Scottish Health Technical Memorandum 2014

(Part 4 of 4)

Operational management

Abatement of electrical interference

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Contents

1. Scope

General

1.1 Medical-electrical equipment in healthcare premises is liable to be susceptible to electrical interference from:

a. alternating magnetic fields;

b. alternating electric fields;

c. transient voltage changes.

Although distinct types, these interrelate and are generally known as Electromagnetic Interference (EMI). Electromagnetic Compatibility (EMC) is achieved when this interference is eliminated.

1.2 Earlier statutory regulations and British Standards Institution publications dealing with EMI were primarily concerned with preventing various types of electrical equipment (including medical-electrical equipment) from interfering with radio telecommunication services.

1.3 A requirement is in place for all electrical products, systems and installations not to cause, or be unduly affected by, EMI. The requirement is in the form of an EC Directive on EMC 89/336/EEC as amended by 91/263/EEC and 92/31/EEC. This Directive has been implemented in UK law by the Electromagnetic Compatibility Regulations 1992 (SI 2372) and amended by SI 3080: 1994 and SI 3180: 1995. Transitional arrangements, until 31 December 1995, were in situ so that member states could continue to allow to be placed on the market, or to be taken into service, apparatus which conforms to the national regulations in force in their territory on 30 June 1992.

1.4 The EMC Directive is not, however, all-inclusive. Apparatus wholly covered by other Directives (for example Telecommunication Terminal Equipment, which has its own specific Directive) is excluded, while medical devices, active implantable medical devices and in vitro diagnostic devices are covered by three specific Directives as follows:

a. Active Implantable Medical Devices - 90/385/EEC, UK legislation Active Implantable Medical Devices Regulations 1992 (SI 3146), effective 1 January 1993 and amended by the Active Implantable Medical Devices (Amendment and Transitional Provisions) Regulations 1995 (SI 1671).

b. Medical Devices Regulations 1994 (SI 3017) implements Council Directive 93/42/EEC concerning medical devices. It lays down essential safety requirements which medical devices must satisfy.

c. The In Vitro Diagnostic Medical Devices Regulations 2000 (SI 1315) implements council directive 98/79/EC on in vitro diagnostic medical devices.

Definitions

1.5 The following definitions apply throughout this document.

1.6 **Management:** is the owner, occupier, employer, general manager, chief executive, or other person who is accountable for the premises and is responsible for issuing or implementing a general policy statement under the Health and Safety at Work etc. Act 1974.

1.7 **Employer:** any person or body who:

a. employs one or more individuals under a contract of employment or apprenticeship;

b. provides training under the schemes to which the Health and Safety (Training for Employment) Regulations 1990 (SI 1380) apply.

1.8 **Department:** an abbreviation of the term “Scottish Executive Health Department”.

1.9 **Duty holder:** a person on whom the Electricity at Work Regulations 1989 impose a duty in connection with safety.

1.10 **Electrical/electronic equipment:** includes anything used, intended to be used or installed for use to generate, provide, transmit, transform, conduct, distribute, control, measure or use electrical energy.

1.11 **Equipment:** abbreviation of electrical/electronic equipment.

1.12 **System:** a system in which all the electrical equipment is, or may be, electrically connected to a common source of electrical energy, including such source and such equipment.

1.13 **High voltage (HV):** the existence of a potential difference (rms value for ac) normally exceeding 1000 volts ac between circuit conductors or 600 volts between circuit conductors and earth.

1.14 **Low voltage (LV):** the existence of a potential difference (rms value for ac) not exceeding 1000 volts ac or 1500 volts dc between circuit conductors or 600 volts ac or 900 volts dc between circuit conductors and earth.

1.15 **Ambient level:** those levels of radiated and conducted signal noise existing at a specified test location and time when the test sample is inoperative. Atmospherics, interference from other sources, circuit noise, or other interference generated within the measuring set comprise the “ambient level”.

1.16 **Antenna-induced voltage:** the voltage that is measured or calculated to exist across the open-circuited antenna terminals.

1.17 **Broadband emission:** emission which has a spectral energy distribution sufficiently broad, uniform and continuous so that the response of the measuring receiver in use does not vary significantly when tuned over a specified number of receiver impulse bandwidths.

1.18 **Conducted emission:** desired or undesired electromagnetic energy which is propagated along a conductor. Such an emission is called “conducted interference” if it is undesired.

1.19 **Cross coupling:** the coupling of a signal from one channel, circuit or conductor to another, where it becomes an undesired signal.

1.20 **Cross modulation:** modulation of a desired signal by an undesired signal. This is a special case of intermodulation.

1.21 **Crosstalk:** an electromagnetic disturbance introduced by cross coupling.

1.22 **Electromagnetic compatibility:** capability of electronic equipment or systems to be operated with a defined margin of safety, in the intended operational environment, at designed levels of efficiency, without degradation due to interference.

1.23 **Emission:** electromagnetic energy propagated from a source by radiation or conduction. This may be intentional or unintentional emission.

1.24 **Field strength:** the term “field strength” should be applied only to measurements made in the far field. The measurement may be of either the electric or the magnetic component of the field, and may be expressed as volts per metre, amperes per metre, or watts per square metre; any one of these may be mathematically converted to the others.

1.25 **Earth plane:** a metal sheet or plate used as a common reference point for circuit returns and electrical or signal potentials.

1.26 **Impulse:** an electromagnetic pulse of short duration relative to a cycle at the highest frequency being considered. Regularly repeated impulses of uniform level will generate a uniform spectrum of discrete frequencies (Fourier components), separated in frequency by an amount equal to the repetition frequency.

1.27 **Impulse bandwidth:** the peak value divided by the area of the impulse response envelope.

1.28 **Impulse emission:** emission produced by impulses having a repetition frequency not exceeding the impulse bandwidth of the receiver in use.

1.29 **Interference emission:** any undesirable electromagnetic emission.

1.30 **Intermodulation:** mixing of two or more signals in a non-linear element, producing signals at frequencies equal to the sums and differences of integral multiples of the original signals.

1.31 **Narrowband emission:** that which has its principal spectral energy lying within the bandpass of the measuring receiver in use.

1.32 **NAMAS:** a specialist NPL test executive approved under the auspices of the National Measurement Accreditation Scheme to accredit test laboratories to undertake EMC testing.

1.33 **Open area:** a site for radiated electromagnetic interference measurements which consists of open flat terrain at a distance far enough away from buildings, electric lines, fences, trees, underground cables and pipelines so that effects due to these are negligible. This site should have a sufficiently low level of ambient interference to permit testing to the required limits.

1.34 **Radiated emission:** radiation and induction field components in space.

1.35 **Spurious emission:** any electromagnetic emission from the intended output terminal of an electronic device, but outside the designed emission bandwidth.

1.36 **Spurious response:** any response of an electronic device to energy outside its designed reception bandwidth through its intended input terminal.

1.37 **Standard reference output:** a condition for a particular test sample that defines normal operation and is used in measuring any deviation from standard performance that occurs during susceptibility testing. This value should be indicated in the individual equipment specification.

1.38 **Susceptibility:** the characteristic of electronic equipment that permits undesirable responses when subjected to electromagnetic energy.

1.39 **Test antenna:** an antenna of specified characteristics designed for use under specified conditions in performing tests.

2. Electromagnetic interference in healthcare premises

2.1 Electromagnetic interference (EMI) occurs when any unwanted signal adversely affects an undesired response from an electrical/electronic device. Potentially, every electronic device is susceptible to EMI and, reciprocally, generates some degree of electromagnetic emissions. These emissions can be transmitted as electromagnetic radiation (non-ionising) or conducted through cables such as signal and power lines.

2.2 For an EMI situation to occur, three elements must be present. These are:

a. a source of conducted or radiated electromagnetic waves;

b. a propagation medium by which electromagnetic energy is transmitted; and

c. an element which suffers adverse effects from unwanted signals.

If any one of these elements is eliminated, interference will not occur. Thus electromagnetic compatibility (EMC) can be achieved by reducing the emission levels at the source, interrupting the propagation path or hardening the victim device to make it immune to undesired signals.

Sources of EMI

2.3 Sources of electromagnetic noise are numerous and have both natural and man-made origins. Natural sources below 10 MHz are dominated by atmospheric noise generated by electrical storms. Above 10 MHz natural sources consist primarily of cosmic noise and solar radiation.

2.4 Man-made sources can be divided into intentional and unintentional. Intentional sources are those which must radiate to perform their task and include AM and FM radio broadcast, television, police and ambulance transmitters, pagers, diathermy machines, etc. Unintentional sources include computing devices, relays, motor appliances, fluorescent lights etc. With the proliferation of both intentional and unintentional sources, EMI has reached levels which have caused concern; the EC Directives have laid down protection requirements to achieve EMC in electronic and electrical apparatus, systems and installations.

2.5 The main sources of electromagnetic interference in healthcare premises are described below.

a. Electromagnetic radiation (radio waves) from equipment within the healthcare premises, for example diathermy apparatus, which incorporates a high frequency generator for functional purposes. The interference is largely due to random modulation of the high frequency carrier wave, causing variable low frequency signals to be superimposed on wanted physiological measurements. Detection rectification of the superimposed low frequency modulated waveform can occur in a non-linear electronic component within any co-located sensitive electro-medical equipment, and the interference signals may become amplified in the subsequent stages of the equipment together with the wanted signals. In addition to direct radiation from the diathermy machines, there is the possibility of unfiltered signals being inserted into mains wiring via the mains connection to the high frequency generator to reach sensitive equipment connected to the same mains supply (common impedance coupling of the mains earth). Interference signals may also be induced into the mains or other wiring in areas of high field strength and be conducted throughout the building by the mains cable network. These signals may also produce parasitic circulating currents in installed engineering services, constructional metal work etc. and re-radiate into other parts of the building.

b. Transient current surges on the mains can occur due to equipment incorporating switching devices, interrupting electrical circuits etc, and electromagnetic radiation can be emitted from equipment such as video display units where monitors using high line density and frame frequency can generate electromagnetic emissions which may be radiated or conducted.

c. Alternating magnetic fields such as are generated by transformers or when phase and neutral conductor cables of an alternating current circuit are not installed in close proximity, for example where erroneously the line conductor of a circuit is run down one side of a room and the neutral conductor down the other, thus setting up a force-field across the area bound by the supply and return conductors.

d. Alternating magnetic fields can also be generated by stray earth currents in water pipes where they form parallel leakage paths to earth due to a load being inadequately connected between line and earth or to a neutral conductor being earthed locally. Similar fields are intentionally created by inductive loop, staff location or building management systems.

e. Electrostatic floors may allow persons to become electrically charged to high voltage potentials, and interference can occur when an inadvertent path to earth allows the electrostatic discharge to flow. This may be caused by electrostatically charged persons walking or moving near patients whilst clinical measurements are made. Highly electrostatic materials on or near the couch or bed can produce similar high voltage interference.

f. Electromagnetic radiation from sources outside the hospital may affect electronic solid state equipment or controls, for example from high-powered radio or television transmitters or local mobile transmitters such as those used by ambulances, police, taxis, etc. Sound broadcasts are less likely to cause trouble as the modulation frequencies are above the maximum frequency to which pen recorders can respond, but interference from these sources may be detected by apparatus employing oscilloscopes. Television broadcasts incorporate a 50 or 100 Hz (frame) signal which can cause interference in areas where strong signals are received, for example in excess of 100 mV per metre.

2.6 Radio frequency sources can radiate over wide areas. This type of interference can be the most troublesome in healthcare premises. Electrostatic and magnetic interference is usually confined to a comparatively small radius surrounding the source.

2.7 The maximum magnetic flux close to a power line is in the order of 10-30 microTesla (μT) decreasing to less than 1 μT at a distance of 50-200 metres. Close to electrical equipment the field can be in the order of 10 μT but decreases to background ambient at only one metre. Generally the background magnetic field is less than 0.1 μT.

2.8 “Transients”, for example due to switching, are liable to occur frequently on any mains distribution system, and in some instances, peaks up to 400 volts may be experienced.

Equipment liable to cause interference

2.9 The types of equipment found in healthcare premises which are liable to cause interference, can be divided into two broad categories of housekeeping systems and medical equipment.

Medical equipment which can cause interference includes:

a. medical (therapeutic) diathermy;

b. surgical diathermy;

c. linear accelerators and other therapeutic X-ray generators;

d. electrically operated appliances incorporating thermostatic controls including ovens, sterilizers, incubators, blankets, refrigerators, food trolleys etc;

e. high resolution visual display unit screens.

Housekeeping electronic/electrical equipment which can generate interference includes:

f. radio communication equipment;

g. motor operated equipment including vacuum cleaners, floor polishers and other domestic equipment;

h. staff location systems (inductive loop and vhf);

i. lifts, including motors and rectifier control equipment;

j. switches, relays, contactors and similar control devices which interrupt circuits;

k. transformer sub-stations and other power transformers;

l. electric clocks (impulse and synchronous [mains] types);

m. fluorescent lamps, including cold cathode and switch mode types.

2.10 Highly electrostatic materials can be found in the proximity of the patient, for example vinyl and other highly electrostatic floors and items on the couch or bed, such as a plastic mattress or couch covers, nylon clothing, sheets and woollen blankets. (Anti-static precautions are dealt with in Health Technical Memoranda Nos. 1 and 2.)

Equipment liable to be susceptible

2.11 Equipment that is most liable to suffer interference will be that concerned with the measurement or indication of low frequency physiological potentials, for example at frequencies up to 20 kHz. The use of sensitive display equipment, for example that used in radiology, is also liable to suffer interference from extraneous signals.

2.12 The following are examples of apparatus that may be affected:

a. electromyographs (EMG);

b. electroencephalographs (EEG);

c. electrocardiographs (ECG);

d. radioactive pulse measuring apparatus;

e. image intensifiers;

f. closed-circuits television;

g. hearing aids employing a magnetic microphone are liable to suffer interference from low frequency, inductive loop, staff location systems and from stray magnetic fields. Those employing crystal microphones are less liable to suffer interference from alternating magnetic fields;

h. heart pacemakers.

3. Detection and measurement of interference

3.1 To enable remedial action to be taken against electrical interference, it is necessary to be able to detect the presence of the interfering signals and to determine the type of interference, that is, whether it is due to high frequency radiation or to an alternating magnetic or electrostatic field. Sensitive physiological measuring apparatus can usually be used as a means of detecting interference, but a small radio receiver or amplifier is fitter for the purpose of detection over a wider band of frequencies.

3.2 Radiated interference signals are usually expressed in terms of the field strength, that is, microTesla magnetic flux or volts per metre, and measured as a voltage induced in an antenna having an effective height of one metre. For assessing interference radiation from a specific source, measurements are made at 10 or 30 metres distance. Noise voltages induced into the supply mains from a source of interference are expressed in microvolts. Specially calibrated radio receivers and spectrum analysers are used for measuring field strength and noise voltages. Reference should be made to SHTM 2014 Part 3 ‘Validation and verification’.

3.3 Before resorting to the use of expert advice and services, the use of comparatively simple equipment may determine whether interference is due to magnetic, electrostatic or radio frequency fields. The source of interference may be easy to find and the elimination an easy, cheap and simple task.

3.4 Interference problems often become evident only after a number of systems have been installed and may appear to be affected at certain rogue sites. Initially, the hardware may be suspect and the immediate action therefore will be replacement of the supposed faulty equipment. However, when replacement and/or equipment checks are not effective in finding the cause of the problems, other actions are required and at this stage it is essential that a logical approach is adopted rather than ad-hoc alterations to the system which may not cure the problems. The following procedures are suggested.

Site examination

3.5 A careful examination of the installation and the local site should be carried out in an attempt to find possible causes of the problem. The following features are of importance:

a. the integrity of the mains supply to the equipment including junction boxes, fuses, switches, etc;

b. the signal control cable runs in relation to the power cables;

c. method of earthing the equipment and adjacent equipment;

d. the presence of adjacent electrical equipment which may produce locally intense interference, for example diathermy machines, other ISM equipment, power cables, transformers, HV lines, radio transmitters, thermostats etc;

e. correlation of the times of occurrence of the interference effects with any relevant electrical or other activity adjacent to the equipment. Note that the evidence provided by operating personnel may sometimes be misleading and every care should be taken to confirm this evidence independently.

Site survey

3.6 Depending on the results of the site examination, it may be necessary to carry out a survey of the site in order to establish whether there are any unusually high levels of interference. The survey may require the use of a variety of measurement techniques, the choice of which should be based upon the types of interference most likely to affect the equipment under consideration. The measurements may include the following:

a. continuous mains monitoring for a period of at least seven days to detect voltage dips, interrupts and transients;

b. measurement of audio frequency magnetic fields, particularly in connection with cathode ray tube visual displays, transformers and overhead lines;

c. measurement of RF fields for radio, television and other perhaps unintended emissions;

d. specialised monitoring of certain conductors, for example signal leads and earth leads while the most likely interference sources are operated.

3.7 During the site tests it will usually be necessary to obtain the assistance of medical personnel to operate the errant equipment.

4. Electromagnetic compatibility

4.1 Electromagnetic compatibility can be achieved by reducing the emission levels of the source, or by interrupting the propagation path or indeed by hardening sensitive devices such that they become immune to undesired signals.

4.2 The chief methods of containing electrical interference in electro-medical apparatus used in healthcare premises are:

a. siting potential interference generating sources away from areas where sensitive equipment may be used;

b. incorporating in-phase rejection in the early amplification stages;

c. provision of filter components in the input (patient) circuits;

d. fitting of suppression (filters and transient) components in the mains power and lighting input circuits;

e. provision of earthed metal enclosures for sensitive equipment and screening associated wiring connections;

f. keeping patient leads as close together as possible to minimise interference due to magnetic fields;

g. decoupling offending circuits;

h. reducing earth impedance thereby reducing common impedance paths;

i. surveying earth paths and removing earth loops;

j. providing a separate earth system for sensitive apparatus.

4.3 Design guidelines for the control of EMI are discussed in SHTM 2014 Part 2 ‘Design considerations’. The essential parameters for the abatement of electrical interference are earthing, including bonding, screening and power or RF filtering. These measures can apply to both inter-system interference and intra-system EMI. The degree of application of these design guidelines will depend on the nature of the problem and the relative ease of implementation of the solution(s).

Filters

4.4 The filtering (or separation) of wanted low frequency signals from unwanted radio frequency signals is a most effective method of rejecting interference. Tests have shown that EEGs and ECGs can be operated successfully in the presence of radio frequency fields of up to 1 V/m when a suitable low pass filter is incorporated. Since wanted signals are at comparatively low frequencies it is an easy matter to filter these from unwanted radio frequency signals. Resistors and capacitors for this purpose are available in very small

sizes and they can usually be incorporated into the apparatus without difficulty. They must be installed with due attention paid to the earthing arrangement and care must be taken not to run the input lines (“dirty” signals) along side the output (“clean”) lines.

4.5 Part of the input capacitance will be formed by the screened cable in the input circuit and this may amount to 300 pF. In the normal multi-core, twisted pair screened cable the capacitance of each conductor to earth will depend on the position of the conductor relative to the cable outer screen. Where the highest degree of rejection is required any deficiency due to this can be overcome by using miniature coaxial cables as the core conductors or separately screened twisted pairs, earthing the screen of each pair separately to the earth system at the terminations.

4.6 It is important that filter components do not adversely affect the proper functioning of the equipment and the added capacitance must not adversely affect the response at the upper end of the required frequency band. In most instances it has been found that the small additional capacitance necessary to give satisfactory results is acceptable. Where additional capacitance cannot be tolerated, for example in EMG apparatus, an alternative for mains harmonics rejection is to use a 50 or 100 Hz band stop filter in a subsequent stage of the apparatus; insertion loss due to filter must be accounted for.

In-phase rejection

4.7 Arrangements for rejecting unwanted in-phase signals, for instance those at mains frequency, are usually incorporated by manufacturers of the apparatus, by the use, for example, of a carefully balanced (differential) amplifier. With suitable arrangements very high rejection ratios are obtainable and such measures form a very effective means of reducing low frequency electrostatic interference.

Low pass filters

4.8 A single section low pass filter will be satisfactory in most instances, but where the highest degree of rejection is required, additional sections will be necessary. Where two or more sections are used the first sections will usually be at the input terminals and the last section at the first stage of amplification.

4.9 For optimum results filter components should be located as close as possible to the first non-linear component, that is, transistor or diode. Where such an arrangement is not convenient, acceptable results may be obtained where the filter components are located close to the input terminals. All parts of the circuit subsequent to the filter should be completely screened with earthed metal.

Low frequency band stop filters

4.10 Since interference to sensitive electro-medical equipment usually manifests itself as a 50 Hz unwanted signal due to mains supply, an effective narrow band stop filter at the interfering frequency would be a convenient means of eliminating this type of interference. In practice, however, there are inherent difficulties with low frequency filters and, as low frequency interference signals are mostly radiated on high frequency carrier waves, it will usually be preferable to reject the high frequency signals before detection (rectification) can occur.

4.11 The main disadvantage of low frequency band stop filters is the loss of information over the bandwidth of the filter, which may be significant in some types of apparatus. Band stop filters, where used, will usually be required to reject signals at 50 or 100 Hz depending on the arrangement of the propagating source. To obtain maximum rejection the filters should be adjustable and should be adjusted to give minimum attenuation at the appropriate frequency. See Figure 17 of SHTM 2014 Part 2 ‘Design considerations’

Mains filters for apparatus

4.12 Extraneous signals on the supply mains can penetrate to recorders or indicators of sensitive mains operated apparatus and appear as “noise” which can cloud wanted signals. Where sensitive circuits are supplied from the secondary winding of a mains transformer incorporated within the apparatus, it has been found that an earthed metallic screen between the primary and secondary windings will assist in filtering high frequency and transient potential directly to earth and so reduce the possibility of their interfering with the secondary load circuits. The connection to earth must be of low impedance and as short in length as possible to an earth electrode.

4.13 Where sensitive circuits are supplied directly from the mains or where a higher degree of suppression is necessary it may be desirable to incorporate filter components in the mains input circuit.

Screening

4.14 The purpose of screening is to confine radiated energy to the bounds of a specific region, or to prevent energy from entering a specific region. This can be achieved at equipment, system or installation level. In any case the screen (whether metal or metallised plastic) has to be bonded to earth via a low impedance path in order to route away the unwanted energy.

4.15 The integrity of the screen must be maintained as far as possible by only introducing the minimum possible number of apertures. Where additional cooling is required, a honeycomb aperture can be fitted. Where cables

penetrate the chassis of the equipment, the cable screens must be bonded to that enclosure in order to prevent noise coupling into the equipment circuitry.

Earthing

4.16 The installation of a good earth system is a most important requirement, for an installation to be interference-free. In combination with effective screening, the main problems can be reduced, or even eliminated.

4.17 Filtering of the mains supply is of a lesser priority, unless mains-borne interference is apparent. All interference investigations should be preceded by an appraisal and servicing of the earth system. Earth systems deteriorate due to environmental attack. When joining dissimilar metals for earthing or bonding, care must be taken to prevent electrochemical corrosion. Tables 3 and 4 illustrate the requirements for this purpose.

Conduit system

4.18 An extensive metal conduit system will usually have a low dc resistance to earth, for example less than 1 ohm, but may have a much higher impedance to earth at high frequencies. In the above circumstances, it is liable to collect interference signals of sufficient magnitude to cause interference to sensitive apparatus (common impedance coupling). To prevent this, it may be necessary to segregate the metal conduit in an interference-free area from the general conduit system of the healthcare premises, by inserting a short electrical insulating section between the two systems, at convenient points, just outside the interference-free zone.

4.19 The segregated conduit should be connected to an independent earth electrode, the connection being kept as short as possible, and be metal clad throughout its length, for example 2.5mm cable in 20 mm diameter conduit. The protective earth conductor should also be bonded to the independent earth electrode at the electrode terminal and connected to the earth pins of all socket-outlets in the segregated section.

Earth electrodes

4.20 The earth impedance necessary will depend on the degree of suppression required, but in general an impedance which satisfies the basic earthing requirements of the IEE regulations will be satisfactory for power distribution and lighting circuits. Refer to Scottish Health Technical Memorandum 2007 ‘Electrical services: supply and distribution’.

4.21 The test measurement will include the impedance of the supply system earth but this will be small relative to the test value. Where long test leads are

necessary a suitable allowance should be made for the impedance of the leads.

Multiple earth connections

4.22 Even where a special earthing system is used there is the possibility of small potential differences existing between separate earth connections, for example between different socket-outlets in a room. Consequently where more than one mains operated monitoring unit is used on a patient at the same time, it may be found that one unit causes 50 Hz interference to the other. A common socket-outlet earth should be tried, with a fused multiple adaptor.

4.23 In some cases, it may be necessary to connect a separate or “clean earth” conductor of low impedance to the main earth electrode, for electronic equipment signal circuits and the screens around the data/signal cables entering and leaving the equipment cabinet.

4.24 The protective earth conductor would have a common termination with the “clean earth,” at both the equipment and main earth electrode, but must be segregated, and routed separately from the “clean earth”.

Electricity at Work Regulations

4.25 The provisions of the Electricity at Work Regulations 1989 and the IEE Wiring Regulations must be followed. The following extract from the HSE ‘Guidance on Regulations’ is considered pertinent in preventing danger due to charged conductors (other than circuit conductors).

4.26 Techniques employed for achieving the requirements of Regulation 8 include:

a. double insulation;

b. earthing;

c. connection to a common voltage reference point on the system;

d. equipotential bonding;

e. use of safe voltages;

f. earth-free non-conducting environments;

g. current/energy limitation;

h. separated or segregated systems.

The areas of interest for the purpose of this document are described in the following paragraphs.

Earthing practice

4.27 It is the practice in the UK for the public electricity supply system at the usual distribution voltage of 240 V single phase, 415 V three phase, to be referenced to earth by a deliberate electrical connection made at the distribution sub-stations or power transformers. It is the existence of this system earthing which enables earth faults on electrical equipment to be detected and the electrical supply to faulty equipment to be isolated rapidly and automatically.

4.28 The earth loop impedance parameters and protection interruption times for final installations of up to 1000 V, may be found in the IEE Wiring Regulations.

4.29 It is rarely sufficient to rely upon an earth rod or rods to provide sufficient conductance for return fault currents. Separate protective earth cables or conductors connected to the neutral point of the supply are usually necessary to provide an earth fault loop impedance of low value, suitable for the rupture of the highest rated fuselink. Other measures such as the use of sensitive residual current protection equipment are used to detect earth fault currents where the combined earth fault loop impedance or earth impedance may be too high for rapid overcurrent protection or personal safety.

4.30 For the duration of the fault, the electrical bonding of exposed conductive parts and their connection to earth serves to limit the shock risk from the transient voltages appearing between metallic enclosures of equipment in the system or between a metallic enclosure and earth. Equipment earthing therefore includes the bonding of metallic enclosures, cable armouring, conduits, trunking etc. so that these conductors are electrically continuous and securely connected to the general mass of earth at one or more points.

4.31 An earthing or bonding conductor must be rated for the maximum time and current it may conduct under fault conditions, and be designed to survive the worst case fault. Construction and strength must be adequate to withstand likely mechanical abuse and ambient and electrochemical corrosion. Refer to Tables 3 and 4.

4.32 Where it might otherwise be difficult to ensure the continued effectiveness of an earth and/or bond arrangement, it may be necessary to provide supplementary protection such as protective earth conductor monitoring.

Connection to a common voltage reference point on the system

4.33 In the UK public electricity supply system, where a transformer neutral point is connected to earth, the voltage reference point is the general mass of earth. Other reference points, to which isolated systems may be referenced,

and to which bonding conductors are connected, may be chosen to suit particular circumstances.

Equipotential bonding

4.34 Equipotential bonds refer to the electrical interconnections between exposed and extraneous conductive parts, which could become electrically charged. They are inter-connected so that dangerous voltages cannot exist between any of the parts, and are limited to, and equal to, the surrounding earth voltage.

Separated systems

4.35 If safety depends on the supply system not being referenced to its immediate environment, whether true earth or surrounding metalwork, then no hazardous potential will normally exist between the live conductors and earth or any exposed metallic parts.

4.36 All systems are to some extent referenced to their environment, by either capacitive or inductive coupling, or by leakage. For this reason, reliance cannot always be placed on the circuit conductors of isolated earthed systems being at zero potential, relative to their environment.

4.37 Unless the isolated system is very small and localised, a leakage current may be large enough to render a path for a fatal electric shock. A hazardous potential is more likely to exist on extensive systems.

4.38 Examples of isolated systems are those supplied from the secondary winding of an isolating transformer, or the winding of an ac generator where there is no connection to any other source of electrical energy. Regular inspection and testing to ensure that system isolation integrity is maintained will also be necessary.

4.39 At all times electrical safety precautions must be applied.

Physical siting of equipment

4.40 Where possible, especially when planning new healthcare premises, the aim should be to allow adequate physical separation between possible sources of interference and those areas where sensitive equipment may be used.

4.41 The minimum separation to ensure freedom from interference will depend on several factors, and will vary with different types of equipment. For the frequencies and distances under consideration the effect of the electric field radiated signals from local sources can be assumed to vary inversely as the square of the distance.

4.42 The distances given in Table 1 are intended as a general guide only, to assist in assessing the possibility of interference being experienced. In arriving at these distances a typical interference source and no special suppression is assumed. In practice it will usually be possible to reduce the distances considerably by the use of equipment filters (refer to paragraph 4.2) and/or by the use of suppressors at the source (where applicable).

4.43 The distances given in Table 2 are intended to be a guide to the minimum physical spacing which will be necessary under average conditions in healthcare premises where appropriate measures (other than room screening) have been taken, as recommended elsewhere in this document, to reject or suppress interference signals within sensitive equipment.

4.44 In arriving at the larger distances in the tables, an allowance has been made for the screening effects of ordinary walls and partitions such as are likely to be met in normal healthcare premises layouts. Where the distances specified in Table 2 cannot be obtained, it can be assumed that a special room or other screening as referred to in SHTM 2014 Part 2 ‘Design considerations’ will be necessary.

Table 1: Approximate minimum spacing for interference-free working with unfiltered equipment

	Distance in metres		
Source of Interference	EMG etc Sensitivity 20 µV/cm	EMG etc Sensitivity 100 µV/cm	ECG etc Sensitivity 1000 µV/cm
Medical diathermy * (27 MHz 100% modulation)	60	60	30
Medical diathermy (27 MHz 30% modulation)	30	30	18
Medical diathermy (27 MHz 10% modulation)	18	18	9
Surgical diathermy (valve type)	21	15	9
Surgical diathermy (HF impulse type)	15	9	6
Surgical diathermy (impulse generator)	9	5	3
Linear accelerator † (impulse generator)	30	21	15
LF inductive loop (paging) distance outside loop ▲	6	0	0
Lift motor rooms (controls unsuppressed)	9	6	3
Lift wells (controls unsuppressed)	9	6	3
Power transformers (100-750 kVA)	9	9	9
Small transformers up to 1 kVA	2	2	2
Commutator motors (unsuppressed)	6	5	3
Thermostats, relays and other switching devices (unsuppressed)	6	5	3
Electric clocks (mains and impulse types)	3	2	2
Fluorescent lamps	5	3	3
Tungsten lamps	3	2	2

* For interference-free working with old medical diathermy sets operating on 40-50 MHz, it will be necessary to increase the distance given.

† Applicable only where the generator is installed outside the radiation screening. When installed within the radiation screening no interference should be experienced.

▲There is a possibility of interference being experienced within an LF inductive loop with ECG and EEG equipment. Interference within this type of loop is much more likely with EMG equipment.

Table 2: Approximate minimum spacing for interference-free working with filtered equipment

	Distance in metres		
Source of Interference	EMG etc Sensitivity 20 µV/cm	EMG etc Sensitivity 100 µV/cm	ECG etc Sensitivity 1000 µV/cm
Medical diathermy * (27 MHz 100% modulation)	18	12	12
Medical diathermy (27 MHz 30% modulation)	15	9	9
Medical diathermy (27 MHz 10% modulation)	9	6	6
Surgical diathermy (valve type)	6	3	3
Surgical diathermy (HF impulse type)	6	3	3
Surgical diathermy (HF impulse type)	5	3	3
Linear accelerator † (impulse generator)	15	9	9
LF inductive loop (paging) distance outside loop ▲	6	0	0
Lift motor rooms (controls unsuppressed)	3	3	3
Lift wells (controls unsuppressed)	3	2	2
Power transformers (100-750 kVA)	9	9	9
Small transformers up to 1 kVA	2	2	2
Commutator motors (unsuppressed)	6	2	2
Thermostats, relays and other switching devices (unsuppressed)	6	2	2
Electric clocks (mains and impulse types)	3	2	2
Fluorescent lamps	9	3	3
Tungsten lamps	3	2	2

* For interference-free working with old medical diathermy sets operating on 40-50 MHz, it will be necessary to increase the distance given.

† Applicable only where the generator is installed outside the radiation screening. When installed within the radiation screening no interference should be experienced.

▲ There is a possibility of interference being experienced within an LF inductive loop with ECG and EEG equipment. Interference within this type of loop is much more likely with EMG equipment.

Table 3: Electrochemical series ordered by decreasing sensitivity to corrosion

	Anodic end (most easily corroded)
Group **I**	Magnesium
Group **II**	Aluminium, aluminium alloys, zinc, cadmium, galvanised iron
Group **III**	Carbon steel, iron, lead, tin, tin-lead solder
Group **IV**	Nickel, chromium, stainless steel, brass
Group **V**	Copper, silver, gold, platinum, titanium, bronze
	Cathodic end (least corroded)

Table 4: Groups of materials recommended for providing protective bond between two dissimilar metals used as anode and cathode

Condition of Exposure	Anode				Cathode
	I	**II**	**III**	**IV**	
Exposed	A	A			
Sheltered	A	A			**II**
Housed	A	A			
Exposed	C	A	B		
Sheltered	A	B	B		**III**
Housed	A	B	B		
Exposed	C	A	B	B	
Sheltered	A	A	B	B	**IV**
Housed	A	B	B	B	
Exposed	C	C	C	A	
Sheltered	A	A	A	B	**V**
Housed	A	A	B	B	

Notes: Bond protection code:

A. The couple must have a protective finish after metal-to-metal contact has been established so that no liquid film can bridge the two elements of the couple.

B. The two metals may be joined with bare metal exposed at junction surfaces. The remainder must be given an appropriate protective finish.

C. This combination cannot be used except where short life expectancy can be tolerated or when the equipment is normally stored and exposed for only short intervals. Protective coatings are mandatory.

5. Fibre optics

5.1 The use of fibre optic data links has grown significantly during recent years. This strong interest arises from the advantages that optical fibres have over metallic conductors for transmitting information. The advantages depend on the application, but include the following:

a. insensitivity to electromagnetic and radio-frequency interference;

b. immunity to ground-loop problems;

c. improved security compared with electronic cabling (no cross-talk among parallel cables);

d. elimination of combustion or sparks caused by short circuits;

e. flexibility in upgrading system capacity without need to install new cables;

f. low transmission loss (greater distance between repeaters);

g. wide transmission bandwidth;

h. potential low cost;

i. relatively small size, light weight, high strength, and flexibility;

j. suitability for digital communications and pulse modulation methods (fibre optic cable losses are independent of transmission frequency);

k. fewer government regulatory difficulties because of the elimination of frequency allocation;

l. suitability for relatively high temperature.

6. Summary of noise reduction techniques

Source suppression

6.1 To maximise source suppression:

a. enclose noise sources in a screened enclosure;
b. filter all leads leaving a noisy environment;
c. limit pulse rise times;
d. provide relay coils with some form of surge damping;
e. twist noisy leads together;
f. screen and twist noisy pairs;
g. earth both ends of screens used to suppress radiated interference.

Coupling reduction

6.2 By use of coupling methods:

a. twist low voltage signal leads;
b. place low voltage leads near chassis;
c. twist and screen signal leads;
d. screened cables used to protect low frequency low voltage signals should be earthed at one end only. High frequency cables (for example coaxial) should be earthed at both ends;
e. insulate the screen on signal leads;
f. separate low voltage lines from noisy lines in the same connector by placing earth lines between them;
g. carry screens on signal leads through the connectors on a separate pin;
h. avoid common earth leads between high and low voltage equipment;
i. keep earth leads as short as possible;
j. apply filters, or decouple leads entering sensitive equipment;
k. keep lengths of sensitive leads as short as possible;
l. keep unscreened cable lengths as short as possible;
m. use low impedance power distribution lines;
n. avoid earth loops;

o. break earth loops by using isolation transformers, common-mode chokes, optical couplers, differential amplifiers, balanced circuits, hybrid ground.

Equipment hardening

6.3 By adaptation:

a. minimise bandwidths of operation;
b. use frequency selective filters;
c. provide power supply decoupling;
d. separate noisy, signal and hardware earth;
e. use screened enclosures.

References

NOTE:
Where there is a requirement to address a listed reference, care should be taken to ensure that all amendments following the date of issue are included.

Publication ID	*Title*	*Publisher*	*Date*	*Notes*
Acts and Regulations				
	Building (Scotland) Act	HMSO	1959	
	Clean Air Act	HMSO	1993	
	Electricity Act	HMSO	1989	
	Health and Safety at Work etc. Act	HMSO	1974	
	Registered Establishments (Scotland) Act	HMSO	1998	
	Water (Scotland) Act	HMSO	1980	
SI 1671	Active Implantable Medical Devices Regulations	HMSO	1995	
SI 1315	In Vitro Diagnostic Medical Devices Regulations	HMSO	2000	
SI 3017	Medical Devices Regulations	HMSO	1994	
SI 2179	Building Standards (Scotland) Regulations	HMSO	1990	
	Building Standards (Scotland) Regulations: Technical Standards Guidance	HMSO	1998	
SI 3140	Construction (Design and Management) Regulations	HMSO	1994	
SI 437	Control of Substances Hazardous to Health Regulations (COSHH)	HMSO	1999	
SI 635	Electricity at Work Regulations	HMSO	1989	
SI 1057	Electricity Supply Regulations	HMSO	1998	
SI 2372	Electromagnetic Compatibility Regulations	HMSO	1992	
SI 2451	Gas Safety (Installation and Use) Regulations	HMSO	1998	
SI 917	Health & Safety (First Aid) Regulations	HMSO	1981	

Publication ID	Title	Publisher	Date	Notes
SI 682	Health & Safety (Information for Employees) Regulations	HMSO	1989	
SI 2792	Health and Safety (Display Screen Equipment) Regulations	HMSO	1992	
SI 341	Health and Safety (Safety Signs and Signals) Regulations	HMSO	1996	
SI 1380	Health and Safety (Training for Employment) Regulations	HMSO	1990	
SI 2307	Lifting Operations and Lifting Equipment Regulations (LOLER)	HMSO	1998	
SI 3242	Management of Health and Safety at Work Regulations	HMSO	1999	
SI 2793	Manual Handling Operations Regulations	HMSO	1992	
SI 1790	Noise at Work Regulations	HMSO	1989	
SI 3139	Personal Protective Equipment (EC Directive) Regulations	HMSO	1992	
SI 2966	Personal Protective Equipment at Work (PPE) Regulations	HMSO	1992	
SI 128	Pressure Systems Safety Regulations (PSSR)	HMSO	2000	
SI 2306	Provision and Use of Work Equipment Regulations (PUWER)	HMSO	1998	
SI 3163	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)	HMSO	1995	
SI 3004	Workplace (Health, Safety and Welfare) Regulations	HMSO	1992	
SI 1895	Wireless Telegraphy (Control of Interference from Electro-medical Apparatus) Regulations 1963	HMSO	1963	
SI 1675	Wireless Telegraphy (Control of Interference from Radio Frequency Heating Apparatus) Regulations 1971	HMSO	1971	
SI 1217	Wireless Telegraphy (Control of Interference from Ignition Apparatus) Regulations 1973	HMSO	1973	
SI 1267	Wireless Telegraphy (Control of Interference from Household Appliances, Portable Tools, etc.) Regulations 1978 (as amended)	HMSO	1978	

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SI 1268	Wireless Telegraphy (Control of Interference from Fluorescent Lighting Apparatus) Regulations 1978 (as amended)	HMSO	1978	
89/336/EEC	Electromagnetic Compatibility (EMC) Directive	HMSO	1992	
90/385/EEC	Active Implantable Medical Devices Directive	HMSO	1990	
91/236/EEC	Telecommunications Terminal Equipment Directive	HMSO	1991	
93/42/EEC	Medical Devices Directive	HMSO	1993	
98/79/EC	In Vitro Diagnostic Medical Devices Directive	HMSO	1998	
British Standards				
BS 5049-1	Radio interference characteristics of overhead power lines and high-voltage equipment. Description of phenomena	BSI Standards	1994	
BS 5049-2	Radio interference characteristics of overhead power lines and high-voltage equipment. Methods of measurement and procedure for determining limits	BSI Standards	1994	
BS 5049-3	Radio interference characteristics of overhead power lines and high-voltage equipment. Code of practice for minimising the generation of radio noise	BSI Standards	1994	
BS 5260	Code of Practice for Radio Interference Suppression on Marine Installations	BSI Standards	1975	
BS 6299	Methods of measurement of the suppression characteristics of passive radio interference filters and suppression components	BSI Standards	1982	
BS 6345	Method for Measurement of Radio Interference Terminal Voltage of Lighting Equipment (based on BS CISPR 15)	BSI Standards	1983	
BS 6626	Code of practice for the maintenance of electrical switchgear and control gear voltages above 1 kV and up to and including 36 kV	BSI Standards	1985	
BS 6667: Part 1	Electromagnetic compatibility for industrial-process measurement and control equipment: General introduction	BSI Standards	1985	
BS 6667: Part 2	Electromagnetic compatibility for industrial-process measurement and control equipment: Method of evaluating susceptibility to electrostatic charge	BSI Standards	1985	

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BS 6902-1	Cardiac Pacemakers: Specification for implantable cardiac pacemakers	BSI Standards	1990	
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BS 727	Specification for Radio-Interference Measuring Apparatus (based on BS CISPR 16)	BSI Standards	1983	
BS 7671	Requirements for electrical installations. IEE wiring regulations	HMSO	1992	16th edition
BS 833	Specification for Radio Interference Limits and Measurements for the Electrical Ignition Systems of Internal Combustion Engines (based on BS CISPR 12 and BS CISPR 21)	BSI Standards	1970	
BS CISPR 12	Vehicles, motorboats and spark-ignited engine-driven devices. Radio disturbance characteristics. Limits and methods of measurement	BSI Standards	1997	
BS CISPR 16-1	Specification for radio disturbance and immunity measuring apparatus and methods. Radio disturbance and immunity measuring apparatus	BSI Standards	1999	
BS CISPR 16-2	Specification for radio disturbance and immunity measuring apparatus and methods. Methods of measurement of disturbances and immunity	BSI Standards	1996	
BS CISPR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods. Reports and recommendations of CISPR	BSI Standards	2000	
BS EN 50065-1	Specification for signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz. General requirements, frequency bands and elecromagnetic disturbances	BSI Standards	1992	
BS EN 50081-1	Electromagnetic compatibility. Generic emission standard: Residential, commercial and light industry	BSI Standards	1992	
BS EN 50082-1	Electromagnetic compatibility. Generic immunity standard: Residential, commercial and light industry	BSI Standards	1992	
BS EN 50083-2	Cabled distribution systems for television and sound signals. Part 2: Electromagnetic compatibility for equipment	BSI Standards	1995	

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BS EN 50098-1	Customer premises cabling for information technology. ISDN basic access	BSI Standards	1999	
BS EN 50098-2	Customer premises cabling for information technology. 2048 k/bit/s ISDN primary access and leased line network interface	BSI Standards	1996	
BS EN 55011	Specification for limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment	BSI Standards	1998	
BS EN 55013	Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment.	BSI Standards	1997	
BS EN 55014 -1	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Emission. Product family standard	BSI Standards	2001	
BS EN 55014 -2	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Immunity. Product family standard	BSI Standards	2001	
BS EN 55015	Limits and methods of measurement of radio interference characteristics of electrical lighting and similar equipment	BSI Standards	2001	
BS EN 55020	Electromagnetic immunity of broadcast receivers and associated equipment	BSI Standards	1995	
BS EN 55022	Information technology equipment. Radio disturbance characteristics. Limits and methods of measurement	BSI Standards	1998	
BS EN 55024	Information technology equipment. Immunity characteristics: Limits and methods of measurement	BSI Standards	1998	
BS EN 60601-1	Medical electrical equipment. General requirements for safety	BSI Standards	1990	
BS EN 60601-1-1	Medical electrical equipment. General requirements for safety. Collateral standard. Safety requirements for medical electrical systems	BSI Standards	1993	
BS EN 60801-2	Electromagnetic compatibility for industrial-process measurement and control equipment. Electrostatic discharge requirements	BSI Standards	1993	
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BS EN 61000-4-1	Electromagnetic compatibility (EMC). Testing and measurement techniques. Overview of immunity tests. Basic EMC publication	BSI Standards	1995	
BS EN 61000-4-3	Electromagnetic compatibility (EMC). Testing and measurement techniques. Radiated, radio-frequency, electromagnetic field immunity test	BSI Standards	1997	
BS EN 61000-4-4	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test. Basic EMC publication. Based on IEC 1000 4-8	BSI Standards	1995	
BS EN 61000-4-7	Electromagnetic compatibility (EMC). General guide on harmonics, interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto. Based on: IEC 1000 4-7	BSI Standards	1993	
BS EN 61000-4-9	Electromagnetic compatibility (EMC). Testing and measurement techniques. Pulse magnetic field immunity test. Basic EMC publication	BSI Standards	1994	
BS EN 61000-4-10	Electromagnetic compatibility (EMC). Testing and measurement techniques. Damped oscillatory magnetic field immunity test. Basic EMC publication	BSI Standards	1994	
BS EN 61000-4-11	Electromagnetic compatibility (EMC). Testing and measurement techniques. Voltage dips short interruptions and voltage variations immunity tests	BSI Standards	1994	

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Scottish Health Technical Guidance				
SHTM 2007	Electrical services supply and distribution	PEF	2001	CD-ROM
SHTM 2011	Emergency electrical services	PEF	2001	CD-ROM
SHTM 2020	Electrical safety code for LV systems (Escode – LV)	PEF	2001	CD-ROM
SHTM 2021	Electrical safety code for high voltage systems (Escode – HV)	PEF	2001	CD-ROM
SHPN 1	Health service building in Scotland	HMSO	1991	
SHPN 2	Hospital briefing and operational policy	HMSO	1993	
SHTN 1	Post commissioning documentation for health buildings in Scotland	HMSO	1993	
SHTN 4	General Purposes States and Functions Model Safety Permit-to-Work Systems	PEF	1997	
	NHS in Scotland – Procode	PEF	2001	
NHS in Scotland Fire Safety Management				
SHTM 81	Fire precautions in new hospitals	PEF	1999	CD-ROM
SHTM 82	Alarm and detection systems	PEF	1999	CD-ROM
SHTM 83	Fire safety in healthcare premises: general fire precautions	PEF	1999	CD-ROM
SHTM 84	Fire safety in NHS residential care properties	PEF	1999	CD-ROM
SHTM 85	Fire precautions in existing hospitals	PEF	1999	CD-ROM
SHTM 86	Fire risk assessment in hospitals	PEF	1999	CD-ROM
SHTM 87	Textiles and furniture	PEF	1999	CD-ROM
SFPN 3	Escape bed lifts	PEF	1999	CD-ROM
SFPN 4	Hospital main kitchens	PEF	1999	CD-ROM
SFPN 5	Commercial enterprises on hospital premises	PEF	1999	CD-ROM
SFPN 6	Arson prevention and control in NHS healthcare premises	PEF	1999	CD-ROM
SFPN 7	Fire precautions in patient hotels	PEF	1999	CD-ROM
SFPN 10	Laboratories on hospital premises	PEF	1999	CD-ROM
	Scottish Executive Health Department 'Fire Safety Policy'	PEF	1999	
	Fire Safety Documentation Reference Guide	PEF	1999	
	A Model Management Structure for Fire Safety	PEF	1999	

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UK Health Technical Guidance				
EH 40	HSE Occupational Exposure limits	HSE	Annual	
MES	Model Engineering Specifications	NHS Estates	1997	As required
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