

# FESHM 9150: REQUIREMENTS FOR EXPERIMENTAL AND ACCELERATOR HIGH VOLTAGE UTILIZATION EQUIPMENT

## Revision History

Author	Description of Change	Revision Date
Steven J. Chappa David E. Mertz	<ul style="list-style-type: none"><li>• Revised title, introduction, and scope</li><li>• Added definitions section</li><li>• Added requirements for cables and conductors, non-coaxial connectors, bolted and post connections, and grounding to the existing coaxial connector requirements</li><li>• Added warning label section</li></ul>	September 2021
David E. Mertz	<ul style="list-style-type: none"><li>• Revised entire document format to match current Fermilab Environment, Safety, and Health Manual (FESHM) template</li><li>• Made grammatical edits as needed to match outline format</li><li>• Identified persons to approve exceptions.</li></ul>	January 2016
Michael J. Utes	Checked all connectors in document for correct part numbers and obsolescence and made changes where appropriate. Kings brand part numbers were unchanged; Amp connectors have been replaced with Tyco connectors and otherwise have the same names. The 10kV cable connector was changed from Reynolds 167-4535 to 167-3554. The 10kV bulkhead adapter was changed from Reynolds 167-3705 to Kings 1069-1. Also, the Fermilab Stock catalog numbers were updated, meaning they all had 00 added to the end of the old numbers.	December 2010

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## 1.0 INTRODUCTION AND SCOPE

This chapter identifies certain requirements and prohibitions for experimental and accelerator utilization equipment that operate at shock hazard voltages at Fermilab. This policy applies to all Fermilab personnel, experimenters, temporary employees, users and subcontract/term employees working at Fermilab and any leased spaces. Along with AC power distribution systems and low-voltage DC power distribution systems, experimental and accelerator shock hazard voltage systems are used to provide bias or drift DC voltages for various experimental apparatus, and to control particle beams in the accelerators. These DC voltages, and to a lesser extent, AC voltages, are produced by specially designed power supplies that can range from just over 50 VDC to 100 kV DC or more. However, the available current is small, usually much less than 100 mA. Specifically excluded from the scope of this Chapter are the electrical distribution systems covered by FESHM Chapter 9120 and the site 3-phase high voltage electrical distribution system.

## 2.0 DEFINITIONS

For the purposes of this chapter, these definitions shall apply:

Low Voltage - A voltage which is less than 50 volts AC or 100 VDC.

Shock Hazard – An electrical potential that exceeds the thresholds listed in FESHM Chapter 9100. As of this revision the AC threshold is 50 volts or more at an available current of more than 5 mA. The threshold for DC is 100 volts or more at an available current of 40 mA. The current thresholds are what the power supply is capable of delivering, not the current expected during normal operation.

High Voltage - A voltage which is equal to or greater than 600 volts AC or 1000 VDC with available currents in excess of the limits in Section 6.1 of FESHM Chapter 9100. Historically, the term “High Voltage” has had many different thresholds depending on the industry, application, location, and era in which the term was applied. Therefore, clarification should be sought when the term is applied so the intent is correctly understood.

Equipment Chassis – The outer shell of a piece of utilization equipment that prevents access to the components contained within which present a shock hazard, without the use of tools or mechanical locks. This shell shall consist of metal panels or integrated structural components that are at ground potential or properly insulated non-metallic components. These chassis units can range from individual pieces of equipment to equipment racks with the properly secured panels and locking doors installed.

Enclosure – An area with a physical barrier that houses, protects, and prevents personal from approaching close enough to components or equipment which present a shock hazard to contact them or come near enough for an arc to occur. These areas shall have the ability to impede and/or restrict unqualified personnel from getting access within this enclosure, either by engineered means or by administrative methods and procedures.

External – Located outside of an equipment chassis or enclosure as defined in this chapter.

Rated - A term used to indicate that a component, connector, or cable is able to safely accommodate the maximum voltage or current available within a system. This rating shall be indicated by manufacturer specifications or other suitable documentation. For custom-designed components, test data and procedures shall be used to document the ability of a component to withstand the maximum voltage/current levels, plus a suitable safety margin, for which the component is designed.

Exposed Terminal or Conductor – Any ungrounded conductive metal, in part or whole, that make up a source connection or its return connection (if isolated) with which finger contact can be made external to the equipment chassis or enclosure which contains a shock hazard.

### **3.0 RESPONSIBILITIES**

#### **3.1 Department Heads and Group Leaders**

The Department Heads and Group Leaders are responsible that the requirements of this chapter are implemented.

#### **3.2 Electrical Authority Having Jurisdiction**

Provide reviews of instances where deviations from the requirements of this chapter are requested and determine if the deviations will be or not be permitted.

### **4.0 REQUIREMENTS**

These requirements apply to the use of voltages which pose a shock hazard both operational and experimental use, with the exception of the electrical distribution systems covered by FESHM Chapter 9120 and the site 3-phase high voltage electrical distribution system. Exceptions to these requirements require approval from the electrical Authority Having Jurisdiction or her or his designee.

#### **4.1 Coaxial and Triaxial Connector Requirements**

The following policies apply to all coaxial connectors used at shock hazard voltages at the laboratory. Triaxial cables can also be used, with the proper ratings and connectors, for these applications. The following manufacturers' part numbers are provided to guide the selection of standard Safe High Voltage (SHV) connectors for several voltage ranges to foster compatibility at the laboratory. The citing of certain manufacturers' products is to provide an example only and does not indicate a preference for those products.

##### **4.1.1. Incompatibility with signal connectors**

Connectors for use at shock hazard voltages are to be chosen such that they are incompatible with connectors for signal cables.

##### **4.1.2. MHV connectors prohibited**

Because of the well-known physical compatibility of Miniature High Voltage (MHV) connectors with Bayonet Neill Concelman (BNC) connectors, which have a lower voltage

rating, the use of MHV connectors is prohibited without the specific approval of the AHJ for each instance of MHV use.

#### **4.1.3. Chassis connector grounding**

Unless used in a specially designed isolated grounding apparatus or system and approved by the AHJ, the chassis connector shell shall be solidly electrically bonded to the panel on which it is mounted.

#### **4.1.4. Chassis connector mounting hole**

A "D" hole, or other suitable mechanical means, shall be used for mounting all panel connectors to prevent rotation of the connector with respect to the panel's mounting hole.

#### **4.1.5. Recommended Standard Connectors for a System up to 5 kV DC**

- a. The standard coaxial cable connector shall be the Kings Electronics 1705-2, TYCO 51426-1 (old #-AMP 51426-1) (for use with RG 58C/U), or equivalent (STK#1435-211000).
- b. The standard coaxial panel connector for flange mount type should be either Kings Electronics 1707-1 or TYCO 51421-2 (old #-AMP 51421), or equivalent (STK#1435-212000).
- c. The standard coaxial panel connector for "D" hole mount type should be either Kings Electronics 1704-1, TYCO 51494-2 (old #-AMP 51494), or equivalent (STK#1435-211500).
- d. The standard bulkhead adapter for coaxial applications shall be Kings Electronics 1709-1, TYCO 225064-2 (old #-AMP 225064-2), or equivalent (STK#1435-210000).

#### **4.1.6. Recommended Standard Connectors for a System up to 10 kV DC**

- a. The standard coaxial cable connector shall be the Teledyne/Reynolds Inc P/N167-3554, the Kings Electronics 1065-2 (cable group 40) for use with type C cable, or equivalent (STK#1435-170000).
- b. The standard coaxial panel connector shall be the Teledyne/Reynolds Inc P/N167-3555, the Kings Electronics 1064-1, or equivalent (STK#1435-480000).
- c. The standard coaxial panel feed-through shall be the Kings 1069-1 or equivalent (not a stockroom item).

#### **4.1.7. Recommended Standard Connectors for a System up to 20 kV DC**

- a. The standard coaxial cable connector shall be the Kings 1765-1 Teledyne/Reynolds Inc P/N167-3516 (for use with RG 213/U) or equivalent (STK#1435-175000).
- b. The standard coaxial panel connector shall be the Teledyne/Reynolds Inc P/N167-3517 or equivalent (STK#1435-490000).

#### **4.1.8. Connectors for DC Voltages over 20 kV or with currents exceeding 5 amperes**

Connectors for systems that will operate in excess of the ratings of SHV connectors shall be rated for the maximum design voltage and current. If no properly rated commercially available connectors exist, the designer shall prepare an engineering note for the connector or termination method to be used demonstrating that it is safe for the intended use.

## **4.2 Cable/Conductor Requirements**

### **4.2.1. Cable jacket color**

When available as a commercial product, red-jacketed cable shall be used for shock hazard applications. Cables of other colors operating at shock hazard voltages shall bear an appropriate warning label near each termination.

### **4.2.2. Voltage rating**

All cabling and conductors used shall be properly rated for the intended application.

### **4.2.3. Twisted-Pair Cable**

External twisted-pair cables may be used for applications that pose a shock hazard under the following conditions:

- a. The source conductor and its individual return conductor shall reside in the same cable. If there are more than one source conductor in a cable, each source conductor shall be paired with its individual return. The twisted-paired conductors shall be protected by a cable jacket or similar method. Use of a grounded cable shield is at the discretion of the designer or user.
- b. The twisted-pair conductors must be rated for the maximum voltage available from the power source. The cable jacket also must be rated for the same voltage.
- c. Termination of twisted-pair(s) cable to a connector or terminals must not allow any exposure of the conductor(s) to damage or touch. All terminations must be

covered/protected so that no ungrounded conductive part of the connector terminals is exposed.

#### **4.2.4. Ribbon and Multi-conductor Cable**

Use of flat ribbon cable for external cabling at shock hazard voltages is prohibited. A multiconductor cable may be used provided that the same requirements, as those required for twisted-pair(s) cables, are incorporated.

#### **4.2.5. Single Conductor Cable**

External use of a single-conductor, bare or insulated but unshielded, for cabling at shock hazard voltages is prohibited.

*Exception: Single conductors marked for cable tray use used for magnet power operating at 600 volts and below installed in cable tray where the two leads remain adjacent to each other save for at connection to the power supply and the load magnets.*

#### **4.2.6. Installation with Signal Cabling**

The National Electrical Code requires that all cables in raceways, cable trays and boxes be insulated for the highest nominal voltage present. Because coaxial cables are rated by power, not voltage, Fermilab has established a limit of 5 kV for coaxial cables in cable trays or raceways that also carry low-level signal cables. Cables carrying voltages of between 5 kV and 10 kV for very low power applications such as ion pumps and purity monitors may be run in these cable trays or raceways at the discretion of the AHJ.

Cabling for systems over 10 kV shall be run in cable trays or raceways only with cables with similar voltages and with the insulation of all the cables rated for the maximum voltage present in the raceway or cable tray. All accelerator and experimental cabling, of any voltage, is prohibited from running in AC power distribution cable trays or raceways.

### **4.3 Connector Requirements for non-coaxial cables**

Unless noted otherwise, connectors described in this section are considered multi-purpose connectors which are rated for use with voltages of 5 kV and below. For specific cabling applications at shock hazard potentials, non-coaxial cable connectors may be used with the following requirements.

#### **4.3.1. Incompatibility with signal connectors**

Connectors shall be chosen such that they are incompatible with connectors for signal cables.

#### **4.3.2. Keying of connectors**

All connectors are to be keyed or polarized to prevent reverse connection or misalignment of pins/sockets in a multi-pin connector. They also must be mechanically robust to protect the

connection from physical damage and incorporate a means to lock the connection so that a cable cannot be disconnected by mechanical tension on the cable alone.

#### **4.3.3. Voltage rating**

All cabling connectors used shall be properly rated for the intended application.

#### **4.3.4. Connector pins/sockets**

No connectors with pins or blades with which a person could make contact shall be used to deliver power from a source.

#### **4.3.5. Connector pins/sockets assignment**

Separate connectors shall be used for circuits that operate at shock hazard potential and those that carry signal or low-voltage DC. In a connector body, each pin/socket must be paired with its return pin/socket in a 1:1 ratio.

### **4.4 Bolted Terminations and Post Termination Requirements**

Equipment fabricated by Fermilab shall use post and bolted terminations are used for connections to components and conductors that operates at shock hazard potential. In all situations, no terminations or components that operate at shock hazard potential may be exposed.

#### **4.4.1. Bolted connections for conductors and components**

The hardware used must include a method to secure the bolt, lugs, washers, nuts, etc. that make up the connection. This usually includes a type of lock, tapered, or Belleville washer that applies constant pressure on the hardware stack and prevents it from loosening up from equipment vibration or temperature changes. This is especially important in cryogenic environments.

#### **4.4.2. Post connections for conductors and components**

Post connections are those that use solder to attach a conductor to a solder-post within the equipment enclosure. The connection to the post shall incorporate a mechanical means of holding the conductor to the post such as wrapping the wire around the post securely. The conductor is not permitted to be simply “tack-soldered” to the post because the conductor end will come loose if the solder joint is defective or if it fails.

#### **4.4.3. Separation between terminals and return or ground terminals**

Sufficient separation shall be maintained between the source terminals and other terminals of a different potential and/or ground. This includes conductive parts of a component or the chassis enclosure itself. This spacing requirement shall consider the connector/component’s



geometry, the environment (be it dusty, free air, vacuum, etc.), and level and type of voltage applied (be it DC, rms, or pulsed).

#### **4.5 System and Equipment Grounding Requirements**

Most of the grounding requirements for systems that operate at shock hazard potentials are found in FESHM Chapter 9190. In addition:

##### **4.5.1. Independent chassis or enclosure grounding connection**

Most sources (power supplies) and load equipment that operate at shock hazard potential are externally and independently grounded through the AC power cord(s)' grounding terminal or through the rack chassis or mounting equipment's ground connection. However, some load or utilization equipment (detectors, PMTs, etc.) are only grounded through the source's return connection, usually a grounded cable shield. In these situations, the equipment external chassis, metal stands, etc. shall be connected to building ground or potential by means other than, and independent, of this return/cable shield connection.

##### **4.5.2. Isolated equipment or system**

Even in systems isolated from ground, exposed conductive parts must still be kept at ground potential to prevent personnel from contacting parts that may be charged up to a hazardous level. This can be accomplished by either using an impedance ground connection, use of a high impedance "bleeder" connection, or similar means.

If enclosure grounding is not possible, it must be fully enclosed in an outer box, fence or screen of non-conductive material or intentionally grounded metal to prevent personnel contact. Preferably, interlocks will be used to automatically de-energize and ground the shock hazard voltage system if the outer enclosure is opened, but administrative controls may also be permitted.

#### **4.6 Warning Labeling Requirements and Recommendations for Equipment and Systems Presenting Shock Hazards**

If a shock hazard exists, as defined in Section 6.1 of FESHM Chapter 9100, in and around any equipment or installation, one or more danger or warning labels must be clearly and prominently displayed or attached to said equipment.

##### **4.6.1. Labels Used**

There are several varieties of labels that are used to warn of a hazard. Normally, these are labels with red lettering, black bordering, and white background. Most will say "Danger: High Voltage," "Shock Hazard," or "Lethal Shock Hazard". For a system or equipment that presents a lethal electrical shock hazard, one of these types of labels must be used. A "Danger High Voltage" label shall be used for shock hazards in excess of 1000 VDC and 600 VAC at

frequencies under 3 kHz. Labels for equipment or systems that operate at higher frequencies shall be evaluated individually.

#### **4.6.2. Recommended use of a colored triangle type warning label**

When the shock hazard is not yet lethal but can present a secondary hazard, such as falling, a surprise “jerking” reaction, etc., it is recommended that a “shock warning” label, of the appropriate color, be used. Refer to ASSP/ANSI 535 regarding the selection of the proper warning sign, color, and words to be used.

#### **4.6.3. Locations of Labels**

Label shall be placed in one or more locations so that personnel approaching the shock hazard from any reasonable direction will encounter the appropriate danger or warning sign before approaching the hazard closer than the Limited Approach Boundary defined in NFPA 70E for the hazard.

## **5.0 REFERENCES**

NFPA 70, National Electrical Code, 2017 Edition