come back through the neutral) the two currents will no longer sum to zero and the sense circuit will react and trip the contactor to shut off the power.

There are also three-phase GFCIs, in which the current transformer sums the currents through all three hot phases.

The time it takes for the GFCI to operate depends on the amount of leakage current: the more current, the faster the trip. (Figure 3) shows the inverse-time response curve, which is set by UL 943 and defined by the equation:

$$T = \left(\frac{20}{I}\right)^{1.43}$$

**Figure 3.**  
Inverse time trip characteristics of UL-listed GFCIs set by UL 943.



## GFCI Classes and Applications

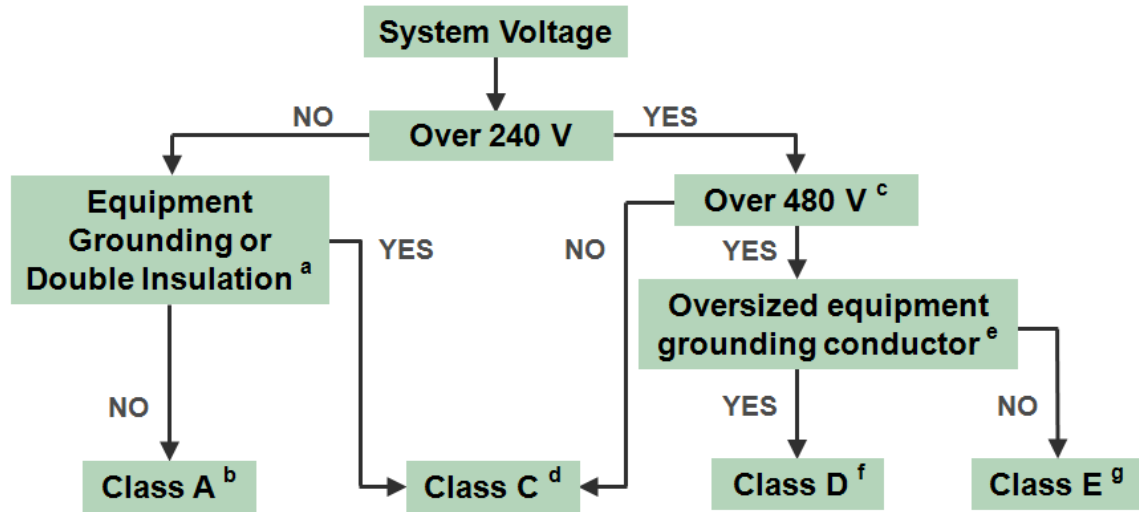
UL divides GFCIs into Classes A and C through E (Class B is obsolete). Household GFCIs, among others, are Class A, while industrial units fall into classes C, D and E.

Class A GFCIs are governed by UL943. In the words of the standard, it covers “single- and three-phase, ground-fault circuit-interrupters intended for protection of personnel, for use only in grounded neutral systems in accordance with the National Electrical Code (NEC), ANSI/NFPA 70, the Canadian Electrical Code, C22.1 (CEC), and Electrical Installations (Use), NOM-001-SEDE. These devices are intended for use on alternating current (AC) circuits of 120 V, 208Y/120 V, 120/240 V, 127 V, or 220Y/127 V, 60 Hz circuits.” Class A GFCIs trip at 6 mA, which makes them unsuitable for most industrial applications.

There are, however, commercial (or quasi-industrial) applications for which Class A GFCIs are completely appropriate. Littelfuse has a line of rental Class A Shock-Block GFCIs that are used to protect workers in the entertainment industry who may encounter wet conditions and cables with worn insulation.

- The SB100 series includes portable plug-in units that handle up to 100 amps over the voltage range of 50 to 240 V; both single-phase and three-phase units are available.
- The SB300 is for three-phase circuits up to 240 V, and can handle up to 100 A.

**Figure 4.**  
How to determine the appropriate GFCI class for a particular application.



**Notes:**

- <sup>a</sup> May be provided but NOT required
- <sup>b</sup> Provides protection against let-go and ventricular fibrillation
- <sup>c</sup> Equipment grounding or double insulation is required by the NEC Sections 250-110 (6) & 250-114 (2)
- <sup>d</sup> Provides protection against ventricular fibrillation while let-go protection is optional
- <sup>e</sup> Required to provide a low-impedance grounding path so that the voltage appearing across the body during a fault does not exceed 150 V
- <sup>f</sup> Especially sized reliable grounding is required (refer to Appendix A of UL 943C for a sample calculation to determine the AWG size required)
- <sup>g</sup> High speed tripping is required since the equipment grounding conductor is not oversized

**Other Classes of GFCIs**

Classes C, D, and E are governed by UL 943C, Special Purpose Ground-Fault Circuit-Interrupters, which was released in November of 2012. UL 943C was introduced to address the two limitations of Class A GFCIs that prohibited their use in many industrial applications. Namely, the system voltage limitation to a maximum of 240 V and a maximum allowed leakage current of 6 mA. These new GFCI Classes are rated up to 600 V, with a trip level of 20 mA. In addition, UL 943C requires the device to monitor the continuity of the ground wire and interrupt power to the load if ground integrity is lost.

- Class C — covers GFCIs for use in circuits with no conductor over 300 V to ground where reliable equipment grounding or double insulation is provided.
- Class D — covers GFCIs intended to be used in circuits with one or more conductors over 300 V to ground, and with specially sized, reliable grounding, to provide a low impedance path so that the voltage across the body during a fault does not exceed 150 V.
- Class E — GFCIs are for use in circuits with one or more conductors over 300 V to ground but with conventional equipment grounding provided for the protected equipment in the system or double insulation.

(Figure 4) shows how to determine the appropriate GFCI class for a particular application.

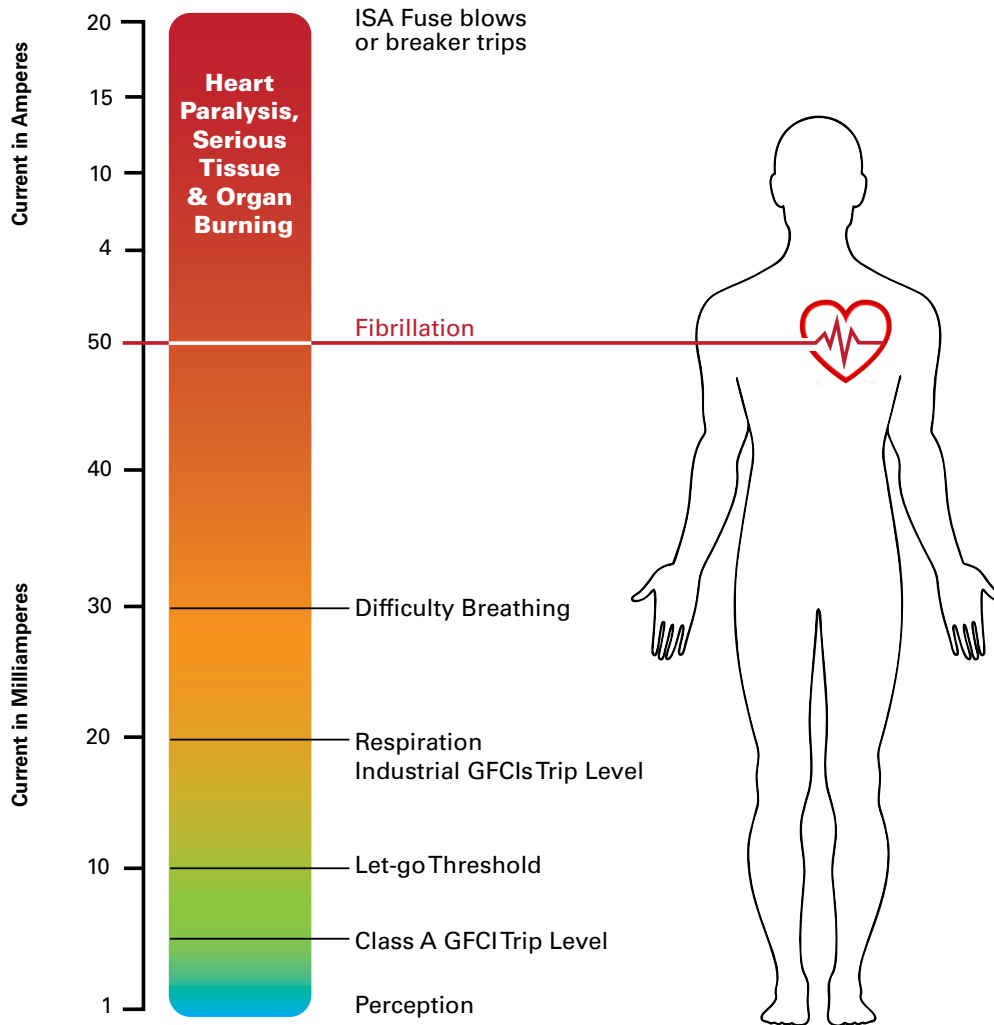
**Is 20 mA Appropriate for Personnel Protection?**

Absolutely it is. There is a misperception that a current more than 6 mA will cause an electric shock and possibly death. This historically roots back to the fact that Class A GFCI personnel protection was set to 6 mA by UL, which was then adopted within North America. On the contrary, the personnel protection level in Europe and Australia is set to 30 mA.

Besides the amount of current flow through the body, the duration of the current flow is another important consideration that is often overlooked. The effect of shock on the body in relation to current and time was shown in (Figure 1). An Industrial GFCI is required to trip not slower than 1 sec for a 20 mA ground faults (Figure 3). Therefore, GFCI protects people as such a trip easily falls into the AC-2 zone of Figure 1. In fact, there is a low probability of injury from currents up to 50 mA that last up to two seconds, which falls in the AC-3 zone – far less risk than many people believe.

The choice of 6 mA for personnel protection was very conservative and was chosen by UL to insure let-go protection to personnel. The let-go threshold is the current level where we lose control of our muscles and we are not able to let go until the current is removed. Typically, the let-go threshold is somewhere between 8-16 mA depending on the age, gender, body size, etc. Accordingly, with the 20 mA trip level, Industrial GFCIs (Classes C, D, and E) provide protection against ventricular fibrillation but do not provide let-go protection.

**Figure 5.** Shows the physiological effects of the amount of AC current flowing through the body.



## GFCIs Compared to Other Devices

There are cases in which normal ground leakage exceeds the 20 mA trip level of an industrial GFCI. In these situations an equipment ground-fault protection device (EGFPD) can be used. EGFPDs can have selectable trip levels up to 50 mA, which helps reduce nuisance tripping on systems with leakage current over 20 mA, but they are not covered by UL 943C (nor listed as GFCIs) because that standard does not allow adjustable trip levels. Yet while UL rates them for equipment protection only, they still provide some protection against shock.

There are also devices called ground fault relays (GFRs). These are used to detect ground faults in HRG systems. While they improve the safety of workers by minimizing other electrical hazards, they do not protect against shock.

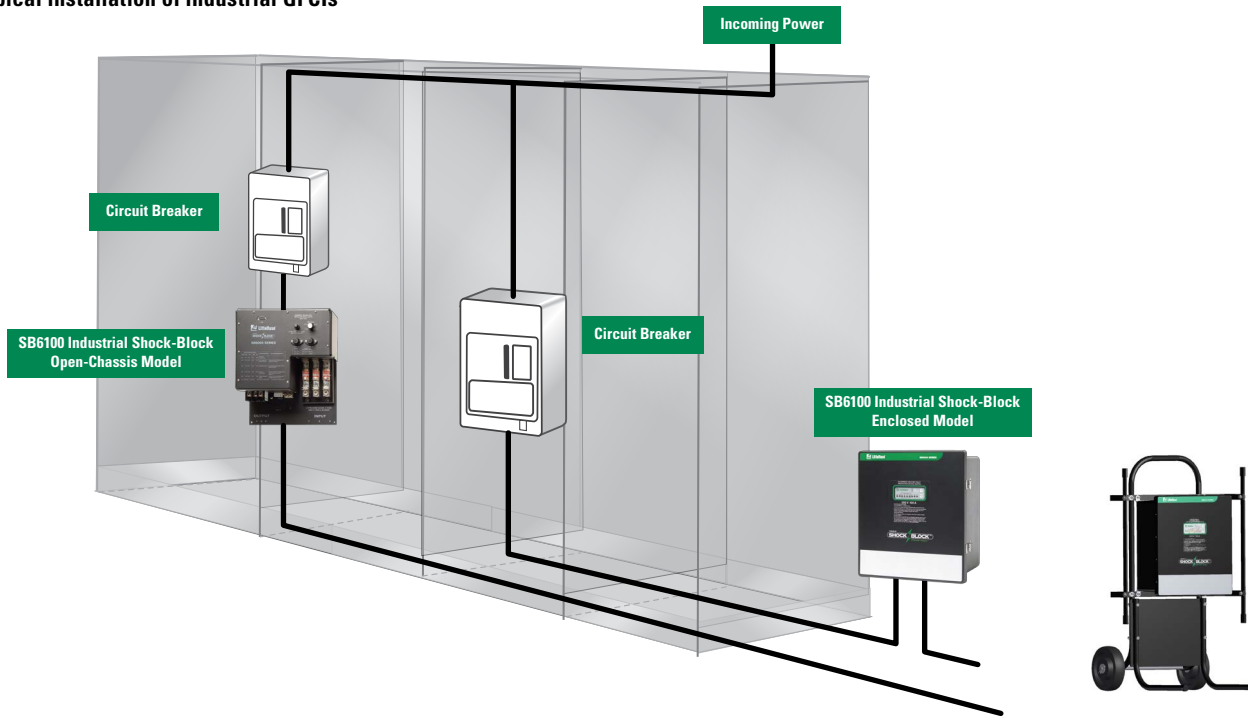
## Industrial GFCIs

Special-purpose GFCIs, such as the SB6100 Series Industrial Shock-Block™, are designed to protect people from electrocutions in industrial facilities. SB6100 is the only GFCI currently on the market that meets the UL 943C standard and is available for voltage from 208 to 600 V with a maximum full load current of 100 A. It has built-in overcurrent protection supplied by Class T fuses. The load can be 1-phase (line-to-line) or 3-phase (without a neutral). The device can be used on either solidly-grounded or high-resistance grounded power systems. It can be used as a GFCI (with a fixed 20 mA trip level) or as an EGFPD (with adjustable trip level of 6 and 10-100 mA in increments of 10 mA).

Two options for enclosures are available: a UL-recognized open-chassis model for installation in existing electrical enclosures, and a UL-listed enclosed model in a NEMA-4X enclosure for stand-alone installations. A movable version is also available. See (Figure 6).



**Figure 6.**  
Typical installation of industrial GFCIs



## Application Examples

### Brick Making

A brick manufacturing plant in the western United States processes clay into bricks and other building materials for residential and commercial projects. The process involves wet saws that operate at 480 V. Out of concern for worker safety, and on the advice of their local electrical inspector, the company searched for an answer. Just about that time the SB6100 Industrial Shock-Block GFCI became available, and the company purchased and installed one. Because of residual leakage current it was necessary to configure the unit as an EGFPD (which has adjustable trip levels settings) and set it to 30 mA, the lowest current that would not cause nuisance tripping. The EGFPD has been operating without incident since installation, and the company is investigating opportunities for additional shock protection at other locations in the plant, including bond beam saws.

### Portable Stud Welder

A coal mine in the southern United States operates a machine repair shop in a building at the mine site. At this shop workers use portable 480 V stud-gun welders. The maintenance manager wanted to find a way to improve worker safety while keeping his process running. He decided to use the SB6100 industrial (GFCI). His challenge was that the device needed to be portable, so it could be used anywhere in the shop, and even in the field. The shop manager purchased a SB6100

Industrial Shock-Block GFCI and a two-wheel hand cart. He wired the GFCI with a six-foot power cord that terminates in a standard plug. On the load side, he added 200 feet of electrical cable that connects to the portable welder. The cables include a ground wire and pilot wire used for ground continuity verification. He reports that his team is happy with the unit because it is lightweight, easy to use, and easy to test. Moreover, he is happy knowing that his workers are protected.

### Working with Submersible Pumps

A large municipal water utility recently acquired a pair of Industrial Shock-Block EGFPD to protect workers who must clean tanks while submersible pumps continue to operate. The utility plans to install the EGFPDs in the motor control centers that supply power to each pump. The shop supervisor is also considering the purchase of a portable version of the SB6100 Industrial Shock-Block EGFPD, which would be mounted on a wheeled dolly. Many dewatering applications are temporary, in which case a portable unit would be useful.



For more information, visit  
[Littelfuse.com/ShockProtection](http://Littelfuse.com/ShockProtection)

Additional technical information and application data for Littelfuse protection relays, generator and engine controls, fuses and other circuit protection and safety products can be found on [www.littelfuse.com](http://www.littelfuse.com). For questions, contact our Technical Support Group (800-832-3873). Specifications, descriptions and illustrative material in this literature are as accurate as known at the time of publication, but are subject to changes without notice. All data was compiled from public information available from manufacturers' manuals and datasheets.