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Sereda, P. J.

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Safety from Fires and Explosions in Hospital Operating Rooms

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P. J. Sereda

Please note

Amid the complexities of hospital design and construction the hazards of fire and explosion in operating rooms may too easily be treated as minor details. These hazards, however, must not be ignored. The Division of Building Research became interested in them in 1953 after receiving an inquiry from a firm of architects about the durability of static conductive flooring for operating rooms.

This article is written primarily for the use of architects and engineers, but hospital administrators also should be aware of the special nature of the equipment and facilities that can be provided. Full advantage of these facilities can be realized only if the operating room staff institute certain procedures and take certain precautions to avoid the sources of ignition of anaesthetic gases.

It may seem strange that in an activity such as surgery, which in itself has great risks attached, there is concern with fires and explosions of anaesthetic gases such as ether cyclopropane and ethylene in combination with oxygen; these accidents occur at a statistical frequency of one in 80,000 to 100,000 anaesthesias that make use of flammable gases. Statistics, however, do not always reveal a true picture of the importance of some hazards. An accident such as an explosion in the operating room has a great psychological impact upon both the operating room staff and the public at large, the potential patients, not to speak of the liability of the physician and the hospital if such an accident is judged as negligence. The presence of a potential hazard may also add unnecessary stress to personnel already under great pressure and thus hinder their efficiency.

The Hazard in the Operating Room

The potential hazard in operating rooms is associated with the mixture of anaesthetic gases with oxygen or air. Extensive field and laboratory investigations have been carried out, notably by the U.S. Bureau of Mines, demonstrating conclusively that mixtures of oxygen or air with anaesthetic gases normally used in operating rooms can be ignited by very low energy sources; energies in excess of this minimum are associated with spark discharges such as are produced from electrostatic charges built up on equipment and personnel in operating rooms. This constitutes the chief source of ignition, although other sources such as open flames, arcs and sparks from non-explosion-proof electrical equipment and faulty wiring, as well as incandescent lamps and endoscopes or high frequency cauteries or coagulators have added to the hazard.

How to Achieve Safety

Safety begins with understanding or awareness of a hazard. To achieve it in operating rooms one must educate the operating room personnel: demonstrate that the hazard exists, what factors contribute to it, and the action that can be taken to reduce to a minimum the chances that an accident will occur.

Safety codes are available to assist in the design and construction of equipment and facilities to eliminate or at least reduce the hazard. The National Fire Protection Association has produced such a document, and the Canadian Standards Association has a committee working on another. Only general aspects of the problem can be discussed in this Digest; the reader is urged to study the available literature.

Ignition Sources

Open flames and hot surfaces. - Open flames, lighted cigarettes, heaters and hot plates, hot cauteries, sterilizers, lamps and light fittings, hot instruments such as hot dental syringes, or any surface with a temperature above 180°C are easily recognized as ignition sources. These can be controlled or eliminated with little effort on the part of the staff. Only vigilance and co-operation are required.

Electrical systems. - Both fixed and portable electric systems and equipment provide many sources of electric spark ignition. Even normal functioning of such equipment as the brush gear of electric motors, switch contacts, receptacles, radio-frequency cutting, coagulating, and diathermy apparatus may result in sparking. There is risk from faulty connections and short circuits on almost all electric apparatus. Sparking may even be electrically induced between objects not directly connected to electric equipment, and there is danger of random or diffuse sparking in electric apparatus and associated objects when radio frequency equipment is used. Hot surfaces can be provided by over-heated components such as cables in which some of the wire strands have broken.

To ensure safety the wiring system and design of electrical equipment should comply with the electrical codes and should be maintained through regular inspection and upkeep. The recommended wiring consists of an ungrounded system, isolated completely from other systems, that can be continuously monitored to detect the presence of faults. Such a wiring system is especially desirable when a static-conductive floor is installed, because of the increased hazard of electric shock. The fact that the system is monitored by means of a ground hazard indicator to give warning when the impedance (consisting of resistance or capacitance) of either or each side of the line to ground drops below 120,000 ohms not only ensures that no serious electric shock can be obtained but also assists in the proper maintenance of the system. Faulty electrical equipment plugged into such a system will immediately cause a warning to be given by the indicator so that the equipment can be taken out of use and repaired.

Electrostatic sparks. - Experience indicates that the most frequent source of ignition of flammable anaesthetics is the electrostatic spark discharge. Surveys of hospitals indicate that there is probably no combination of equipment and personnel activity anywhere more liable to produce casual, dangerous charges of static electricity than that found at present in the anaesthetizing areas of most hospitals.

Although little is known of the nature and mechanism of static electrification, a great store of observation and experience is available to define conditions under which this phenomenon occurs. Generally, any insulating material will exhibit the phenomenon of separation of charges when separated from another insulating or conducting surface. The higher the specific resistivity of the surface and the more intimate the contact, as occurs with very smooth surfaces or by sliding one surface over another, the more pronounced will be the separation of charges.

A charge held by any body or part thereof is a product of its capacity and the electrostatic voltage. Capacity of most objects is small, and the potentials encountered when there is a separation of charges are measured, therefore, in thousands of volts. If the electrostatic voltage is above 350 volts, there is a definite chance of a spark discharge through the air to some body not similarly charged, provided that body is close enough and has the capacity to receive the charge, as by conduction to ground. Any object carrying a charge can induce one in another object or body in close proximity, especially if the second object is a conductor of electricity. Equalization of the charge to other objects or to ground across a small gap can result in sparks, especially if there is a charge on a conducting object such as a person.

To eliminate static electrification it is necessary to eliminate from use in operating rooms all materials that have high specific resistivity and can be classed as insulators. All items made of ordinary rubber such as sheets, casters, shoes; woolen goods such as blankets; and all items, with the exception of undergarments, made of nylon, orlon, dacron, silk, acetate; and artificial leather and sharkskin should be eliminated from the operating room and replaced by items made of metals, conductive rubber, conductive plastic or cotton. Cotton is safe only when the humidity in the room is controlled at a value in excess of 50 per cent; by virtue of its hygroscopic properties its resistance is a function of the relative humidity in the air; at values of relative humidity in excess of 50 per cent the surface conducts electrostatic charges fast enough to prevent the build-up of dangerous voltages. Cotton can be rendered non-static-producing at low humidity by treatment with anti-static agents. This procedure, however, requires regular attention.

It bas been found that resistivity increases exponentially as the relative humidity is decreased to zero. It follows that electrostatic charging is at a maximum at a relative humidity of about 35 per cent, and decreases as the relative humidity is decreased below this value. Thus there is no advantage, and there may be some hazard, in providing some humidity in the operating room during very dry periods, unless it is possible to maintain an adequate humidity of at least 50 per cent.

With a relative humidity of 25 to 35 per cent clean cotton will charge to a higher voltage than synthetic fabrics such as nylon, although nylon continues to retain its charge, even at a humidity of 60 per cent at which cotton does not charge at all. It is important that all cotton items used in operating rooms should be allowed a minimum of several hours to come to equilibrium with the high humidity before they are used.

Despite efforts to, eliminate the presence of insulating materials and to maintain a high relative humidity it must be conceded that some charge may still occur and that a second line of defence is required. It has been found that the provision of a static conductive floor is the most effective safeguard against the accumulation of dangerous electrostatic charges. Each individual must wear some form of conductive footwear, however, and all objects must make effective electrical contact with the floor through static conductive casters, metal leg tips or other grounding devices. To be completely effective everyone and everything must be electrically inter-coupled via a static conductive floor at all times during the use of flammable anaesthetics. This implies constant vigilance, inspection (by testing) and a high standard of "housekeeping." Wax or dirt accumulation on the floor and on grounding devices can provide high resistance and cancel the effect of static conductive flooring.

Static Conductive Flooring

The Committee on Hospital Operating Rooms of the National Fire Protection Association has given much consideration to the establishment of safe limits of resistance for a suitable static conductive floor, based on a method of test that attempts to simulate the contact between a shoe and the floor. An upper limit of resistance of 1 megohm was established to ensure the dissipation of electrostatic charges. For this purpose floors with lower resistance or a greater conducting surface are desirable. Because of the hazard of shock in the event of electrical faults in equipment, however, a lower limit of resistance of 25,000 ohms is also necessary. The safe upper limit of resistance may be much higher than 1 megohm; but at the present time a factor of safety is justifiable because the properties of static conductive floors are not too well established, nor is the phenomenon of electrification completely understood.

Common flooring materials do not usually provide sufficient conductivity under conditions of normal indoor use to ensure the dissipation of electrostatic charges. Terrazzo floors with metal gridwork may provide high conductivity near the grid, leading to the possibility of electric shock, but may provide little conductivity, elsewhere. Many other flooring materials such as wood, linoleum and asphalt act as electrical insulators. The problem, therefore, is one of finding a suitable material for the floor or floor covering that will provide an electrical path with a resistance that can be maintained within safe limits.

Ideally, a static conductive floor for use in hospital operating rooms should consist of a chemically and physically homogeneous semiconducting material that provides resistance within desired limits under all conditions of service. Flooring materials in common use are generally not sufficiently conductive. To make them so it is necessary to mix a conductive ingredient into the non-conductive body of the flooring material. Obviously the particle size and grading of both ingredients should be as fine as possible and the dispersion very uniform to achieve satisfactory results. It is also desirable that all the ingredients are free of water-soluble salts in order that their conductivity is a function of the proportions of the conductive to the non-conductive ingredients only and is independent of such changing conditions of use as moisture content and humidity.

Acetylene carbon black is added to the ingredients of conventional flooring to make many types of static conductive flooring; terrazzo and tile, linoleum, rubber and vinyl plastic, and a variety of static conductive floor coatings such as special mastics or paint are examples. Other static conductive flooring materials rely on soluble salts for their conductivity, and some have metal or metal oxides as the conductive ingredient. All have had some measure of success.

Floor surfaces made up of an aggregation or mosaic of conductive and non-conductive elements pose a question as to the allowable size of the non-conductive element. It is desirable to limit it to ensure satisfactory electrical contact between furniture legs and casters and the floor.

A number of flooring materials of the cementitious type owe their electrical conductivity, in part or in whole, to the presence of soluble salts, oxychloride flooring being a good example. With these floors the resistance is a function of the moisture content of the floor; this is governed by humidity in the air and water added during washing. Since these factors are not normally controllable in operating rooms, the resistance will fluctuate over wide limits. In fact, the lower limit of resistance can be met only under ideal conditions; if any water is spilled on such a floor, the resistance drops to a very low value. In addition, such floors tend to lose their conductivity with time because of the washing away of soluble salts from their surface. These are serious problems that make maintenance of resistance within specified limits difficult.

The durability of most static conductive flooring materials would be improved by the use of a preservative such as wax. Most waxes, however, impair conductivity and cannot be safely used. Although the development of suitable sealers and waxes to preserve such floors without affecting their conductivity is under study, too little is yet known about them to permit any specific recommendation.

The foregoing discussion has explored some of the practical difficulties in the development of suitable static conductive floorings only from the point of view of safety. The problem for the architect is further complicated by the attention he must give to economics, durability, comfort, and finally to the aesthetic appearance of floors. The author hesitates to put these basic criteria in any order of precedence beyond suggesting that safety, consistent with reasonable economy, should always come first.

Grounding Devices

The necessity of achieving electrical inter-coupling between all items and persons in the operating room bas already been discussed. Assuming that a satisfactory static conductive flooring bas been installed it remains to complete the circuit to personnel through static conducting footwear and to equipment and furniture through grounding devices such as static conductive casters, metal leg tips or drag chains.

Over the years a variety of static conductive footwear bas been proposed and used. Shoes with static conductive soles are reliable but difficult to sterilize. Devices acting as grounding contacts attached to shoes are easily damaged and often do not remain conductive because of accumulation of dirt. It appears that the most satisfactory solution to the problem lies in the provision of a static conductive bootie or slip-on, which can make static conductive contact with the ankle of the wearer through a static conductive plastic or rubber strap and through the sole of the bootie with the floor. These booties can be washed or sterilized and worn over regular shoes. Whatever type of static conductive footwear is used, it should be tested each day while worn to ensure electrical conductivity in the desired range.

Devices used for grounding equipment and furniture to static conductive flooring, whether static conductive casters, metal leg tips or drag chains, must be kept clean and must be checked to see that they actually do complete the electric circuit. This can be done only by regular inspection and test. Such testing can readily be carried out by placing an electrode (type used for flooring test) on the metal part of furniture or equipment and another electrode on the static conductive flooring. In this way both the equipment and flooring may be checked in one operation. In checking an anaesthesia machine one electrode may be placed on the face mask of the machine and the other on the floor. One ohm-meter should be used to test both flooring and footwear. Specifications for the electrodes and test meters are given in the various codes.

Safety Requirements in New and Old Hospitals

Where safety is involved there should not be two sets of standards; those for new hospitals, which must now meet the safety requirements of codes with regard to electrical wiring and equipment, humidity control and electrostatic control, and those for old hospitals, which were built before such standards were defined, must somehow agree. Now that standards have been set down clearly in the form of regulations and codes it should be the responsibility of hospital administrative staffs as well as the various levels of government - municipal, provincial and federal - to see that these standards are realized in all hospitals as soon as possible.

Humidity control. - The maintenance of high humidity in operating rooms presents design problems in the severe winter climate of Canada. Not only must the walls be insulated to prevent condensation, but adequate vapour barriers must also be provided to prevent excess moisture from accumulating in the walls and causing frost damage. Windows present the greatest problem from condensation; one solution eliminates them from operating rooms entirely. These problems can be solved during design and construction in new hospitals, but in old hospitals the solution may require considerable adaptation.

Housekeeping and equipment maintenance. - In discussing the various means for eliminating ignition hazards, the importance of a high standard of housekeeping and maintenance cannot be over-emphasized. Such standards can be maintained only through frequent inspection and testing according to a schedule. This should include checking all precautionary measures, and should be the responsibility of one person, with the administrative staff of hospitals in charge of organizing the necessary inspection and testing.

Education and training. - It should be the responsibility of the administrative staff to organize a program of instruction through posters, signs and lectures or demonstrations in the safe handling and use of anaesthetic gases and oxygen. All efforts to design and construct safe equipment and facilities can be nullified by one careless or thoughtless act. Safety is like a chain-only as strong as the weakest link.