You have decided to conform to the requirements of NFPA 70E, the standard for electrical safety in the workplace. You already have an electrical program for preventing shock; here is an explanation of how to address the 70E requirements for arc-flash.

Flash hazard analysis

On the subject of arc-flash, 70E requires a flash hazard analysis. Although itdoes not explain how to conduct an analysis, it does say the analysis shall determine a "flash protection boundary" and the personal protective equipment (PPE) requirements when working within that boundary.

70E formula to calculate arc-flash boundaries

Dc = (2.65 x MVAbf x t)1/2
where
Dc = distance in feet from an arc source for a second-degree burn
MVAbf = bolted fault capacity in mega volt-amperes available at the point involved—a function of availab
t = time in seconds of arc exposure

Flash protection boundary

Arc-flash boundaries are required around electrical equipment such as switchboards, panelboards, industrial control panels, motor control centers, and similar equipment, when an individual works on or in the proximity of "exposed energized" (energized and not enclosed, shielded, covered, or otherwise protected from contact) components. This includes conducting activities such as examination, adjustment, servicing, maintenance, or troubleshooting. Equipment energized below 240 V need not be considered, unless it is fed by a 112.5 kVA transformer or larger.

The arc-flash boundary is a distance at which a person working any closer at the time of an arc-flash may receive permanent injury (the onset of a second-degree burn or worse) if not properly protected by flame-resistant (FR) clothing. Research has shown that permanent injury results from an arc-flash that causes an incident energy of 1.2 calories/cm2 (cal/cm2) or greater

at the skin's surface.

This distance (boundary) cannot be determined by a casual survey of electrical equipment. The only practical way of determining this boundary is to calculate the magnitude of the arc (a function of the available short circuit current), estimate how long the arc will last (a function of the interrupting time of the fuse or circuit breaker), and then calculate how far away an individual must be to avoid receiving an incident energy of 1.2 cal/cm2.

Small facilities

In small facilities, such as small businesses and offices that use only 240 V and less and have minor power requirements (primarily lighting and receptacle loads), it may not be practical or economical to calculate arc-flash boundaries. It appears the authors of 70E realized this, as they established a default flash boundary that can be used without calculations. The default boundary extends four feet from the energized, exposed components. Any time individuals are inside this boundary, they must wear proper PPE to avoid a permanent injury in the event of an arc-flash.

In most small facilities, the four-foot boundary is likely overly restrictive, making it probable individuals will attempt to avoid use of the PPE, potentially resulting in enforcement issues. In a few cases the opposite may be true; the four-foot boundary may be inadequate to avoid injury due to high incident energy.

70E addresses this limitation in a footnote, qualifying that the four-foot boundary is applicable only where the available short circuit current does not exceed 50,000 A and the clearing time of the fuse or circuit breaker does not exceed 0.1 sec, or any combination not exceeding 5000 A sec. This footnote seems to place small facilities back into the position of collecting data and calculating short circuit current and clearing times to justify using the four-foot boundary. However, in the vast majority of small facilities, if the electrical system were properly designed and if it has been properly maintained by competent electricians (always installing properly sized fuses and circuit breakers), the four-foot boundary should be more than adequate to avoid any permanent injury from an arc-flash.

ting PPE When using 4-ft default boundary

Example of NFPA 70E Hazard/Risk Category Classifications by Task

600V equipment other than MCCs, panelboards, and switchgear

Task	Category
Work on energized parts, including voltage testing	2*

(2* means a double-layer switching hood, hearing protection, hard hat, leather gloves, and leather work shoes are required in addition to the Category 2 clothing requirements.)
(If the available short circuit current is less than 10,000 amperes the hazard/risk category can be reduced by one category level.)

Fig. 1. The first table matches a "hazard/risk category" to a specific task by voltage level and type of equipment.

Other facilities
For other facilities, especially those having employees, contractors, or service personnel who perform functions exposing them to energized components, the four-foot default boundary is probably not practical or appropriate. The experience of this author indicates that a substantial percentage of the equipment operating at 480 V and less in most facilities will have an arc-flash boundary of less than 12 in., which means FR clothing for the face/chest area is not required when working on or near that equipment.

However, experience also has shown that practically every large facility has some equipment where even the four-foot default boundary is not adequate to avoid permanent injury in the event of an arc-flash. Consequently, 70E provides an alternative: a formula (based on IEEE Standard 1584) to be used under engineering supervision, when the limitation of 5000 A sec is exceeded or when realistic flash boundaries are desired. (See accompanying text "NFPA 70E Formula to Calculate Arc-flash Boundaries.") To use the formula requires knowledge of available short circuit current and corresponding clearing time.

Available short circuit current
Determination of short circuit current starts with the electric utility providing information about its

delivery capability at the service entrance/meter point. Receiving this data from the utility can be as easy as a phone call or as difficult as pulling teeth.

Proceeding from the service entrance to the equipment to be worked on, the length, size, and type of every conductor and the nameplate information of every transformer in that path must be recorded. With this recorded data and the right software, a reasonable estimate of the available short circuit current can be calculated for use in the flash boundary formula.

Clearing time

Determination of the arc-flash clearing time at equipment requires collection of data on every fuse and circuit breaker in the circuit between the utility service and the equipment, where the flash boundary is to be determined. Time vs current interrupting information is then acquired from the protective device manufacturer based on the data collected.

Using the short circuit current previously determined and time-current data from the protective device manufacturer, a reasonable estimate of the time required to interrupt the arc-flash can be determined for use in calculating arc-flash boundary.

Formula, software, consultants

For facilities having only a few circuits to be evaluated, using the 70E formula to determine the arc-flash boundary may be feasible. If many circuits are involved, however, commercially available software or a consultant should be considered.

Some commercially-available software performs all the calculations required, including determination of available short circuit current, fault clearing time, and arc-flash boundary. The cost of this software can exceed $10,000, and it should be used under engineering supervision. Keep in mind that data collection is still required for input into the software program.

NFPA 70E establishes five "hazard/risk categories" of FR clothing based on ability to limit the injury to a

Category 0	acceptable for incident energy exposure of	0Ð2 cal/cm2
Category 1	"	2Ð4 cal/cm2
Category 2	"	4Ð8 cal/cm2
Category 3	"	8Ð25 cal/cm2

Category 4	"	25Ð40 cal/cm2

Fig. 2. The second table describes the FR clothing and corresponding incident energy for each of five hazard/risk categories.

PPE selection

NFPA 70E requires that the employer provide and the employee wear appropriate FR clothing and other PPE when within the arc-flash boundary. Selection of FR clothing is based on the level of incident energy the individual will be exposed to in the event of an arc-flash. The level of incident energy is a function of the distance the individual is from the arc-flash (incident energy increases rapidly as the individual moves closer to the arc-flash). Generally, 18 inches is assumed to be the distance between a worker's face/chest and the arc-flash.

Using the same information as was used to determine the arc-flash boundary, the engineer can calculate the incident energy in cal/cm2 at 18 inches. Since FR clothing is rated in cal/cm2, this allows selection of appropriate clothing to protect against the incident energy of exposure.

It is not uncommon for calculated results at 18 inches to show an arc-flash incident energy of less than 1.2 cal/cm2, resulting in no FR clothing requirement for the face/chest area, only clothing that will not melt, such as cotton. However, additional PPE may be required for parts of the body that are closer than the 18-inch basis. It is also not uncommon to find at least one location in facilities where the calculated incident energy at 18 inches exceeds 40 cal/cm2, the highest level that 70E recognizes as being practical to protect (some clothing manufacturers offer clothing with higher ratings).

Small facilities that choose to use the four-foot default boundary in lieu of using the formula will not have the incident energy results necessary to select the proper level of PPE for the arc-flash hazard. For these facilities, 70E provides two tables to use in selecting PPE. The first table matches a "hazard/risk category" to a specific task by voltage level and type of equipment (Fig. 1). The second table describes the FR clothing and corresponding incident energy for each of five hazard/risk categories (Fig. 2).

Limitations of the NFPA 70E tables

Use of the 70E tables to select PPE has limitations. The first table matching the category to the task is limited to electrical systems that do not exceed specified levels of available short circuit current and fault clearing times as described in the table footnotes. Additionally, 70E states that for tasks not included in the table, and for electrical systems that exceed the footnote limitations, the tables cannot be used, and the incident energy must be calculated for PPE selection.

Using the tables when the electrical system exceeds the levels described may expose individuals to hazardous energies beyond the protection of their FR clothing, potentially resulting in serious injury or death. On the other hand, when the footnotes are met, the level of protection can be overly conservative, which may increase hazards to the individual by limiting vision, mobility, and dexterity. In other words, it is always better to select the proper PPE based on the calculated incident energy of exposure. Selecting PPE based on incident energy also may result in substantial savings over the cost of selecting PPE based on the tables.

Labeling

Although not required by 70E, labeling of equipment is an essential part of the flash hazard analysis. Establishing an arc-flash boundary and determining the appropriate PPE is useless if the information is not communicated to the individuals working on or near the equipment with the hazard. The label should be placed in a conspicuous location that will be seen by individuals before they open equipment.

Since 2002, the National Electrical Code (NEC) has required labeling of equipment to warn of potential flash hazards. Although the current NEC requirement does not specify the information to be provided on the warning label, it is likely that future editions will. This author recommends that, at a minimum,, the following information should be included on the label:

- Maximum voltage in the equipment
- Arc-flash boundary
- Required PPE (hazard/risk category or cal/cm2)

Advantages of qualified consultants

An arc-flash analysis by a qualified consultant should provide more than just results of the analysis. The consultant should review each location with an arc-flash hazard requiring Category 1 FR clothing or greater, to determine if any changes can be made to reduce the hazard. He or she should evaluate changing fuse types or breaker settings and other opportunities to reduce or eliminate the need for FR clothing. Thes recommendations can result in substantial economic savings in FR clothing, and reduction or elimination of arc-flash

hazards.

The consultant should provide one-line drawings of the electrical system that has been evaluated, as well as labels for all equipment having the potential of a hazardous arc-flash.

As part of the short-circuit analysis, the consultant should identify any problems in the interrupting capacity of protective devices. Inadequate interrupting capacity can result in the protective device exploding during a major fault, potentially causing injury to personnel and/or costly downtime.

Consultants should make recommendations to improve any overcurrent coordination problems. The objective is for the interrupting device closest to the fault to open first. This minimizes the equipment affected in the event of a fault, improving operations and safety by limiting exposure to electrical hazards when troubleshooting.

Summary

Before purchasing FR clothing and requiring individuals to wear clothing that they may or may not need, complete an arc-flash hazard analysis. Identify the equipment that has the potential to cause permanent injury or death from arc-flash and then evaluate opportunities to eliminate or reduce the hazard, in lieu of using PPE.

After taking advantage of every feasible/realistic opportunity to reduce or eliminate arc-flash hazards, purchase or arrange, through a uniform service, to provide the appropriate PPE. Label equipment with the information necessary for individuals to know the hazard and the required PPE. (This information is also essential for contractors and service personnel who work on or near exposed energized components.)

Train qualified and affected personnel on how to recognize and avoid electrical hazards (shock and arc-flash), and train them on the results of the arc-flash hazard analysis.

John C. Klingler, P.E., is vice president and an instructor for Lewellyn Technology, Inc., Linton, IN. Telephone: (800) 242-6673; e-mail: jklingler@lewellyn.com ; Internet: www.lewellyn.com