ELECTRICAL EQUIPMENT OF THE OPERATING ROOMS IN THE NEW HARTFORD HOSPITAL

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Since the introduction of combustible volatile liquids and gases for the production of anesthesia by inhalation, operating rooms and adjacent areas in hospitals have been recognized as hazardous locations. Application of improved techniques and skills has greatly reduced mortality rates but the hazards due to electrical shock, fires and explosions continue to exist. Up to the year 1940, a total of 260 explosions and fires in operating rooms were reported. Some of these accidents resulted only in injury to patients and personnel while others were responsible for deaths. There were probably many more accidents which were never reported.

In many instances the exact causes of these catastrophies could not be determined but, where the causes were known, they appear to have been the result of the following listed in order of decreasing frequency: 1. Ignition by electrostatic spark discharge. 2. Ignition by spark or arc in the electric power system. 3. Ignition by flame or hot body such as a cautery. 4. Ignition by spontaneous combustion.

Fires, explosions and shocks, resulting from electric sources in one form or another appear to be the most frequent of all known causes, but until 1941 no comprehensive over-all plan has been proposed to eliminate, as far as humanly possible, all factors contributing to such disasters. In May of 1941, there was presented to the National Fire Protection Association, during its annual meeting at Toronto, a comprehensive set of specifications outlining procedures intended to reduce or eliminate physical hazards in Operating Rooms produced by the several causes previously enumerated.

These specifications were prepared by a committee of eleven, after exhaustive research and investigation under the chairmanship of J. Warren Horton, Professor of Biological Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts. They were adopted, tentatively, by the N.F.P.A. and published subsequently in pamphlet form under the title "Combustible Anesthetics and Operating Room Explosions." This booklet is available to any one interested in procuring it. These special requirements were included in the edition of National Electrical Code for 1947, by reference only, in the finely printed footnote following subparagraph a. Section 5004, Article 500.

Construction of the first unit of the new Hartford Hospital, known as the Maternity Wing, was begun in 1941 and was completed in 1942. It included six delivery rooms and two operating rooms. The management of the hospital decided to incorporate in these rooms all recommendations of the N.F.P.A., as a trial installation. The author of this article was requested to make a practical interpretation of the requirements. This was done in cooperation with Dr. Ralph M. Tovell, Chief Anesthesiologist at Hartford Hospital and the late Victor H. Tousley, then Secretary, Electrical Committee, National Fire Protection Association, both of whom served on Professor Horton's committee which prepared the recommendations, tentatively adopted by the N.F.P.A.

In the Maternity Wing, a complete air conditioning system was installed. It was designed to maintain in each delivery room and in each operating room a temperature...
of 75 F. and a relative humidity of 55 per cent. This combination has been found satisfactory for comfort of personnel and for creation of atmospheric conditions unfavorable to the accumulation and dangerous discharge of static electricity.

Conductive rubber flooring was installed in all delivery and operating rooms and in adjacent areas as specified in the Code. This floor covering was laid in each room in a fashion to provide complete insulation from the frame of the building and all piping or other objects connected to ground except where it was electrically connected to a common ground conductor through a fixed resistance. The flooring consists of an insulating lower layer of high grade rubber, a woven wire mesh and a top layer of conductive rubber. Each strip of floor covering was interconnected mechanically and electrically. At one point in each room an electrical connection was made between the metallic mesh and a common No. 8 ground conductor through a 50,000 ohm fixed resistor installed in an accessible outlet box. The purpose of the resistor is to permit passage to ground of any static electricity that may, under existing conditions, accumulate on any person or object within the room. At the same time, the system limits the severity of electric shock that may be experienced by persons coming accidentally into physical contact with either of the ungrounded conductors used to supply portable lights or other electrically operated appliances.

All lighting fixtures installed to permanently remain 7' above the floor were considered, in the presence of adequate ventilation, to be in a non-hazardous area and they were therefore connected to normal grounded neutral a.c. building wiring. All wall switches within 7' of the floor were considered to be in a hazardous location and consequently types approved for such location were procured and installed.

Each delivery and operating room was equipped with five utility wall receptacles, 3 pole, 15 ampere rating, installed 1' above the floor to supply 125 volts for portable lamps and electrically operated tools and appliances. These receptacles are of a
type approved for use in hazardous locations. One identified pole of each receptacle is permanently connected to ground and each of the remaining two poles to one of the ungrounded circuit conductors. The wiring from each receptacle was extended in conduit to a flush accessible steel box located 7 1/2" above the floor in the corridor outside the room supplied. In this box were installed on each conduit an approved seafitting to prevent the passage of combustible gases to a non-hazardous location where circuit fuses and other circuit interrupting devices were installed. From this box the ungrounded conductors were extended in conduit to a circuit fuse panel located in a closet especially designed to contain all of the equipment necessary to operate the isolated ungrounded supply system. In this installation, panels of the plug fuse type, only for the ungrounded circuits, were selected for two reasons: it is sometimes necessary to replace a blown fuse as quickly as possible and occasionally it becomes necessary to temporarily install a fuse of greater capacity than normally required. Circuit breakers of fixed capacity have not proven satisfactory for this service and plug fuses can be removed and replaced with comparative safety by relatively inexperienced persons.

In the closet referred to above one complete unit for each individual delivery and operating room was installed as the following description indicates. A single pole, 60 amp., automatic switch, electrically operated by two momentary contact switches located in the room supplied was installed. The automatic switch makes electrical connection between the grounded neutral building circuit and the primary winding of a 3 Kva, insulating, dry type, transformer. From the secondary winding of this transformer, two No. 6 conductors ungrounded, at 125 volts, extend through a ground detector relay cabinet to the circuit fuse panel, from which the several ungrounded circuits extend to the several wall receptacles and the White pilot light in each room.

The ground detector relay consists of a highly sensitive relay capable of operating on a minimum of six volts in series with a maximum of 25,000 ohms. Connected in series across the No. 6 ungrounded supply conductors are two 5000 ohm resistors with a midpoint connection. From the midpoint of the two resistors one wire is connected to the sensitive relay and continues through relay winding to permanent ground.

Even a high resistance connection between either of the ungrounded conductors and ground or between either ungrounded conductor and the metallic enclosure of a portable lamp or other appliance (provided a grounding conductor has been properly connected to the grounded pole of the wall receptacle and metallic enclosure) will serve to operate the sensitive relay which in turn will operate a second relay, the function of which is to operate signal lights, one green and one red, located within sight of the anesthetist, in the delivery room or operating room.

When the isolated ungrounded system has been energized by operating the momentary contact switch marked ON the White pilot light beside the momentary contact switch should light and remain lighted as long as the system is energized. Simultaneously, the Green signal light should light and remain lighted until someone plugs in a lamp or other device which may have one or both wires internally grounded to the metallic frame or enclosure. If both wires should be internally grounded the protective fuse will blow and thereby disconnect the circuit. If only one wire were internally grounded, and the frame or enclosure has been grounded, as previously referred to, then the Green signal light will go out and the Red warning light will come on, giving instant warning of defective equipment, unsafe for use in the presence of combustible volatile liquids or gases used as anesthetics. Under such circumstances the anesthetist is warned to turn to employment of non-explosive gases for completion of the operation in progress at the time the Red warning signal comes on. On completion of the operation, an electrician is expected to locate and remedy the electrical fault. Because each delivery or operating room is individually wired, there need be no interference with operating schedules for
the other rooms. It is noteworthy that, although the actual voltage between either of the ungrounded conductors and the conductive floor covering is 24–26 volts and comparatively harmless, even a slight shock is, under certain conditions, in such hazardous locations, both disturbing and dangerous. It is to avoid such situations that the warning signals were installed.

The foregoing describes in a general way the main characteristics and operation of what we are told is the first installation of its kind ever attempted. Great credit is due the Management of Hartford Hospital for having the courage and foresight to authorize the installation. If it contributes to the prevention of even one fire or explosion, the expenditure will be justified.

After six years of use, the system is apparently fulfilling the purpose for which it was installed. The only part of the installation which has not come fully up to expectations is the conductive rubber flooring. In spite of the utmost care in installation, there have developed leaks in the insulation between metallic mesh and ground thereby reducing the resistance between conductive rubber and ground to as low as 25,000 ohms instead of 50,000 ohms as intended. It is the writer's present belief that the insulating layer should be both thicker and tougher. Possibly some form of plastic with high dielectric could be substituted for the comparatively thin layer of high grade rubber. If such insulation could be developed to insure a resistance of 100,000 ohms between conductive rubber and ground it would be ideal and would reduce the voltage between ungrounded conductors and floor covering to 8 volts or less.

Although this article is intended to deal primarily with the electrical system, the following observations may serve some useful purpose. The ventilating system should be so designed that conditioned air enters the room at ceiling level through Anemostats. The air should be exhausted at floor level at a point as far as possible from doors leading to the corridor and if possible, into an adjoining room with final exhaust being made at ceiling level. The purpose is to dilute flammable vapors or explosive gases as much as possible before they enter the exhaust duct. The volume of exhaust should exceed slightly, or at least equal, the volume of supply to insure a slightly negative air pressure in each operating room, thereby lessening the chance of dangerous gases being forced out into corridors or into conduits. Since the complete functioning of the safety measures installed in Hartford Hospital or in any installation patterned after it, depends to a large extent upon the air conditioning and ventilation, it should be recognized that a considerable hazard could exist if it were necessary to employ anesthetics of a combustible type during a period that these systems were out of operation.

The warning system will not function, as such, unless each portable lamp or other electrically operated device is equipped with a 3 conductor cord, one conductor of which is securely connected to the enclosure or frame (if of metal) and to the grounding contact of the insertion plug.

The complete dissipation of static charge that may accumulate on persons or objects within the room can not be expected unless reasonable conductivity can be maintained at all times during the use of combustible anesthetics, between persons and objects and the conductive floor covering. To insure such complete conductivity, the metal parts of portable lamps of all types and electrical appliances of all types, should be connected to ground when in use, through the ground conductor of the portable cord. When this is not possible or practicable, the metal parts enclosing wiring should be grounded by means of a drag chain in contact with the floor covering or by other means which will assure a definite ground connection. The operating table, operating platforms and similar objects, if not equipped with electrically conductive casters or their equivalent should be, by some alternative means, so grounded that no non-conductive materials will prevent electrical conductivity between persons (including the patient) and the conductive floor covering. Assuming that some form of conductive flooring is used having an internal resistance of not less than 50,000 ohms or an insulated conductive floor covering connected to ground through a resistance of not less that 50,000 ohms, additional conductivity between body and ground can be assured by moistening the
soles of shoes provided they are of leather or conductive rubber. Electrically heated sterilizers and canyters constitute an exceptional hazard and should never be used in the same room where combustible anesthetics are in use.

Between 1945 and 1948 the Main Building of the new Hartford Hospital was completed and included a total of 15 operating rooms and two cystoscopy rooms, all of which were equipped similarly to those in the Maternity Wing except for the use of conductive linoleum instead of conductive rubber floor covering which has not been available since World War II. Our experience with the linoleum has not been of sufficient duration to determine its faults or value but we do know that with 125 volts between each conductor of the isolated ungrounded supply system, the voltage between either conductor and the linoleum floor covering is 50 to 52 with no method of limiting it except through the internal resistance of the floor covering itself. Therefore, from the standpoint of accidental shock, the evidence seems to favor the conductive rubber with its limiting resistor in the grounding connection.

When the Main Building was planned, conductive rubber flooring being at least temporarily out of production, a choice was offered between conductive linoleum and a metal grid, grounded, imbedded in terrazzo flooring. Experience over several years has demonstrated the latter method to be one of the most dangerous of all. While it will, under favorable atmospheric conditions, successfully conduct electrostatic charges to ground, it also provides a low resistance path to ground when actual contact is made with the metallic grid, enabling a person coming in contact between the grid and an ungrounded conductor to receive a shock which could be disastrous. Where this type of flooring is used, it encourages the use of insulation between working personnel and the floor to prevent shock. It thereby defeats largely the very purpose for which it was installed, namely, the free and complete dissipation of static accumulations. So far as Hartford Hospital is concerned, there seemed to be but one choice and conductive linoleum having none of the disadvantages and incorporating far less in the way of hazard than the grid system it was chosen for this installation.

The accompanying diagrams show the complete wiring connections for the isolated ungrounded systems as installed in these two buildings here described. While these installations may not be the last word they certainly represent a big step in the right direction. An illustration indicating comparative conditions with conductive rubber flooring, conductive linoleum and a grounded metal grid embedded in terrazzo is included.

During the past few years several new methods of anesthesia have been developed which do not require the use of combustible mixtures. They have resulted in less frequent use of combustible anesthetics but there is no indication at present that the use of combustible agents will be discontinued for several years to come. Therefore, it would seem that all future operating rooms (and existing ones insofar as possible) should be provided with every safeguard that science and experience have been able to devise.

Since the first occupancy of the Maternity Wing in July 1942 to date, 33,624 babies have been delivered. Since the first occupancy of the Main Building in March 1948 to date, approximately 5000 operations requiring anesthesia by inhalation have been performed and about 7000 requiring other types of anesthetic.

It will be noted on one of the diagrams that the operating rooms in the main building include two x-ray viewing boxes which are not of the explosion resisting type. Although such boxes of the so-called explosion type became available before completion of the building, their cost appeared prohibitive to the Hospital management and it was decided to recognize and accept the hazard which was considered to be not too great in view of their distance from the operating table. They are located about 5' above the floor and each box is separately controlled by a factory sealed type of switch which practically eliminates the chance of explosion due to electric are.