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Impact of Electrostatic Discharges in the Hospital Environment

NEMA

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NEMA Standards Publication SB 29-1994

IMPACT OF ELECTROSTATIC DISCHARGES IN THE HOSPITAL ENVIRONMENT

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Foreword

In January of 1990, experiments were conducted at Underwriters Laboratories, Inc. (UL) in response to the NEMA Hospital Signaling Group (a subgroup to the NEMA Signaling, Protection, and Communications Section). Laboratory investigative work was done to determine the characteristics of a hospital bed as an electrostatic discharge generator and to learn the characteristics of the discharge current from the hospital bed.

The widely perceived need for technical guidance related to the control and prevention of electrostatic discharge (ESD) in the hospital environment resulted in the formation of an ESD Ad Hoc Committee appointed by Underwriters Laboratories, Inc. (UL). The Committee was charged with evaluating the significance of the ESD problem within a healthcare facility and responsible for formulating recommendations related to the control and prevention of ESD-related problems.

In February of 1991, the ESD Ad Hoc Committee visited several hospitals in Canada to record ESD levels and to discuss the problem with hospital staff.

At this time, neither UL nor the Technical Committee of the NEMA Hospital Signaling Group has a specific repeatable testing program to qualify equipment as "hardened" to survive the worst case scenario problem related to ESD in a hospital.

This Standards Publication was developed in 1994 by NEMA's Hospital Signaling Group to provide information on the impact of electrostatic discharges in the hospital system. The Standards Publication is reviewed periodically for any revisions that may be necessary to keep it up to date with advanced technology. Proposed or recommended revisions should be submitted to:

Vice President, Engineering Department
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Scope

An electrostatic discharge (ESD) event at the equipment level may result in the corruption of system data, equipment lock-up, equipment damage, and the remote possibility of risk to life safety. This Standards Publication provides the technical guidance related to the ESD and its threat in the hospital environment.

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Section 1
REFERENCE STANDARDS AND DEFINITIONS

1.1 REFERENCE STANDARDS

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1.2 DEFINITIONS

AIR DISCHARGE METHOD

A method of electrostatic discharge testing, in which the charged electrode of the test generator is held within some distance of the equipment under test but not in direct contact with it.

AMPERE (EIA)

Unit of electrical current. One ampere of current is 6.24 x 10^{18} electrons passing one point in one second. Abbreviated as amp or A. Example: 1 amp = 1 coulomb/second.

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ANTISTATIC

Having a level of conductivity that typically leads to charge dissipation in from 0.1 to 1 second. Antistatic materials typically have a surface resistivity greater than 10^5 but less than 10^{11} ohms per square inch.

CAPACITANCE (EIA)

Capacitance (C) is the ability of a component or material to store an electrical charge. Typically units are microfarads (mfd) or picofarads (pfd.)

CHARGE (EIA)

Charge (Q) is the energy stored in a capacitor or on an insulated object. Charge is measured in coulombs. The static charge on a body is measured by the number of separated electrons on the body.

CONDUCTOR (EIA)

A substance or body that allows a current of electrons to pass continuously along it or through it when a voltage is applied across any two points.

CONTACT DISCHARGE METHOD

A method of electrostatic discharge testing, in which the charged electrode of the test generator is held in direct contact with the equipment under test.

CORONA (IEEE/ANSI)

The glow or "crown" in the air surrounding a sharp point on a body when the electric field reaches the breakdown (partial discharge) level of air. The charge on a body is sustained and the upper limit is determined by the breakdown level of air. For a given electrostatic charge on a body, charge density is greater at sharp points, edges, or corners. The electric field strength of air, where is starts to breakdown, is approximately 3×10^6 volts per meter at 1 atmosphere of air pressure.

COULOMB (EIA)

A specific quantity of electrons (charge) on a body expressed as 1 coulomb = 6.24×10^{18} electrons. In electrostatics, a much more practical unit is the nanocoulomb, 10^{-9} coulombs, representing a charge of 6.24×10^9 electrons.

CURRENT (EIA)

The flow of electrons past a certain point in a specified period of time, measured in amperes or a fraction thereof. Current is measured in terms of electrons per second, but as this number would be very large, it is usually stated in coulombs per second. Example: 1 coulomb per second = 1 amp.

ELECTROMAGNETIC INTERFERENCE (EIA)

Electromagnetic interference (EMI) is a disturbance caused by static sparks, lightening, radar and television transmission, brush motors, line transients, etc. A spark from a static discharge is a source of EMI. By line conduction or air propagation, EMI can induce undesirable voltage signals in electronic equipment causing malfunction and occasionally component damage.

ELECTROMAGNETIC SHIELD (EIA)

A screen or housing placed around devices or circuits to reduce the effect of both electrical or magnetic fields on or by them. An electromagnetic shield acts as a good electrostatic shield (e.g. iron or steel), but an electrostatic shield does not necessarily act as a good electromagnetic shield (e.g. aluminum or copper).

ELECTROSTATIC CHARGE (EIA) (IEEE/ANSI)

The result of transferring electrons from one object (or human) to another that results in a positive or negative charge that is developed on both human bodies and objects with respect to local electrostatic ground potential.

ELECTROSTATIC DISCHARGE

Electrostatic discharge (ESD) is an extremely rapid equalization of charges between surfaces.

ELECTROSTATIC FIELD (EIA)

The region surrounding an electrically charged object in which another electrical charge will experience a force.

ELECTROSTATIC SHIELD (EIA)

A barrier or enclosure that prevents the penetration of an electrostatic field.

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ENERGY (EIA)
The ability to do or perform work. Electrical energy is measured in watt-seconds or joules. Electrostatic energy is calculated from the relations:

$$W = 0.5 \times C \times V^2$$
$$0.5 \times Q^2 / C$$
$$0.5 \times Q \times V$$

EUT

Refers to equipment under test.

FARADAY CAGE (EIA)

An electrically continuous, conductive enclosure that provides electrostatic shielding; that is, a region of no electrostatic field.

GROUND (EIA)

A metallic connection with the earth to establish zero potential or voltage with respect to ground or earth. There may or may not be an actual connection to earth, but it is understood that a point in the circuit said to be at ground potential could be connected to earth without disturbing the operation of the circuit in any way.

GROUND REFERENCE PLANE

A ground reference plane (GRP) is flat conductive surface whose potential is used as a common reference.

INDUCTION (EIA)(IEEE/ANSI)

The process by which portions of humans or objects can become differentially charged. An electrostatic discharge establishes a charge in a nearby object without physical contact.

INSULATOR (EIA)

A material that does not conduct electricity.

JOULE (EIA)

A unit of energy. The energy of a static discharge is:

$$W = 0.5 \times C \times V^2$$

Where: K = dielectric constant of the medium (1 for air)
C = capacitance of the object
V = voltage of the object

MULTIPLE ESD EVENT

An electrostatic discharge event in which more than one discharge occurs. The time interval between successive discharges may be several microseconds to several tens of milliseconds.

OHM (EIA)

The unit of electrical resistance. It is the resistance through which a current of 1 amp will flow when a voltage of 1 volt is applied.

PHYSICAL CHARGE TRANSFER (IEEE/ANSI)

When a human body or object builds up charge, that charge can be transferred by direct physical contact to equipment or to other objects.

RADIO FREQUENCY INTERFERENCE (EIA)

Radio frequency interference (RFI) is a part or subset of electromagnetic interference. The spark from a static discharge is a source of RFI.

STATIC DISSIPATIVE

Having a level of conductivity that typically leads to charge dissipation in less time than for antistatic materials (i.e., less that 0.1 second.)

TRIBOELECTRIC CHARGE (EIA)

An electrical charge generated by the frictional movement or separation of two surfaces.

TRIBOELECTRIC SERIES

A list of substances in an order of relative positive to negative charging as a result of triboelectric charging effect.

VOLT (EIA)

Term used to designate the difference of electrical potential that exists between two points of a conductor carrying a constant current of 1 ampere when the power dissipated between these points is equal to 1 watt.

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1.3 ATOMIC STRUCTURE OF MATTER

To understand electrostatic discharge (ESD), it is necessary to examine the basic atomic structure of matter. The smallest division of any element is an atom. The atom has a nucleus composed of protons and neutrons. The nucleus is surrounded by particles called electrons which orbit around the nucleus similar to the way planets circle the sun in our solar system. The neutron has no charge; the proton has a positive charge; and the electron has a negative charge. All base elements have the same number of electrons and protons and thus, have a net charge of neutral. The orbits of the electrons represent energy levels or bands. The electrons in the outermost band can be removed, yielding a net positive charge on the atom. This phenomenon occurs as a result of triboelectric action. This is the friction between two nonconducting bodies. When friction occurs, one surface takes on a positive charge and the other surface takes on a negative charge. These charges accumulate on the surface of the body. Conductive surfaces will quickly neutralize excess charge, but nonconductive bodies (called insulators) allow the positive or negative charges to remain on their surfaces.

Like charges repel and opposite charges attract. The force between charges can be determined by Coulomb's Law:

$$F = \langle q(1) \times q(2) \rangle / (k \times r^2)$$

Where q(1) and q(2) are the charges on objects 1 and 2 respectively, r is the distance between the objects, and k is the dielectric constant of the medium. All mediums other than a vacuum act to lessen the force; however, the difference between air and a vacuum in this equation is negligible. Coulomb's Law is the fundamental equation of electrostatics.

The energy on a charged object is expressed by the formula:

$$E \text{ (in Joules)} = (1/2) \times C \times V^2$$

Where C is the capacitance of the object and V is the voltage on the object.

For example, if a hospital bed has a capacitance of 250 picofarads and it was charged to 20,000 volts, the energy, in Joules, would be calculated as:

$$E \text{ (in Joules)} = (1/2) \times C \times V^2$$
$$E \text{ (in Joules)} = (1/2) \times 250 \times 10^{-12} \times (20{,}000)^2$$
$$E = .05 \text{ Joule}$$

When friction occurs between two bodies, one will tend to give up electrons (assuming a positive charge) and the other object will tend to accumulate electrons (assuming a negative charge). The transfer of electrons takes place rapidly and then reduces as the surface energies equilibrate. The magnitude of the charge and associated voltage depends on the speed of movement, types of materials, ambient humidity, surface characteristics, and surface geometry.

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Section 2
PRIMER ON ELECTROSTATIC DISCHARGE (ESD)

2.1 INTRODUCTION

Electrostatic discharge interference is a specialized type of ambient interference that results from the extremely rapid equalization of charges between surfaces. Humans experience ESD as a brief electric shock. Electronic parts straddling a charged and uncharged plastic surface experience ESD as a current flow that can be large enough to instantly cause damage or disruption.

ESD produces heat, light, sound, and electromagnetic radiation throughout the entire spectrum. The failure of only one semiconductor junction in an electronic device can render the device useless. Worse, ESD can cause latent failures so that components can pass tests, but later fail in field use. Modern electronic equipment can have millions of semiconductor junctions. The effects of ESD are cumulative and progressive degradation, over time, that is not readily apparent.

Electrical and electronic equipment have been plagued by ESD problems ever since the semiconductor was invented. In the days of electron tubes, ESD was of little concern. Because of their physical construction, they were highly immune to ESD interference. In semiconductor devices, which require very low power to operate and have circuits smaller than the human eye can see, the effects of ESD began to show up first as mysterious failures of field effect transistors. As the operating current requirements of semiconductor devices decreases, their operating speed increases; as the size of the devices decreases, their susceptibility to ESD damage increases.

The minimum voltage necessary for a person to be aware of his or her involvement in an electrostatic discharge is approximately 3,000 volts. Nevertheless, sufficient energy may be contained in electrostatic discharges that occur below this threshold of human perception, to cause upset or damage to electronic equipment that may be involved in such an ESD event. Much attention has been paid to higher voltages because the test voltages used to test equipment in the laboratory have generally been much higher than an actual field event. These voltage levels have then become the standard for establishing "field readiness" for equipment. Unfortunately, ESD solutions based solely on high voltage levels were not always adequate. As a result of a better understanding of the ESD phenomenon, better test equipment and test methods have been developed to eliminate these problems.

Test equipment and test standards (IEC, ECMA, IEEE/ANSI, etc.) place emphasis on the discharge current waveform as observed and characterized by studies on human and furniture ESD events.

2.2 THE EVENT

The electrostatic discharge phenomenon occurs when charges of opposite polarity accumulate on the surface of two items in relatively close proximity. This imbalance of positive and negative charges causes a flow of charge that results in neutralizing one or both surfaces. This flow of charge can include an arc (or spark) that has current and voltage.

The term "ESD event" includes not only the discharge voltage and current, but also the electromagnetic fields and corona effects before and during a discharge.

It has been shown that ESD sparks generate electromagnetic interference (EMI) in the range from 25 MHz to above 1 GHz.

This EMI can be picked up by conductors or devices in electronic equipment that tends to act as antennae. These induced voltages can be as disruptive as any conducted discharge. Thus ESDs can affect circuits by direct contact or by induced charges from as much as 10 to 20 feet.

2.3 PRINCIPAL CHARGING PROCESSES

One common type of charging process is called "triboelectric charging" or static generated by frictional movement together of two insulating materials.

When friction occurs between two bodies, one will tend to give up electrons thereby assuming a positive charge and the other object will tend to accumulate electrons becoming a negative charge. The transfer of electrons takes place rapidly and then reduces as the surface energies equalize based on object capacitance. Paramount in this charging process is the envelope of conditions and geometry that surrounds the objects and therefore impacts their charging. Variables such as relative humidity,

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temperature, atmospheric pressure, materials, contaminants, and the object's shape and size will control the charge that is developed on the bodies with respect to each other and with respect to local electrostatic ground.

In addition, the geometry of the object surfaces, as well as object spacings, affect the charging process.

Any object can become positively or negatively charged, depending upon the material with which it comes into contact.

The following list empirically established provides a rough guide to determine the relative magnitude and polarity of the charge when two objects on the list are involved in triboelectric action:

POSITIVE

- Air
- Human Hands
- Asbestos
- Rabbit Fur
- Glass
- Mica
- Human Hair
- Nylon
- Wool
- Fur
- Lead
- Silk
- Aluminum
- Paper
- Cotton
- Steel
- Wood
- Amber
- Sealing Wax
- Hard Rubber
- Nickel, Copper
- Brass, Silver
- Gold, Platinum
- Sulfur
- Acetate Rayon
- Polyester
- Celluloid
- Orlon
- Polyurethane
- Polyethylene
- Polypropylene
- PVC (Vinyl)
- Silicon
- Teflon

NEGATIVE

Typically, the further apart two substances are on the list, the greater the magnitude of the charge generated. Items nearer the top of the list will tend to become positively charged when rubbed with an item from lower on the list. Conversely, items lower on the list will tend to become negatively charged when rubbed with an item higher on the list.

This list is general; such environmental factors as humidity, surface cleanliness, and the total surface area are also involved.

For example, if you were to rub nylon with orlon, the nylon will become positively charged and the orlon will become negatively charged. If you were to rub orlon with teflon, the orlon then becomes positively charged and the teflon will become negatively charged.

Charges on insulators are immobile and tend to remain in the localized area of contact, while those on conductors are mobile and are rapidly distributed over the surfaces of all conductive objects they touch. This is because conductors have millions of free electrons that can move among the atoms and flow in a continuous stream. Insulators, such as glass, mica, or plastics, have few free electrons and oppose the movement of electrons.

Air is generally considered a good insulator, but moisture (humidity) in the air can increase conductivity. Pure water is also a good insulator, but the addition of natural minerals and other impurities greatly will enhance its conductivity.

Earth is an excellent conductor. If a charged object connects to earth, it is said to be grounded. Conductivity is classified based upon the surface resistivity of the material. (See Table 2-1.)

When an object becomes charged, that charge can be transferred by direct physical contact. This is referred to as charging by physical charge transfer. Objects that are in close proximity to charged bodies can also become charged by induction, where there is no physical contact.

The geometry of the surface of a charged object limits the surface charge density and the electric field intensity associated with it. For a given electrostatic charge on a body, charge density is greater at sharp edges or corners. The corona discharge voltage limits the amount of charge an object can sustain.

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Table 2-1
CONDUCTIVITY CLASSIFICATION FOR PURPOSES OF ELECTROSTATIC DISCHARGE (12)

Classification	Surface Resistance in Ohms-per-Square
Conductive	0 to 10^4
Static-dissipative	10^5 to 10^9
Anti-static	10^{10} to 10^{13}
Non-conductive	> 10^{13}

The electric and magnetic fields produced by an electrostatic discharge will vary depending upon the charge voltages and other parameters. Characteristics of these induced fields are:

a. The field spectra is broadband in nature. Field components may produce from the low kHz to the low GHz depending upon the type of discharge.

b. The fields are transient in nature, the duration being dependent upon the charge transfer method.

c. The peak levels produced can be on the order of a few kV/m for the electric field and a few tens of A/m for the magnetic field. Specific levels are dependent on the exact discharge current waveform.

Field levels and characteristics produced in any ESD event are dependent on the discharge current waveform. The equipment receiving the field charge and the person or equipment transmitting the charge each act as an antenna and the radiated energy levels will vary as their geometry, shapes, and materials are changed.

2.4 FAILURES CAUSED BY AN ESD EVENT

The voltage sensitivity of several technologies is listed in Table 2-2. ESD created failure modes include:

a. Junction burnout in which a hot spot is formed in a semiconductor junction by a constant voltage pulse. If the pulse is long enough, the silicon in the hot spot will melt and short circuit the junction.

Table 2-2
SUSCEPTIBILITY OF VARIOUS DEVICES EXPOSED TO ESD

Device Type	Range of ESD Susceptibility (Volts)
VMOS	30 – 1,000
MOSFET	100 – 200
GaAsFET	100 – 300
EPROM	100
JFET	140 – 7,000
SAW	150 – 500
Op-amp	100 – 2,500
CMOS	250 – 3,000
Schottky Diodes	300 – 2,500
Film Resistors (Thick, Thin)	300 – 3,000
Bipolar Transistors	300 – 7,000
ECL	500 – 1,500
SCR	600 – 1,000
Schatiky TTL	1,000 – 2,500

b. Dielectric breakdown (oxide punch-through) is typical of MOS-type components where voltage applied across the dielectric exceeds the breakdown voltage of approximately 8 x 10^6 volts per centimeter (80 volts for 1000 Angstrom technology). When the dielectric is punctured, current flows, destroying the oxide and creating a short circuit.

Dielectric breakdown occurs in insulators when an induced electric field exceeds the electric field between nuclei and the electrons which bond the nuclei together.

In conductors not all of an atom's electrons are needed to create chemical bonds. The left over electrons are free to move under the influence of an external electric field without damaging the bonds. In an insulator, however, all the electrons of each atom are necessary to form the bonds that hold the material together. Consequently, when an induced internal field wins the tug of war over the nuclei for the bonding electrons, some electrons break loose from their atoms. These initially freed

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electrons create an internal current, causing an avalanche effect as they move through the insulator. The material, in effect, falls apart in the region of the insulator where the breakdown occurs, often creating a channel through the insulator.

If a charged conductor contacts a MOSFET device's lead, the conductor's charge will transfer to the conductive area of the chip, creating very high localized electric fields because of the small capacitance (i.e., 1 pF or less) of these internal areas. After breakdown is initiated the conductor's charge will add to the induced internal current, thereby causing substantial heating of the conducting path. Often there is sufficient heat to melt some of the metalization and spew it along the surface of the breakdown channel, causing what is referred to as a "gate short" of the semiconductor substrate in a MOSFET.

c. Metalization melt occurs when an ESD transient increases the temperature of the part sufficiently to melt metalization strips or fuse bond leads creating an open circuit. (See Figure 2-1.)

d. Another ESD-created failure is disruption of microprocessors. This is likely to occur when a charge is conducted or induced onto high impedance tristated data and control busses of microprocessors, disrupting data, program counters, memory address, or even serial data in multiplexed systems. Such failures need not actually damage the device to cause a unit failure. If a microprocessor is severely disrupted, it can lock into an endless instruction loop or even into a continuous restart mode. A severe enough ESD event can also cause limited and/or permanent damage to a microprocessor-based system.

2.5 MEASUREMENT TECHNIQUES

To date, there are no accurate methods or devices for measuring either the voltage or current produced during an ESD event. Most technical reports in this field utilize developed standards of measurement or, due to inconsistencies in existing measurement devices, take repeated measurements in order to provide an average value. In all cases measurements should be made in an environment of controlled humidity (typically 10% relative humidity) and temperature (typically 72 degrees Fahrenheit).

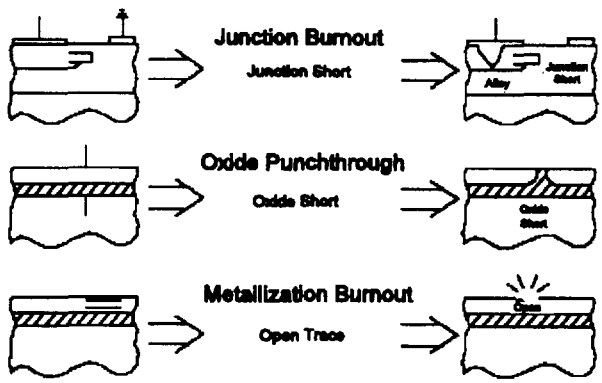


Figure 2-1
ELECTRICAL OVERSTRESS INDUCED FAILURE MECHANISMS

It has been claimed that charge voltage can be as high as 70 to 100 kV when both extremely low humidity environments, below 20% relative humidity, and nonconductive synthetic materials are involved.

The issue is the accuracy of the simple charge meters that may have been used in some of these investigations, when the charged object is very large. The most popular hand-held measuring devices for ESD are called static meters, electrostatic voltmeters, electrostatic field meters, static sensors, etc. They are generally calibrated in voltage (kV) and are claimed to measure the charging voltage when they are reset to zero at zero potential (far away from the charged object) and then held a fixed distance away from the charged object. In fact, field meters do not measure the voltage. Some of them measure the field strength at the surface of the field meter's probe. Others form a kind of capacitive voltage divider between the charged object and the person holding the field meter. In both cases, the measurement result depends on the geometry of the measurement situation. Measurements of charged persons with a field meter should not be considered unless the geometry dependent measurement error is carefully corrected.

All known field meters used to measure the voltage produced by an ESD event are non-contact and, therefore, do not lower the voltage to be measured by introducing its own input impedance between the item to be measured and

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ground. The field meter is then placed a fixed distance from the item to be measured, and is sensitive to the electric field produced by the charged item. Some field meters are connected to ground and voltage measurements are made with respect to ground. Others are battery powered and require no ground connection.

Since fieldmeter measurements are based on field strength and convert field strength to voltage based on an average object capacitance, object size and shape are critical to measurement accuracy. All fieldmeters seem to show acceptable results when measuring a charged object that is 10 centimeters or less in diameter. For larger objects, the voltage reading is typically overestimated by as much as 5 to 10 times.

The most reliable method of measuring ESD voltage levels is with a high impedance contact probe. Potential errors using this device are relatively small. In addition, this method of measurement should be the reference for determining the charging voltage of a person.

2.6 SIMULATION AND TESTING

No precise model exists for replicating the ESD effects of the human body or furniture, such as a hospital bed, on an intended environment. However, it is possible to simulate these effects using an ESD gun and then measuring the results. The current waveform from an ESD event is normally depicted as a rapidly rising pulse with an exponentially falling tail. Many studies have been conducted on what constitutes an ESD event, in particular, the act of a person's charged finger touching a device. In the past, the human body model consisted of a highly charged (10,000 volts to 25,000 volts) capacitor (60 pF to 300 pF) in series with a resistor (100 ohms to 1500 ohms). Presently, a more accurate model has been developed. This new model takes into account an initial spike in the current pulse waveform that may be the main cause of equipment disruption and damage.

Without the proper test equipment and test procedures to measure and simulate discharge event characteristics, equipment that passed tests in the laboratory could fail in the field. Two standards that specify this improved model, and the proper testing and simulation of it, are IEC 801-2 and IEEE/ANSI C63.13 (draft). These standards not only specify a more accurate testing and simulation model, but they also specify transferring energy through a vacuum using a vacuum relay to discharge through. This allows repeatable testing and simulation. ESD simulators are available today to meet these requirements. The probe specified by the IEC and IEEE/ANSI standards resembles a human finger and is imparted with a voltage potential of up to 15,000 volts for air discharge and up to 8,000 volts when the vacuum relay is used.

During ESD testing, the device under test is plugged into the power line and the tip of an ESD gun is brought into the vicinity of targets on the device that deserve scrutiny. Usually 20 to 50 shots are used to determine acceptability with no malfunctions occurring. A log is created of performance on several points on the device. Any cracks, crevices, metal parts, sharply curved areas, keypads, etc. should be specially included in the log. A single isolated failure is usually not considered significant but repeatable failures are.

The voltage on the ESD gun is always adjusted to the lowest level first, usually 1,000 volts. Unless the device has previously been characterized, higher voltages must never be tested before lower voltages. An unusual property of ESD is that failures can occur over a range of voltages due to the random flow of currents in the device.

At low voltages, there is very little corona, and therefore rise times will be fast and peak currents high. At high voltages, there is much corona, which bleeds off the charge, but multiple ESD events become common. Successful correction of ESD malfunctions often require component, layout, and even software changes.

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Section 3
ESD RELATED TO THE HOSPITAL ENVIRONMENT

3.1 THE PROBLEM

Any piece of signaling equipment that can be touched by a human can be victim to an ESD event. The patient's room is considered to have the highest ESD activity in the hospital and is considered to be the greatest area of threat to the nurse-call system. The most common ESD event in the patient room is the charged hospital bed discharging to humans, nearby objects, or directly to the nurse-call system. This results in disruption or even damage to the nurse-call system.

The environment in which the nurse-call system is susceptible to ESD damage or disruption is very predictable:

a. The facilities are equipped with a majority of ungrounded beds.

b. Low humidity (less than 20%) contributes to the ESD problem. Low humidity occurs during the heating and/or cooling season. Steam heated (closed hot-water hydronic) and other non-forced air systems are particularly prone to dry heat, as can a forced air system with no humidity control. The charge can remain on the bed for periods over 30 seconds in duration. The humidity in the air allows charge to bleed off over a period of time. These charges seek either earth ground, an oppositely charged body, or a large conductor (such as a conduit system.)

c. Air tends to circulate less during heating/cooling on the upper floors of high rise facilities, and becomes drier, resulting in more ESD problems.

d. Facilities with poor installations or installation techniques are susceptible to ESD-related problems. The back box and conduit system provide an excellent electromagnetic and electrostatic shield. This does not eliminate damage or disruption to nurse-call systems, but does limit damage and disruption. Also, a conduit system can be an important contributor to protection schemes that are available.

Electrostatic voltages are easily created by changing the linens on an ungrounded (typically non-motorized) hospital bed. The resulting ESD can be capable of damaging an electronic system in contact or in close proximity to the bed. The triboelectric charge generated by the friction between the bed linen and the mattress cover is accumulated on the mattress and bed frame, but cannot discharge to earth ground because the bed is suspended on plastic or rubber insulating wheels. Discharge currents from an ungrounded bed can reach peak currents of several hundred amperes compared to a human body that may produce ESD currents of 5 to 10 amperes. Voltages are always present on the bed. Due to the factors listed above, these voltages will typically be at the upper voltage limits as compared to other equipment or objects in the hospital.

The patient call station is particularly susceptible to damage. This is due to the fact that the call cord or pillow speaker is often left tied to the bed rail or clipped to the sheet or pillow case. This provides a convenient path for the charge to discharge to earth ground. A spark discharge to the patient call cord can create electrical stress that can disrupt or damage the patient station (i.e., false calls can be generated.)

Hospital personnel often question the vulnerability of nurse-call equipment by comparing these systems with other patient monitoring systems, telephones, and other patient room equipment. None of this other equipment is in close proximity to the bed during linen changes and consequently are not subject to potentially damaging ESD from the bed.

Some wonder why new nurse-call systems are more vulnerable to ESD than the older systems they replace. In general, the increased sensitivity is due to changes in nurse-call system technology that facilitate the use of large scale integration (LSI) components, enabling the system to provide many more features in a smaller unit with fewer conductors. The older nurse-call systems that were more immune to ESD typically used relay logic.

A typical device used in modern bedside stations can have over 20,000 transistors in the same area occupied

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by one relay. The smaller size of the individual gate or junction is directly related to the increased sensitivity to ESD. Potential system problems are more likely within specific market groups, all of which share the ESD-vulnerable environment. This group includes:

a. Canadian hospitals built before 1980.

   Ninety to ninety-five percent of all hospital beds in Canada are non-motorized ungrounded beds. Nearly all hospitals built in the late 1950's and the early 1960's (when the Canadian hospital market went through a large construction boom, many of which are now undergoing or planning renovation) were multiple story steam-heated (closed hot-water hydronic) facilities.

b. U.S. Veterans Administration (VA) hospitals built between 1945 and 1970.

   In the 1950's and early 1960's, many multiple-floor steam-heated (closed hot-water hydronic) VA facilities, with multiple generations of beds, a large percentage of them non-motorized and ungrounded, were built. There are also many beds in these facilities with orthopedic assistance hardware that contributes to the potential ESD problem.

c. Pediatric hospitals and wards of hospitals.

   These smaller beds and cribs are often non-motorized and ungrounded and frequently used to transport patients, making it inconvenient to ground beds.

d. Nursing homes in the northern U.S. and Canada.

   In these multiple floor facilities grounded beds are seldom found and steam-heating (closed hot-water hydronic) is common.

e. Older rural and community hospitals in the northern and mountain areas of the U.S.

   Typically funds to replace beds in these facilities are limited. Often the beds and cribs are non-motorized and ungrounded and steam-heating (closed hot-water hydronic) is common.

These market groups generally award installation to the lowest bidder, discouraging contractors from including ESD-preventative installation measures (i.e., conduit, shielded cabling, etc.) due to the added cost.

3.2 THE HOSPITAL BED

3.2.1 The Ungrounded Bed

An ungrounded (typically non-motorized) bed can be described as a large insulated conductor. The bed frame is insulated by the plastic or rubber wheels on the bed. The vinyl covered mattress is in direct contact with the bed frame and the bed linen on top of the mattress.

Triboelectric charge is produced when the linen is removed from the bed. A negative charge accumulates on the mattress cover and a positive charge accumulates on the bed linen and the staff member removing the linen from the bed. The charge on the bed frame occurs from the induction process due to the contact between the mattress and the frame.

If the bed was grounded, the charge would be drained off. The charge on the mattress cover would also drain off through the bed frame to the ground conductor to earth. This draining would occur simultaneously as the charge is developed, preventing the mattress charge from reaching excessive levels. The bed frame would have no charge.

If the humidity in the room is high, the charge would be dissipated into the air again as fast as it is generated. If the humidity is low and the bed is not grounded, the bed frame and the mattress cover will retain this large charge.

When the call cord or pillow speaker from the nurse-call system is attached or is wrapped in close proximity to the bed frame or bed rail or attached to the bed linen or pillow case, it provides a conducting path for the charge seeking the ground wires inside. A direct discharge can occur with a spark from the frame to the wires inside the cord or entertainment speaker. If the discharge occurs to the floor or some other object and not the pillow speaker wires, voltages will be inductively coupled into the pillow speaker wires in the form of EMI. Secondary charges will occur in the patient station circuitry as a result of either the direct or indirect ESD events. A large charge will spark from the patient station circuitry to the back box or conduit system, whichever provides the shortest spark gap. This secondary spark inside the station is particularly damaging to the electrical components.

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In addition to the high voltage and current directly coupled into the device leads, the spark disrupts signals on the station conductors and field wires through induction. This additional coupling can damage other nurse-call system equipment connected to the affected room by the field wiring.

There is seldom only one discharge. In addition to the initial discharge from the bed frame, the staff member holding the bed linen has a charge of equal magnitude. When this staff member leans against the bed or touches the pillow speaker, a second discharge occurs repeating the process. Manufacturers of ESD-related test equipment, have developed a human body and furniture model (Figure 3-1) called the dual RLC (Resistor Inductor Capacitor). The dual RLC circuit model has become generally accepted to account for an electrostatic discharge from a human body and small metal furniture.

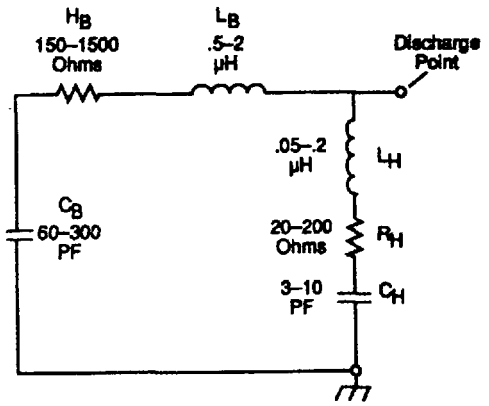


Figure 3-1
THE TWO-RLC MODEL FOR HUMAN ESD

The human body model takes into consideration the initial current spike of the hand holding a metal object.

In addition, when applied to furniture, the dual RLC takes into consideration the capacitance and inductance of the furniture to free space and through the discharge point.

The dual RLC includes the capacitance to free air of the body and of the element of the point of discharge (such as a finger at the end of an arm). The stored energy is initially transferred from this localized area first before the rest of the energy stored on the main body is transferred. This occurs in less than a pico-second. Series resistance is also present and is a small limiting factor as to how fast and how much energy is transferred initially. A series inductance exists that is the primary limiting component that controls the pulse speed and energy amount.

It should be noted that the hospital bed frame reduces the inductance in this equation. This reduction in inductance has a direct effect on the rise time of the initial discharge waveform and can reduce this rise time to less than 1 nanosecond. A change in waveform rise time has a direct effect on the protection circuitry to reduce ESD failures and on grounding schemes used to conduct is charges to ground. ESD protection circuitry must be able to react to signals with rise times of less than 1 nanosecond and ground conductors must be conductive for giga-hertz signals (a 2-foot, 22 GA wire will look like an open circuit to a 1 giga-hertz impulse).

3.2.2 The Empty Bed

When bed linen is changed on an empty bed, the staff tends to quickly remove the sheets thereby generating a large amount of friction. With no patient in the bed, there is no patient monitoring equipment attached. Also, the staff tends to replace a telephone onto an adjacent table or cabinet before changing the linen, but leaves the nurse-call call cord and/or entertainment speaker wrapped around the bed rail.

3.3 CHARACTERISTICS OF AN ESD EVENT WITH A HOSPITAL BED

Electrostatic discharges from the bed are examined here. Discharge waveforms characterize typical events. Human body discharges to the bed, where the nurse call equipment can be indirectly affected, are not presented here. Investigations of the human body discharge have been characterized using present day instrumentation (1 GHz) and are described in the IEEE/ANSI C63 (draft) and IEC 801-2 standards. Common mobile furnishings, such as chairs and carts, discharging to the bed, can also affect nearby nurse call equipment. Furniture discharge of this type will not be presented here. Furniture discharge of this type have also been characterized and specified by ECMA TR40 and IEEE/ANSI C63 (draft). What is important, however, is that discharges from furniture and other large metal objects have a much higher amplitude than human ESD and can cause equipment disruption and damage at lower threshold levels.

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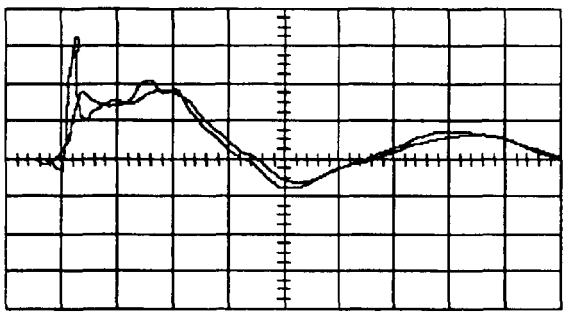
3.3.1 Electrical Characteristics

The electrical characteristics of the hospital bed and the relationship between the bed's mechanical construction and its electrical characteristics were investigated. The capacitance of the bed is approximately 300 pf. It has been determined (see reference 27) that the structure and its distance to ground had little affect on its capacitance. The bed has twice the free space capacitance of an equipment cart and has four times the free space capacitance of a metal-framed chair. (See reference 27.) This capacitance is, however, still in the range of the human body capacitance.

3.3.2 Typical Current Waveforms

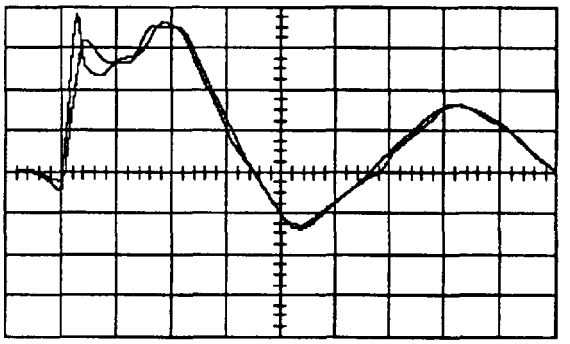
Figures 3-2 through 3-5 are of typical hospital bed current discharge waveforms. Charge voltages of 2 kV, 4 kV and 8 kV were used to correlate with present furniture test charge levels (ANSI and ECMA).

Figure 3-2 shows discharges from a bed that was charged to 2 kV. Shown are two waveforms that are discharges from the same discharge point. Note that in one waveform an initial spike precedes the main waveform. The initial spike is common in human body discharge and is less common in furniture discharge. This phenomenon is easily produced by discharging from the corners of the head of a screw, empty hole or bolt. The peak current of the oscillatory wave is up to 20 amperes (10A/div). Note the fast rise time of the wavefront is less than a nanosecond. This depicts the discharge capability of producing frequencies in the giga-hertz range.



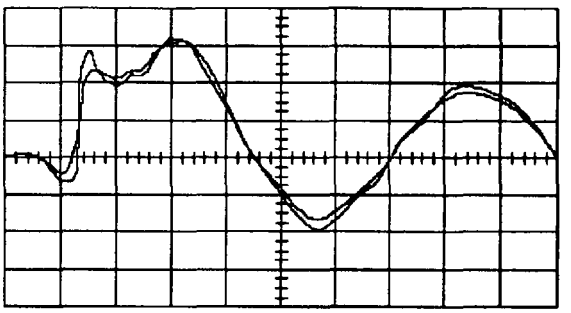
10.0 ns/div

Figure 3-2
2 KV BED DISCHARGE (10A/DIV)



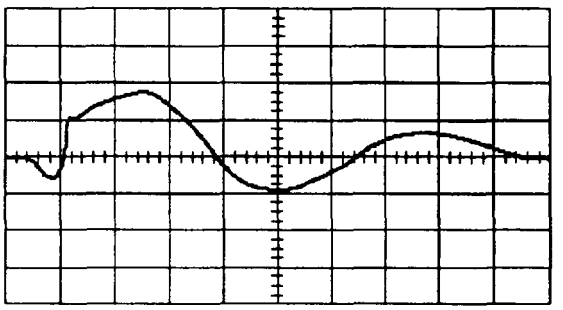
10.0 ns/div

Figure 3-3
4 KV BED DISCHARGE (10A/DIV)



10.0 ns/div

Figure 3-4
8 KV BED DISCHARGE (20A/DIV)



10.0 ns/div

Figure 3-5
4 KV BED DISCHARGE

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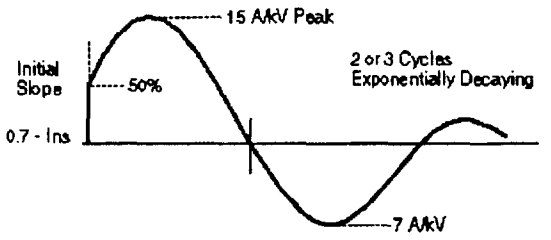


Figure 3-6
ECMA TR40 SPECIFICATION

Figure 3.3 shows discharges from a bed that was charged to 4 kV. Again, two different waveforms could be produced as before. The main wave tends to "swamp" the initial spike at this charge level. The peak current is 34 amperes (10A/div).

Figure 3-4 shows discharges from a bed that was charged to 8 kV. The peak current is almost 60 amperes (20A/div).

Figure 3-5 shows a discharge at 4 kV from a larger screw head revealing a more typical waveform pattern for furniture discharge. (Note the absence of the initial spike.)

3.3.3 Current Waveform Comparisons

The waveforms depicted in Figures 3-2 through 3-5 are compared with the ECMA TR40 test standard (see Figure 3-6) and are also supported by later investigations (see reference 27, "Survey of Furniture ESD".)

The ESD from the hospital bed reveals the fast rise within 1 ns and a damped oscillatory main wave, typical of a furniture discharge. Discharges from small objects such as small screw or bolt heads and holes can cause an initial spike preceding the main wave. This spike is common in human body discharges but has been known to occur, but is not as common, in furniture discharges. The discharge from the bed does not reach the peak currents or reveal as high a resonant frequency when comparing it to other furniture discharges as from a cart or chair. The ECMA TR40 test standard specifies a peak current of 15 amperes per 1 kV. The bed's discharge typically is 10 amperes per 1 kV. The referenced study (see reference 27) showed that the discharge from a chair was 14 amperes at 1 kV and a cart to be 29 amperes at 1 kV. The resonant frequency is also lower when compared to common furniture discharges due to the fact that the bed's combined inductance and capacitance are higher than common furniture. The resonant frequency is between 20 MHz and 30 MHz. ECMA specified a frequency between 33 MHz and 45 MHz.

The standard furniture discharge specified by ECMA and IEEE/ANSI C63 (draft) is similar to the discharge characteristics of the hospital bed.

3.3.4 Possible Solutions

3.3.4.1 PREVENTION

The best approach to minimize the effects of ESD on electronic equipment is to prevent the discharge from happening in the first place. The most effective way to do this is to inhibit buildup of charge on personnel and objects. Various techniques for achieving this are employed including artificial means for increasing relative humidity, as well as grounding straps, ionizers, etc. In any case, reduction in charge voltage is the best that can be achieved; the complete elimination of charge voltage is virtually impossible. Conductive chairs, floors, garments, workstations, protective packaging, and ionizing systems all offer the same simple goal: to ensure that conductors have the same charge level when they meet. This is the essence of ESD prevention.

ESD problems are fought either by insulating devices or by providing extremely low impedance paths for conduction of the currents back to the source. Typically, the power mains are where the currents will flow because they are at earth potential. Insulation is one very effective way of dealing with ESD. In this method, the device employs a high dielectric insulator, such as mylar, which makes it difficult for the ESD event to occur. The same approach is used by adding plastic or other non-conductive coatings on equipment surfaces. Low impedance rubber or impregnated plastic with carbon filler may prove effective because the ESD pulse may be absorbed and turned into heat energy. However, this approach is not a complete solution since an ESD event in the vicinity of equipment is capable of causing upset via associated induced electric and magnetic fields. The ESD charge may also find a random way to travel across the insulator to some grounded surface. The insulator itself may become charged if its resistivity is too high. Conduction is an equally effective way of dealing with ESD. Lowering the RF impedance of the case material will improve ESD performance. ESD disruption and damage can be minimized and even prevented if the

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hospital staff and nurse-call system installers consider the following three environmental factors:

a. Utilize grounded beds whenever possible. A charge dissipates through a grounded bed frame as quickly as it accumulates. On an ungrounded bed frame, the charge accumulates until there is enough energy to jump (spark) to a grounded or large conductive surface.

b. Whenever possible, maintain humidity level above 20 percent. Low relative humidity during the heating or cooling seasons contribute to the ESD problem. Steam heated (closed hot-water hydronic) and other non-forced air systems are particularly likely to dry the air thus reducing the dissipation of charge to the normally moist atmosphere. High-rise facilities will have more problems on the higher floors. Air tends to circulate less during heating/cooling on the upper floors thereby those floors get drier and have more ESD-related problems.

c. Provide back box and conduit systems for nurse-call cabling. The use of open-wired and cable tray installed systems generally increase the risk of multiple station damage due to ESD. Back box and conduit systems provide an excellent electromagnetic and electrostatic shield that reduce damage and disruption to other nurse-call equipment connected to the room where an ESD event occurs. The conduit system alone can be a vital element in protection schemes.

3.4.4.2 TRAINING AS A MEANS OF PREVENTION

When changing bed linens within the hospital room, hospital staff can be instructed to remove the call cord or entertainment speaker from the bed and hang it up on the wall. They will also have to be trained to discharge themselves before reattaching the cord or pillow speaker to the bed. This can be very effective if all hospital staff members are aware of the problem.

The effectiveness of a training program depends upon the level of awareness of all hospital staff members to the reality of the problem. Surveying hospital staff members on local hospital nursing floors shows nurses are very aware of ESD (by the shock they receive when changing the bed linen). But, interviews with their immediate supervisors show that administrative staff (who do not change bed linen) believe that their staff is not experiencing ESD-generated shocks. This extends all the way up the chain of command in the hospital. Administrative and biomedical engineering staff need to be made aware of the potential problem and its costs.

3.3.4.3 NURSE-CALL EQUIPMENT PRECAUTIONS

a. Grounding the Hospital Bed

Adding a ground wire between the bed frame and earth ground will drain off charge as it is generated. A flexible and durable cord should be used (tested for 1 million flexes). The 3M 2010 ground strap, or equivalent, with a series 1 million ohm resistor to limit the current flow and prevent possible electrocution by an active short to the bed frame by an electrical fault, has been very effective. This has been done with great success in installations in the United States and Canada. Hospital staff must be consistent and remember to reattach the ground strap when beds are moved.

Additionally, antistatic mattress covers should be used. These black mattress covers are in wide usage, but many older facilities have a green PVC mattress cover. Charge can accumulate on the top surface and not conduct to the bed frame. In this case, it will be necessary to ground the top surface of the mattress by wrapping a piece of conductive tape from the top surface to the bottom surface.

b. Nurse-Call Equipment Certification

As part of the regulatory approval for a nurse-call system, the equipment could be subjected to a test simulating typical electrostatic discharges in a hospital room. Any Nationally Recognized Testing Laboratory (NRTL) should use the dual RLC model for simulating an ESD event and the ESD measurement and testing procedures as specified by the IEEE/ ANSI standards. The criterion for acceptance would be that the equipment shall be operative and not damaged after all parts of the system were subjected to these ESD tests.

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c. Nurse-Call Equipment Warning Labels

Nurse-call equipment could be marked indicating that the bed on which its call cord or entertainment speaker is used shall be electrically connected to ground. An explanation of the reason for the need to ground the bed should appear in the instruction manual for the nurse-call equipment. The explanation would be aimed at the hospital staff, and would say that the nurse-call equipment can be disrupted or damaged from static electricity if the bed on which it is used is not connected to ground by way of a grounding strap or an equipment grounding conductor in the power cord of an electrically operated bed.

3.3.4.4 INSTALLATION CONSIDERATIONS

Nurse-call systems installed in continuous back boxes and continuous metal conduit will be much more resistant to inductive coupling of ESD than other wiring methods. Installation in partial or discontinuous conduit (conduit is stubbed to the ceiling and then cable is run open or in a cable tray) is the worst possible case. Circulating chassis ground wires (often used to tie floating back boxes together) are seldom attached to actual nurse call wiring and can contribute to multiple station damage. These conductors take the charge from the back box of a patient station that has been struck by ESD and couple the discharge into all system wiring.

3.3.4.5 SUMMARY

Any solution to the static problem related to nurse-call systems will require three basic items:

a. Identification of potentially ESD sensitive sites before a system is installed

b. Acknowledgement by the user (the hospital personnel) that this problem exists

c. Selection and implementation of a realistic protection scheme, such as air bubble cords, bed grounding, shielded cords, or other solutions covered in this Standards Publication.

It will always be more expensive to implement a protection scheme after a system has been installed. Many hospitals view the problem as the manufacturers' and simply want the problem handled (at no cost to them). In order to achieve meaningful ESD immunity, the design, installation, and use of the entire nurse-call system must be considered, both for direct discharge and for induced fields.

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NEMA STANDARDIZIATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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