Wiring Matters

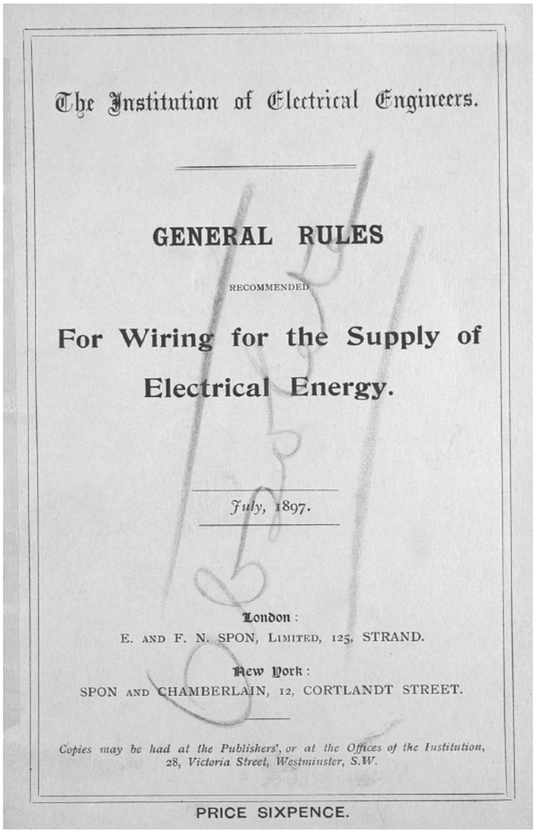
July 2020

History of insulation resistance testing

Michael Peace

There has been a lot of activity on the IET Engineering Communities forum recently regarding the background of the 1 megohm minimum value for insulation resistance. Let's take a look at how this value was arrived at in BS 7671:2018+AMD1:2020.

Insulation resistance testing, or 'megger' testing as it is more commonly known, does what it says on the tin: it tests the resistance of the insulation of all live parts in electrical circuits. The measured value is then compared with minimum values stated in the Standard, in order to verify that there is not a breakdown of insulation caused by damage to cables and other component parts of a circuit.


The Institution of Electrical Engineers.

GENERAL RULES

RECOMMENDED

For Wiring for the Supply of Electrical Energy.

July, 1897.

London:
E. AND F. N. SPON, LIMITED, 125, STRAND.

New York:
SPON AND CHAMBERLAIN, 12, CORTLANDT STREET.

Copies may be had at the Publishers', or at the Offices of the Institution, 28, Victoria Street, Westminster, S.W.

PRICE SIXPENCE.

The First Edition of the IEE Wiring Regulations in 1882 required testing to be carried out, but it did not provide minimum values of insulation resistance. However, it did recognise the importance of testing an installation and stated:

> ***The difficulties that beset the electrical engineer are chiefly internal and invisible, and they can only be effectually guarded against by "testing" or probing with electric currents. They depend chiefly on leakage, undue resistance in the conductor, and bad joints, which lead to waste of energy and the production of heat. These defects can only be detected by measuring, by means of special apparatus, the currents that are either ordinarily or for the purpose of testing, passed through the circuit.***

The Second Edition of the IEE Wiring Regulations in 1888 did not provide any further detail in terms of the tests required or the minimum values of insulation resistance to be achieved, but Regulation no. 37 stated that ***"records should be kept of all tests, so that any gradual deterioration of the system may be detected"***. This was the first requirement in the Wiring Regulations for a schedule of test results to be provided.

It wasn't until the Third Edition of the IEE Wiring Regulations in 1897 that specific details for insulation resistance testing appeared. It was stated, in Regulation no. 15, that:

> ***EMF equal to twice the EMF which will ordinarily be used is to be applied, and the insulation resistance between the whole system and earth must be measured after one minute's electrification. The insulation should not be less than 10 megohms, divided by the maximum number of amperes required for the lamps and other appliances.***

A similar test was also required to be carried out 15 days after the installation was put into service. At this time, the main concern of the Regulations was fire, as opposed to electric shock. It is unclear where this value came from originally; it is likely to have been something that was agreed amongst committee members.

Table 1

Table.

SHOWING MAXIMUM CURRENTS, THICKNESS OF DIELECTRIC, AND INSULATION RESISTANCE FOR COPPER CONDUCTORS INSULATED AND LAID IN CASING OR TUBING.

1.	2.	3.	4.	5.	6.	7.	8.
Size, S.W.G.	Maximum Current for High External Temperatures.	Total Length in Yards of Lead and Return giving 1 Volt Drop.	Maximum Current Allowable.	Total Length in Yards of Lead and Return giving 1 Volt Drop.	Minimum Thickness of Dielectric in Mils or Thousandths of an inch.	Minimum Insulation Resistance in Megohms for One Mile of Class A.	Minimum Insulation Resistance in Megohms for One Mile of Class B.
18 or 62/38 or 97/40	3·1	23	4·2	18	35	1,200	300
3/22	3·3	23	4·4	17	36	"	"
17 or 130/40	4·0	25	5·4	19	36	"	"
3/20	4·8	26	6·6	19	38	"	"
16 or 110/38 or 172/40... ...	4·9	27	6·8	19	36	"	"
15	5·9	28	8·2	20	37	800	"
7/22	6·2	28	8·7	20	38	"	"
14 or 172/38 or 7/21½	7·0	29	9·8	21	38	"	"
3/18	7·5	30	11·0	20	40	600	"
7/20	9·3	31	13·0	22	41	"	"
7/18	14·0	37	21·0	25	44	"	"
19/20	20·0	39	30·0	26	48	"	"
7/16	23·0	40	34·0	27	49	"	"
19/18	31·0	45	48·0	29	54	"	"
7/14	32·0	45	49·0	29	54	400	"
19/16	49·0	51	77·0	32	62	"	"
19/14	70·0	56	110·0	35	70	"	"
37/16	83·0	59	130·0	37	75	"	"
19/12	100·0	66	170·0	39	82	300	"
37/14	120·0	64	190·0	40	86	"	"
61/15	150·0	67	240·0	42	95	"	"
61/14	170·0	74	290·0	43	102	"	"
37/12	180·0	73	300·0	44	103	"	"
61/12	260·0	82	450·0	47	124	"	"
91/12	350·0	90	620·0	51	144	"	"
91/11	420·0	94	740·0	53	158	"	"

Table 1 is taken from the Third Edition and shows different minimum values of insulation resistance according to cable size and length.

By the time of the Fourth Edition of the IEE Wiring Regulations in 1903, the requirements had changed. Regulation no. 78 stated that ***"the insulation resistance to earth must not be less in megohms than 30 divided by the number of points under test.*"** At this time, points were considered to be a ***"number of pairs of terminal wires from which it is proposed to take the current, either directly, or by flexibles, to lamps or other appliances"***. This edition described an alternate method of testing with the installation complete: a reduced minimum value of 25 megohms divided by the number of 30 watt lamps. Connected equipment such as motors, heaters and other electrical appliances were required to have a minimum insulation resistance value of ***"500,000 ohms"***. (Note that the value was in ohms, as opposed to megohms.)

The Fifth Edition of the IEE Wiring Regulations introduced a new minimum value of insulation resistance for any individual sub-circuit. It stated that the value must not fall below 1 megohm, as for connected equipment.

It wasn't until the Ninth Edition of the IEE Wiring Regulations in 1927 that the requirements for insulation resistance testing became more detailed and differentiated between lighting, heating and power circuits. Interestingly, this edition stated that ***"heating and power circuits, with or without lighting points, may be tested, if desired."*** Testing of lighting circuits, however, was a *requirement*, as it was stated that these ***"shall"*** be tested. The Regulation for minimum insulation resistance value for equipment connected to the installation was amended to state that it ***"shall not be less than that specified in the appropriate British Standard Specification or, where there is no such specification, shall not be less than half a megohm"***. The requirement for the minimum value of insulation resistance for the whole installation remained at 1 megohm.

The Thirteenth Edition of the IEE Wiring Regulations in 1955 acknowledged the need to test circuits separately if required, and stated that ***"any reading less than 0.5 megohm shall be disregarded and the wiring under test shall be sub divided until a reading higher than 0.5 megohm is obtained."***

When the Sixteenth Edition of the IEE Wiring Regulations was published in 1991, a table was introduced defining minimum values of insulation resistance, and test voltages were provided according to the nominal voltage of the circuit. The minimum value of insulation resistance for a distribution circuit or a switchboard up to and including 500 volts was 0.5 megohms.

The first European Regulations, CENELEC Part 6 Harmonized Document (HD), were published in 2006. At this point, agreements were in place obliging the committee responsible for BS 7671, JPEL/64, to adopt the technical intent of the HD. The Seventeenth edition, BS 7671:2008, was published shortly afterwards: the table from the Sixteenth Edition was subsequently amended and the minimum value of insulation resistance was revised to 1 megohm – the value that is still used today.

Cables are manufactured to various standards, which detail minimum insulation resistance values for particular cable types at specific temperatures. However, these are the minimum values required to achieve compliance with the standard – the actual values will be different and will vary between different manufacturers and according to the length of the cable.

The values identified in BS 7671:2018+AMD1:2020 are for distribution circuits and switchboards that are acceptable for the majority of installations. However, there may be special installations, such as lighting installations with cable runs several kilometres long, that may not comply with these values. In these situations, it would be appropriate to record this on the Electrical Installation Certificate (EIC) as an intended departure. The design values obtained using manufacturers' data can be compared with the measured values, which will need to be adjusted according to temperature.

This information should be recorded on the EIC. It would assist in demonstrating that there is no lesser degree of safety than that required by Regulation 120.3 of BS 7671:2018+AMD1:2020. It could also prove useful when testing the installation in the future.

Summary

The minimum values of insulation resistance have changed over the years. There is no documented justification for the 1 megohm minimum value of insulation resistance, but it has survived the test of time and in practice has proved to be a useful starting point when determining the condition of the insulation of cables and electrical equipment.

There may be some special installations that do not meet this requirement. In these cases, the electrical designer must make an engineering judgement based on values obtained from the manufacturer and measurements taken on site. In such cases, it would be appropriate to record this as an intended departure, provided the resulting degree of safety is not less than that obtained by compliance with BS:7671:2018+A1:2020, as stated in Regulation 120.3.

Draft for Public Comment: IET Code of Practice for Electrical Energy Storage Systems 2nd edition

We are happy to announce that the Draft for Public Comment for IET Code of Practice for Electrical Energy Storage Systems 2nd Edition is now live.

This Code of Practice looks at EESS applications and provides information for practitioners to safely and effectively specify, design, install, commission, operate and maintain a system. This second edition has been updated to take account of developments in the industry, and progress in standardisation.

The scope of this Code of Practice addresses EESS intended for fixed installation applications including:

- individual dwellings
- commercial applications, including multi-occupancy buildings and multi-occupancy residential buildings
- industrial applications.

and covers:

- electrochemical energy storage systems in electrical installations
- integration into low voltage (LV) power systems (AC and DC), and
- systems aligned with existing standards, regulations and guidance.

Readers who are interested in this area are encouraged to go to the DPC page at the below link and download the document for review before the consultation period elapses on 10th July.

Further information on Draft for Public Comment procedure can be found on the page.

https://electrical.theiet.org/get-involved/consultations/draft-for-public-comment-iet-code-of-practice-for-electrical-energy-storage-systems-2nd-edition/

The all-new 5th Edition of the IET Code of Practice for In-Service Inspection and Testing of Electrical Equipment

In this article, James Eade, author of the 5th edition, gives a brief insight into the changes to this important Code, due for publication later this year.

Readers will undoubtedly be familiar with 'PAT testing' as a concept – if not in practice, then certainly as an observer of electrical equipment in the workplace sporting the ubiquitous green 'pass' label or similar. The origins of this process can be traced back to the first edition of the IET Code of Practice for In-Service Inspection and Testing of Electrical Equipment (commonly referred to by many by the easier-to-pronounce acronym 'COPISITEE'), which this year sees quite a significant revision.

History of the Code

Before giving an insight into the proposed changes contained within this latest revision, it is interesting to reflect on the origins of the Code, first published in 1994. When the Electricity at Work Regulations (EWR) came into force in 1989, the subject of electrical safety management was debated and in particular, how businesses could comply with the requirements of the Regulations in the workplace. It was acknowledged that the design, construction and maintenance of most electrical installations was adequately catered for in the (then) IEE Wiring Regulations, but this left the question of how to manage all the equipment connected to the installation itself.

The IEE formed a working group to look at the issue, comprising many representatives from industry, including appliance manufacturers and trade associations. As a starting point of reference, manufacturing representatives detailed the electrical safety tests that are conducted on appliances at the time of manufacture, as required in product safety standards. These were subsequently used as a basis for the first edition of COPISITEE, as a means of verifying the ongoing electrical safety of appliances. Thus, 'portable appliance testing' (PAT) was born….

Those familiar with previous editions of the Code will have seen that these origins are fairly prevalent throughout, with, for example, appendices detailing the requirements of appropriate product standards. Over time, as data about the effectiveness of appliance testing became available, it was accepted that not all the tests were really suited to routine maintenance; older readers might remember the 'hi-pot' or flash test and microwave leakage tests, for instance.

In successive editions, changes aimed at moving towards the original intent of verifying the **safety of electrical equipment for continued use** were made. A clue to the change of focus in the forthcoming edition can be found in the title of the COPISITEE itself, which is often overlooked: 'In-Service Inspection and Testing of **Electrical Equipment**'.

Appliance or equipment?

While the industry is familiar with portable appliance testing, generally the approach in most workplaces is simply to check those things fitted with a plug that are – to varying degrees – 'portable'. An appliance, however, is actually defined in Standards as "apparatus intended for household or similar use", which of course excludes many types of electrical equipment found in the workplace. It's also noteworthy that generally the EWR do not apply at home in a domestic setting, with a few limited exceptions. It can be seen that use of the word 'appliance' is not representative of what the COPISITEE seeks to embrace, namely 'electrical equipment' that is 'in-service', i.e. used at work.

Looking at 'electrical equipment', this is actually defined in the Code as an "Any item for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy, such as machines, transformers, equipment, measuring instruments, protective devices, wiring systems, accessories, appliances and luminaires.". Electrical equipment therefore includes appliances such as washing machines and vacuums.

This is a definition that is fairly all-encompassing, including within it most (if not all) of the items of electrical equipment to be found in a workplace. For this reason, the forthcoming 5th edition of the Code places a much greater emphasis on the original intent of managing electrical equipment in the workplace that is not covered under other maintenance regimes, such as the electrical installation itself. The equipment may not be fitted with a flex and plug and could be wired into the installation, such as an air-conditioning unit or a security access control system. These types of equipment often fall through the gap of in-service inspection and testing, with the person conducting the Electrical Installation Condition Report (EICR) stopping at the fused connection unit or isolator supplying the equipment, and the 'PAT' tester seeing it as part of the installation itself, and not a portable appliance.

The 5th edition of the COPISITEE therefore makes no mention of the words 'portable' and 'appliance', other than in the explanatory notes in the preface. In fact, another allied change is the removal of the terms 'stationary', 'portable', 'fixed' and 'moveable', as the key focus is on the verification of equipment for safety in continued use. The equipment's ability to move or be relocated (or not, as the case may be) doesn't affect the nature of the testing and inspection required, although it might have a bearing on the frequency of the maintenance activity.

The changes in brief

The 5th edition is a significant departure in respect of layout too. Previous editions were broadly split into two sections: the first concerning the management of electrical safety and the legal requirements, and the second aimed at the person conducting the inspection and testing, comprising the test requirements, visual inspection checks and more.

Approximately 26 years on from the first edition of the COPISITEE, the need for management of electrical safety in the workplace is better understood and the structure of the Code has thus been revised into a series of sections, taking the reader through the need for electrical maintenance, the legal requirements, the competencies of those conducting the work, types of equipment and tests, as well as a section on the frequency of inspection and testing. New appendices include guidance on low-risk equipment and environments such as IT server racks; a basic electrical theory primer; a workplace poster for user-checks and example risk assessments for ascertaining the frequency of testing.

The revision also reflects modern equipment and practices, with commentary on second-hand and hired equipment, as well as on the perennial issue of equipment that may be fake or sourced from suppliers where its provenance may be in doubt.

In recent years, there have been changes to product manufacturing standards, in which the methods of providing protection from electric shock have been reclassified and changed. Readers may be familiar with separated extra-low voltage (SELV), for example, where protection against electric shock is provided by electrical separation from earth and other circuits, coupled with extra-low voltage. This has been widely used in Class III equipment, but is no longer a method of protection prescribed in BS EN 62368 *Audio/video, information and communication technology equipment*, which has combined and replaced other common product safety standards.

The classifications for safety are now described as 'energy source classes', which is subtly different to the previous methods of description. While to the end-user the changes may be of little consequence in practice, it is important that those performing the inspection and testing of electrical equipment understand the new classifications. Confusingly, SELV is still a valid method of protection for electric shock when used in an **electrical installation** (i.e. one complying with BS 7671 *Requirements for Electrical Installations*), but it is no longer a valid method for an **item of equipment**. The distinction is important to understand, especially when selecting products that may be used in an installation requiring SELV as a protective measure. The 5th edition of the COPISITEE has been updated to reflect these new classifications.

The conducted tests are another area of change, with the inclusion of a flowchart to aid those performing the inspection and testing to select appropriate tests according to the equipment. Again, the focus has been on the verification of equipment for electrical safety for continued use, and this has led to the list of required tests being revised. For example, some items of Class II equipment may no longer require testing, with a visual inspection being satisfactory on its own. The high-current earth bond test has given way to a preference for a lower-current one, because empirical evidence suggests that the higher current does not stress the connections as much as first thought, given the duration of the test. The insulation testing voltage has also been revised, taking into account the design of modern electrical and electronic equipment.

A significant change (perhaps the most significant, depending on your view!) is a complete review of the frequency of testing, currently exampled in Table 7.1 of the 4th edition. This table disappears in the 5th edition, although if you want to know what it has been replaced by, you'll have to wait for the next instalment of this article, due in the Autumn issue of *Wiring Matters*.

The 5th edition of the IET Code of Practice for In-Service Inspection and Testing of Electrical Equipment is currently due for publication in September 2020, although given the ongoing Covid situation, the date may shift somewhat. It is possible to pre-order a copy online, via: https://shop.theiet.org/code-of-practice-for-in-service-inspection-and-testing-of-electrical-equipment-5th-edition

Amps per Pound

Introduction

The idea of sizing a cable to reduce energy loss in distribution is nothing new and has been considered for many years, but with competitive tendering for work and the continual search for cost reductions (also known as 'value engineering'), the modern design of an electrical installation tries to reduce the materials utilized to a minimum. Copper has always been relatively expensive, and continues generally to rise in price, so trying to reduce the size of cables used has always had an economic attraction in the initial design of an installation – not to mention that smaller cables are easier to install and support, effectively yielding a double saving.

However, every cable has resistance: when current flows through a cable, it results in a dissipation of power (I^2R) and, over the time the circuit is in operation, there is a waste of energy. Thus, in these times of energy conservation and global warming, energy efficiency and the minimizing of wasted energy is a useful strategy to consider.

The new Appendix 17 of BS 7671:2018 *Energy Efficiency* comments briefly on this, stating, in item 17.4:

> *Increasing the cross-sectional area of conductors will reduce the energy losses but will increase initial installation costs. The decision as to whether to do this should be made by assessing both the savings within a time scale and the additional cost due to the increased size. Practical constraints, such as size of terminations, will also affect the sizing of conductors.*

In 1990 David Latimer of the IET and Richard Parr, a consultant at ERA Technology, produced a paper entitled *Amps per Pound* (pound sterling), which looked at the selection of suitable cable types for an installation and the capital cost/energy losses of such cables. In this article, we bring the consideration of energy losses in cables up to date.

Tradition?

The traditional approach to the selection of a cable size has been to aim for the maximum utilization of cable materials. To achieve this, cable manufacturers have striven to produce cables that will operate satisfactorily at increasingly higher temperatures, with rules for safe installations in BS 7671 based on such temperatures. In addition, to achieve minimum initial capital cost, international wiring rules now permit greater values of voltage drop than was previously the case.

In 1888 the second edition of the *Rules and Regulations for the Prevention of Fire Risks Arising From Electric Lighting*, published by the Society of Telegraph Engineers and Electricians (now, after several editions, known as BS 7671 *Requirements for Electrical Installations*, published by the IET) placed limits on the operating temperature of loaded conductors such that if a conductor carried double its rated current, the conductor temperature was to rise to no more than 65 °C. The first specific mention of voltage drop was in the fifth edition, published in 1907, which allowed 2 % for lighting circuits. Over time, this rose in subsequent editions of the Regulations through '2 % plus one volt', '3 % plus one volt' (during World War II), back down to '2 % plus one volt', and then through '2.5 %' and '4 %' – finally settling on '3 % for lighting and 5 % for other uses' in the current 18th edition of BS 7671. This allows for an increasing energy loss in conductors, which to some extent may be offset by the better refining of copper over the years, providing a lower conductor material resistivity.

An alternative?

Contrary to the intention of maximum conductor utilization, it can be demonstrated that there are sound economic and practical reasons for moving away from a simple choice of the smallest permissible conductor size and the lowest initial cost of an installation. Indeed, the minimum first cost approach may well develop into an unwelcome financial burden over the life of an installation. The cost of energy continues to rise, and apart from increasing initial fuel costs, there are environmental and social considerations affecting the provision and cost of generation and distribution, all pushing towards a more efficient use of energy and decreasing waste and losses. It is wise to recognise that the true cost of an installation should include the consideration of future operating costs: lifecycle cost analysis should thus be a primary decision-making factor.[1]

We therefore pose the question: should industry require all energy-consuming equipment and systems to be quoted in the following way?

Price of equipment, delivered to site, including commissioning	£ XXXX
Cost of electrical installation	£ XXXX
Cost of energy consumed over N years (agreed formula)	£ XXXX
Cost of maintenance over N years (agreed formula)	£ XXXX
Total cost over N years	**£ XXXX**

In addition, the embodied energy and lifetime carbon emissions could be quoted.

The energy and maintenance costs would have to be calculated on standard industry agreed formulae (appropriate to the product), including operational hours, percentage loads, fuel price and maintenance labour rate. It is to be hoped that responsible manufacturers with quality products might take up the initiative.

A similar form of comparative presentation could be adopted for various systems, such as power distribution, traced hot water, lighting and lighting controls, when their use is being considered or proposed. How many people who make these selections actually know the relative total cost, as noted above? As engineers and designers, we all should. It is a fundamental requirement for engineers to have, and be acknowledged to have, the comprehensive understanding and knowledge necessary to discharge their duties professionally.

Cost calculations

Latimer and Parr considered the cost of owning and operating an installation in significant detail and looked at the initial capital cost of cable installation methods as well as installation operational energy consumption. This article is necessarily brief and can only consider a few sample cables, sizes and loads, but the basic theory will hold true for all installations, and it is hoped that it will serve as an illustration of the possible 'hidden' costs involved over the life of an installation.

It can be argued that all the costs used in the following examples are approximate and that a contractor or installation owner may have better buying power. The calculations can always be reworked for a specific proposed installation with accurate cost and operational data; however, the conclusions are inescapable.

The spreadsheet in Table 1 shows estimated capital and operational costs for certain single-phase and three-phase armoured cables, installed in free air and rated in accordance with the data given in Appendix 4 of BS 7671. Cable costs were taken from freely available suitable cost data[2] and current electrical energy costs were taken as 16 p per kWh, with an annual increase of 2 % and an annual inflation rate of 3 %.

Table 1

	Size mm (SWA)	Cores	£/m	£ for 20m	Install £	Installed cost £	Route m	I rating	I load	Cores load	R mΩ	Vd/m	Load Vd	Watts	kWHr 8 hr/day	Unit cost (£) £0.16p	kWHr 5 day/wk	Unit cost (£) £0.16p	kWHr 52 wk/yr	Unit cost (£) £0.16p	kWHr 10 years	Unit cost (£) £0.16p
Exceeds BS 7671 volt drop	2.5	2	0.65	9.40	100.00	109.40	20	36	20	2	19	19	7.60	152.00	1.22	0.19	6.08	0.97	316.16	50.59	3161.60	505.86
	4	2	0.9	18.00	100.00	118.00	20	49	20	2	12	12	4.80	96.00	0.77	0.12	3.84	0.61	199.68	31.95	1996.80	319.49
	6	2	1.15	23.00	100.00	123.00	20	62	20	2	7.9	7.9	3.16	63.20	0.51	0.08	2.53	0.40	131.46	21.03	1314.56	210.33
	10	2	1.72	34.40	150.00	184.40	20	85	20	2	4.7	4.7	1.88	37.60	0.30	0.05	1.50	0.24	78.21	12.51	782.08	125.13

	Size mm (SWA)	Cores	£/m	£ for 50m	Install £	Installed cost £	Route m	I rating	I load	Cores load	R mΩ	Vd/m	Load Vd	Watts	kWHr 8 hr/day	Unit cost (£) £0.16p	kWHr 5 day/wk	Unit cost (£) £0.16p	kWHr 52 wk/yr	Unit cost (£) £0.16p	kWHr 10 years	Unit cost (£) £0.16p
Exceeds BS 7671 volt drop	4	4	1.44	72.00	150.00	222.00	50	42	40	3	10.00	10.00	20.00	2400.00	19.20	3.07	96.00	15.36	4992.00	798.72	49920.00	7987.20
	6	4	2.11	105.50	150.00	255.50	50	53	40	3	7.90	7.90	15.80	1896.00	15.17	2.43	75.84	12.13	3943.68	630.99	39436.80	6309.89
	10	4	3.12	156.00	200.00	356.00	50	73	40	3	4.70	4.70	9.40	1128.00	9.02	1.44	45.12	7.22	2346.24	375.40	23462.40	3753.98
	16	4	4.73	236.50	200.00	436.50	50	94	40	3	2.90	2.90	5.80	696.00	5.57	0.89	27.84	4.45	1447.68	231.63	14476.80	2316.29
	25	4	6.79	339.50	200.00	539.50	50	124	40	3	1.60	1.65	3.30	384.00	3.07	0.49	15.36	2.46	798.72	127.80	7987.20	1277.95
	35	4	9.21	460.50	250.00	710.50	50	154	40	3	1.15	1.15	2.30	276.00	2.21	0.35	11.04	1.77	574.08	91.85	5740.80	918.53
	50	4	12.26	613.00	250.00	863.00	50	187	40	3	0.86	0.87	1.74	206.40	1.65	0.26	8.26	1.32	429.31	68.69	4293.12	686.90
	70	4	17.44	872.00	300.00	1172.00	50	238	40	3	0.59	0.60	1.20	141.60	1.13	0.18	5.66	0.91	294.53	47.12	2945.28	471.24
	95	4	23.81	1190.50	300.00	1490.50	50	289	40	3	0.43	0.45	0.90	103.20	0.83	0.13	4.13	0.66	214.66	34.34	2146.56	343.45
	120	4	30.14	1507.00	400.00	1907.00	50	335	40	3	0.34	0.37	0.74	81.60	0.65	0.10	3.26	0.52	169.73	27.16	1697.28	271.56
	150	4	36.93	1846.50	400.00	2246.50	50	386	40	3	0.28	0.30	0.60	67.20	0.54	0.09	2.69	0.43	139.78	22.36	1397.76	223.64
	185	4	44.58	2229.00	400.00	2629.00	50	441	40	3	0.22	0.26	0.52	52.80	0.42	0.07	2.11	0.34	109.82	17.57	1098.24	175.72
	240	4	59.26	2963.00	400.00	3363.00	50	520	40	3	0.18	0.21	0.42	42.00	0.34	0.05	1.68	0.27	87.36	13.98	873.60	139.78

For simplicity, it is assumed that energy consumed is paid for only once a year, at the year-end. In addition, it is widely understood that with inflation, a sum of money spent in the future has less value than an equivalent sum spent now, so there is a 'present value' to be calculated for the future energy cost, to allow comparison with current costs ('future value'). Energy costs are expected to rise over the life of an installation, so an annual energy cost increase should also be included. Finally, there should be a finite installation life for calculation: ten years has been chosen, but in reality, installations may operate for much longer, with resulting increased waste energy costs. (In the longer term it may be a valid proposition to rewire an installation using the same plant, simply to reduce energy costs.)

The basic present value of a future sum value can be calculated from the formulae:

$$PV = \frac{FV}{(1+r)^i}$$

PV is present value of a sum of money
FV is future value
r is the inflation or discount rate
i is the number of years considered

However, to consider the additional annual increase in the cost of energy, at 2 %, and the cumulative costs over the ten-year period, the formulae is modified to:

$$NPV = Co + \sum_{i=1}^{T} \frac{Ci \cdot (1+e)^i}{(1+r)^i}$$

Co is installation capital cost
C is the energy cost per year
e is the annual increase in energy cost – 2%
r is the inflation rate – 3%
T is the time in years – 10 years in this case
i is a 'counter', 1-10

For simple examples, three single-phase and five three-phase loads will be considered further. Looking at Table 2, it can be seen in both the single- and three-phase cases that the most economic installation occurs when the cable installation capital cost and the lifetime energy running cost are effectively equal. In the single-phase installation, the costs are reducing, and it is expected that a 10 sq mm cable would be the optimum. In the three-phase model, the minimum occurs somewhere between a 35 sq mm and a 50 sq mm cable and the final choice would need to be refined by calculation, using specific data for a specific installation.

Table 2

Size	Cores		Yr 1 £ per year	Yr 2 £ per year	Yr 3 £ per year	Yr 4 £ per year	Yr 5 £ per year	Yr 6 £ per year	Yr7 £ per year	Yr 8 £ per year	Yr 9 £ per year	Yr 10 £ per year	Total £10 yr energy	Install £	Total £ cost	% energy	% capital
10 sq mm	4	SWA	375.40	371.76	368.15	364.57	361.03	357.53	354.06	350.62	347.21	343.84	3594.17	356.00	3950.17	90.99	9.01
25 sq mm	4	SWA	127.8	126.56	125.33	124.11	122.91	121.72	120.53	119.36	118.20	117.06	1223.59	539.50	1763.09	69.40	30.60
35 sq mm	4	SWA	91.85	90.96	90.08	89.20	88.33	87.48	86.63	85.79	84.95	84.13	879.39	710.50	1589.89	55.31	44.69
50 sq mm	4	SWA	68.69	68.02	67.36	66.71	66.06	65.42	64.78	64.16	63.53	62.92	657.65	863.00	1520.65	43.25	56.75
95sq mm	4	SWA	34.34	34.01	33.68	33.35	33.03	32.71	32.39	32.07	31.76	31.45	328.78	1490.50	1819.28	18.07	81.93
2.5 sq mm	2	SWA	50.59	50.10	49.61	49.13	48.65	48.18	47.71	47.25	46.79	46.34	484.36	109.40	593.76	81.58	18.42
4 sq mm	2	SWA	31.95	31.64	31.33	31.03	30.73	30.43	30.13	29.84	29.55	29.26	305.90	118.00	423.90	72.16	27.84
6 sq mm	2	SWA	21.03	20.83	20.62	20.42	20.23	20.03	19.83	19.64	19.45	19.26	201.35	123.00	324.35	62.08	37.92
10 sq mm	2	SWA	12.51	12.39	12.27	12.15	12.03	11.91	11.80	11.68	11.57	11.46	119.77	184.40	304.17	39.38	60.62

However, any selection of larger conductors will also bring increased cost associated with bigger containment, enclosures, etc. and these will need to be considered in detail for each installation.

Conclusion

As noted previously, this article is only illustrative. More detailed factors applicable to a specific installation would need to be considered in any design. The calculation does, however, show clearly that a smaller cable is not always the most economic choice overall. In the three-phase example, installing a smaller 10 sq mm cable, which could carry the load, could cost the installation owner some £2,400 more in running costs than initially installing a 35 sq mm cable over a ten-year installation life – and that's just for one cable!

Further investigation into running costs should also be made, as it must be noted that the figures given in the cable rating tables in Appendix 4 of BS 7671 assume a conductor resistance at the full rated current of the cable, whereas a larger conductor carrying less than full rated current will allow the conductor to run cooler, and thus the resistance will be less (the calculation $R = R_o (1 + \quad T)$ is very relevant). See item 6.1 of Appendix 4 of BS 7671 for further information.

Acknowledgements

[1] Graham Manley, presidential address to the Chartered Institution of Building Services Engineers (CIBSE), 2004.

[2] With assistance from Gary McCafferty, Assistant Manager, Cleveland Cables.

Thanks also to Dr Iain Brock, Shahid Kahn (ECA) and the IET Technical Regulations staff for their helpful comments.

Asbestos Guidance for electricians

By Michael Peace

Introduction: aims of this guidance
Asbestos was widely used in building construction, both as a building material and for its useful insulation and fire protection properties, for many years during the 20th century. Its use was progressively reduced between the 1970s and 1999, when all remaining forms were finally prohibited in the UK with the implementation of the Asbestos (Prohibitions) (Amendment) Regulations 1999. Asbestos has also been removed from various properties over the years for various reasons, for example, because of damaged material, or for refurbishment and demolition, but a substantial proportion of the original products still remain. These materials, if undetected, can present an ongoing to risk to workers carrying out building repair and maintenance or improvement and refurbishment work. Workers at potential risk include electricians and other building trades.

This document has been prepared to provide guidance on asbestos for electricians.

The document has the following objectives:

a) to describe asbestos and asbestos-containing materials (ACMs);
b) to explain the health effects and risks from exposure to asbestos and the legal requirements;
c) to explain the risks for electricians;
d) to provide information on where ACMs are likely to be found in electrical and related work;
e) to highlight the actions to take to reduce the potential for inadvertently disturbing ACMs in buildings;
f) to describe the asbestos-related work (with appropriate controls) that electricians can carry out where adequate training has been provided; and
g) to provide information for dealing with emergencies.

Asbestos and ACMs
'Asbestos' is the collective commercial name for a range of naturally occurring fibrous silicate minerals, which include crocidolite, amosite and chrysotile. These minerals are commonly known as 'blue', 'brown' and 'white' asbestos, respectively. Historically, asbestos minerals were mined, processed and refined through a series of crushing and size separation stages and manufactured into an extensive and eclectic range of products, items and materials. Tens of millions of tonnes of ACMs were manufactured in the UK, particularly for use in the construction industry. Many of these products were installed in new or refurbished premises, such as domestic houses and flats, hospitals, schools, department stores, university buildings and municipal and community buildings during the post-war construction period between 1950 and 1980. Asbestos has excellent fire, chemical, water and heat-resistance properties, which explains its widespread use.

The more common construction applications of ACMs include:
a) insulation/lagging on pipes, tanks and boilers.
b) sprayed coatings used for fire protection on roofs, ceilings and structural supports such as columns and beams.
c) asbestos insulating board (AIB) materials/firebreaks as panels and boards (including door panels, ceiling tiles and partitions and walls).

d) asbestos cement (AC) items, including roof and wall profiled sheeting, drainage pipes and gutters. (Chrysotile used in AC products was the most commonly commercially used asbestos type.)

Health effects and risks from asbestos

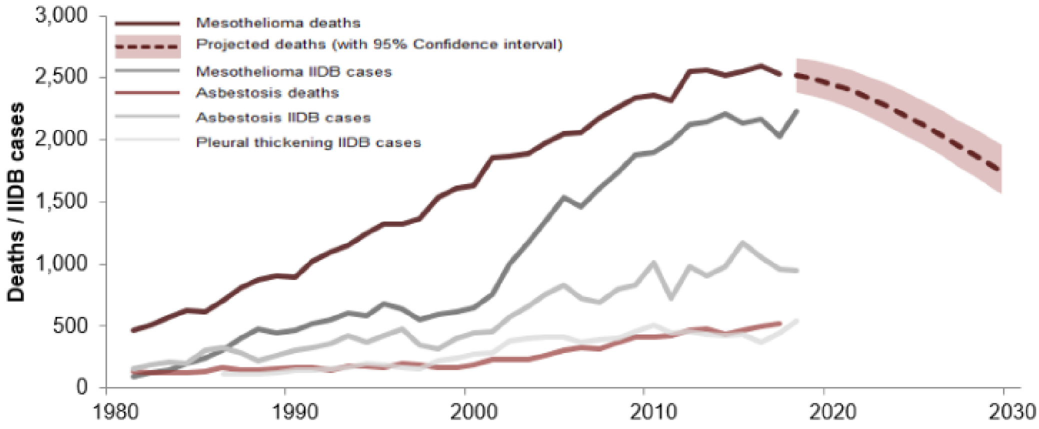
Asbestos is an extremely hazardous and dangerous material. All the main asbestos types are classed as Group 1 human carcinogens by the International Agency for Research on Cancer (IARC). Inhalation of asbestos fibres can cause a number of fatal or serious respiratory conditions, including lung cancer, pleural and peritoneal mesothelioma (cancers of the chest lining/chest cavity and abdominal cavity lining, respectively) and asbestosis (fibrosis of the lung). Smoking greatly increases the risk of developing asbestos-related lung cancer.

Freely occurring asbestos fibres are microscopic (i.e. around some two thousand times smaller than a human hair) and can only be identified under a microscope. Asbestos fibres are produced and released into the air when asbestos products are damaged or disturbed, particularly by physical action such as being broken, smashed, cut, drilled, sanded, scraped, sawed or otherwise insulted, and also when asbestos debris and dust is disturbed or dislodged, for example, when sweeping up. It is, however, important to note that asbestos products do not pose a risk to health simply by being present in buildings or any environment.

The [latest data from the Health and Safety Executive (HSE)] shows that currently over 5,500 people die each year from asbestos-related diseases (2017 data). This includes some 500 and 2,500 deaths from asbestosis and mesothelioma, respectively (see Figure 1). These are primarily work-related deaths. Around 40-50 % of these deaths are from building trades-related occupations (including electricians, joiners and plumbers) and maintenance workers. The deaths are the result of previous exposures, as the latency period for disease to develop is usually 20-40 years after initial exposure. Asbestos-related deaths are far greater than the total number of people killed in road traffic collisions in 2018, which stood at 1,784.

People often fail to recognise the dangers of asbestos, or are complacent regarding the risks to health, because there is no immediate or acute effect. Other dangers we encounter every day, such as electrical or gas risks, or even the danger of driving on the road, seem more dangerous and are taken more seriously, as the consequences of these are instant.

Figure 1 - Mesothelioma, asbestosis, and pleural thickening: time trends in annual deaths and Industrial Injuries Benefit Disablement (IIDB) cases*



**Latest statistics are for 2017 for deaths and 2018 for IIDB cases*

However, it is important to recognise that there is no 'safe' level of exposure to asbestos. Every exposure and every incident gives rise to a risk of developing mesothelioma in its own right. Each exposure also builds on previous exposures, so that the risk of disease increases with every incident.

Consequently, the risk of developing future disease can only be reduced by avoiding and minimizing asbestos disturbance and exposure incidents.

Legal requirements for asbestos

There are specific legal requirements that apply to all 'work' (and potential work) with asbestos and to premises that contain asbestos. The main piece of legislation is the Control of Asbestos Regulations (CAR) 2012.

The Regulations place duties on two main groups:

1) employers (for example, electrical contractors) whose employees may carry out any work that is liable to disturb ACMs; and
2) 'property' dutyholders (i.e. the owners and occupiers of non-domestic premises) who have maintenance and repair responsibilities for the property.

Employers' duties

Employers must identify the presence of asbestos before any electrical or other work is carried out that is liable to disturb asbestos (CAR 2012, Regulation 5). This 'work' includes access or preparatory work, etc. around electrical equipment. The purpose of the identification of asbestos will in many cases be to avoid disturbing the material.

If work on the ACM is actually planned by the employer, there are further requirements on the company to carry out a risk assessment and to prepare a plan of work that identifies the appropriate controls for minimizing exposure and preventing the spread of fibres. There are also additional requirements for training of workers and for cleaning of workers and work areas.

Electrical contractors can carry out low-hazard work on ACMs so long as they are trained and competent. High-hazard work can only be performed by specialist (licensed) contractors.

Duties of property holders

The presence of asbestos in buildings is usually established in a survey of the premises (see section on Asbestos surveys below). This is required by property dutyholders in non-domestic premises. Property holders should pass this survey information onto electrical and other contractors carrying out repair or maintenance and other work. If there is no information available from the property holder, the electrical contractor has a responsibility to identify the asbestos themselves.

Why is asbestos a hazard to electricians?

Asbestos was used extensively as a building product. It was also used in certain electrical equipment, due to its heat resistance and fire protection properties. During the course of their work, electricians, like all tradespeople, are very likely to encounter asbestos at various points in their careers. Asbestos may be found in electrical equipment and also in the surrounding building materials. It is therefore important to be able to identify the locations where it may be encountered, to prevent accidental exposure.

Where might I find asbestos?

Electrical equipment that contains ACMs

Some of the most likely ACMs to be encountered by electricians are asbestos flash guards within rewireable fuse carriers. These are a loosely bound material and extremely friable, which means that they release fibres easily.

Flash guards are most likely to be found within fuse carriers in distribution boards and would require an operative carrying out maintenance, such as replacing a fuse, to remove the fuse from the carrier, which would expose the flash guards, potentially releasing fibres into the atmosphere that could be breathed in. If such items are discovered during the course of compiling an Electrical Installation Condition Report (EICR), the client should be advised of the hazard and the risk to persons likely to be in the vicinity or carrying out maintenance on the equipment should be assessed. The safest course of action would be to remove and dispose of the equipment in accordance with HSE requirements. Removal of such items must only be carried out by competent persons and special precautions must be taken when handling or during removal or disposal of such items, in accordance with the guidance available on the HSE website.

Arc chutes are used in circuit-breakers to insulate and protect circuits from shorting by preventing a high voltage spark from jumping from one contact to another. The arc chute acts as a barrier between two contacts. Prior to the mid-1980s, arc chutes were made from asbestos-containing plastic moulding compound. It is possible that a high voltage spark could crack the arch chute, creating dust and particles.

Storage heaters can be a problem, as they may contain asbestos and, once the cover has been removed, fibres may be released. Information can be found on the Asbestos Information Centre (AIC) website, which details the storage heater makes and models that contain asbestos. This information can be reviewed before work commences, reducing the risk of possible exposure.

Other ACMs that may be encountered whilst accessing work areas

Asbestos insulating board (AIB) is particularly dangerous if drilled, cut, broken or disturbed in any way, as it can release thousands of fibres into the air, which will contaminate the surrounding areas and could be breathed in. This material came in large sheets and had many uses, including lining the inside of boiler rooms or warm air unit cupboards. AIB was also used extensively as fire protection on or in the vicinity of electricity and gas meters. Guidance was published on this in 2014 by the Association of Meter Operators.

Pipe lagging and insulation is a material that is particularly dangerous. It is fibrous and easily disturbed when carrying out electrical works in close proximity. Work on these products is to be carried out by a licensed contractor only.

Older textured coatings (i.e. pre-1990), more commonly known as Artex, represent another possible risk of exposure to asbestos. Asbestos in Artex ceased to be used around 1985-90 and was banned in 1992. Precautions should be taken if drilling is required in textured coatings. The HSE document a26 provides guidance on drilling and boring through textured coatings and is available on the HSE website.

Asbestos surveys

Due to the extensive use of asbestos in buildings and electrical equipment, ACMs are likely to be encountered by electricians. Work will therefore need to be properly planned and the potential for asbestos properly considered. The main source of information will be the asbestos survey.

CAR 2012 requires building dutyholders, such as building owners and other persons with responsibility for maintenance, to manage asbestos in their premises. ACMs should normally be identified by having a survey carried out, which will provide a report, detailing information to enable asbestos to be managed safely. It will provide accurate information on the type, quantity and condition of any ACMs present. The asbestos register should be made available to anyone carrying out works in the building. It is important to understand any restrictions to the report, which should be clearly documented.

There are two types of asbestos survey: a management survey and a refurbishment and demolition survey.

A management survey is likely to involve minor intrusive works. It will usually involve sampling and analysis to determine if suspected materials contain asbestos. It can also involve the presumption of the presence or absence of asbestos.

A refurbishment and demolition survey is required before any refurbishment or demolition works are carried out. This is a fully intrusive survey. The asbestos surveyor will require an extensive knowledge of the scope of works to be carried out, in order to ensure the relevant areas are thoroughly inspected and samples taken and analysed.

This can sometimes be something of a chicken and egg situation: an asbestos inspector will not be competent to carry out the necessary procedures to isolate the supply for electrical equipment to safely carry out the inspection, so is likely to presume the presence or absence of ACMs. This can be unhelpful, as if material is presumed to be an ACM, the electrical contractor will have to take additional precautions, which will increase the cost to the client. Equally, if material is presumed not to be an ACM, the electrical contractor could be at risk if it turns out to be an ACM. It may be prudent to consult a licensed asbestos contractor and electrical contractor to attend site at the same time.

Electricians must always check the survey document before starting work. There is a danger that the survey document will not be up to date or complete or will not cover the area to be worked on. If there is any doubt about the quality or completeness of the survey report, work should not start. Employers have legal duties to comply with the requirements of CAR 2012 to ensure that workers are not exposed to asbestos. The HSE website provides more guidance on asbestos surveys.

Domestic properties
The requirement to manage asbestos in buildings only applies to non-domestic properties such as commercial, industrial and public buildings. It does not apply to domestic properties. Therefore, in domestic properties, self-employed electricians and employers of electricians have a duty under Regulation 5 of CAR 2012 to identify any asbestos before work starts, to prevent disturbance and risk to health.

Can I work with asbestos?
There are certain items of work, classed as non-licensed work, that can be carried out by electricians if they are competent to do so. This work must be carried out carefully and in strict accordance with HSE guidance. It can be very expensive and time-consuming to purchase the necessary equipment and to gain sufficient information, instruction and training to work with asbestos as an electrical contractor, and most therefore employ the services of a licenced asbestos contractor, as this is far more cost-effective. The HSE website provides guidance on managing and working with asbestos.

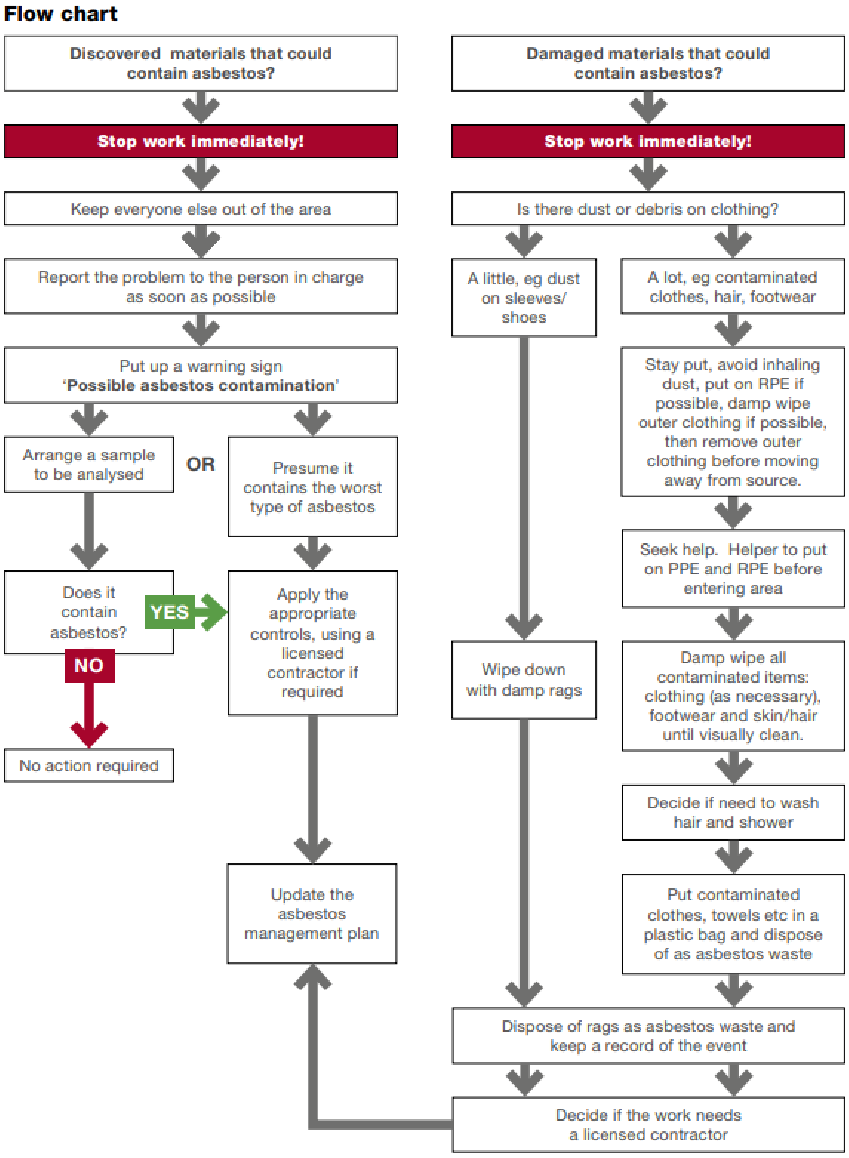
What should I do if I discover or disturb asbestos?
If you think you have discovered asbestos, it is important to stop work immediately and make sure nobody can access the area. You must then report it to your supervisor or manager, as it will need to be investigated.

If asbestos has actually been disturbed, a precautionary approach should be applied. Clothing may have become contaminated, in which case you must follow the emergency procedures as detailed on the HSE website.

You must report the incident to your manager and person in charge of the building and provide a warning sign to warn others of the 'possible asbestos contamination'. A licensed specialist asbestos contractor will be needed to decontaminate the area if required and to take a sample to be analysed and confirm the presence of asbestos.

If, following analysis, it is confirmed that asbestos exposure has occurred, the incident may have to be reported to the HSE under the Reporting of Injuries, Diseases and Dangerous Occurrences (RIDDOR) Regulations 2013, as a dangerous occurrence. Details on the circumstances in which incidents should be reported are set out on the HSE Asbestos FAQ page.

In the event that asbestos is discovered or disturbed, the HSE website provides guidance on what to do. This should be strictly followed.



How can I stay safe from asbestos?

Education is the best way to stay safe from asbestos. You should arm yourself with sufficient information, instruction and training.

Do I need asbestos training?

Employers must ensure that anyone who is likely to disturb asbestos during the course of their work (including self-employed workers) has the correct training to enable them to work safely and competently without risk to anyone. There are many training providers and at least two training associations, including the Independent Asbestos Training Providers (IATP) and the United Kingdom Asbestos Training Association (UKATA). These organizations will be able to provide information on asbestos awareness training and working with asbestos.

There are courses available on asbestos awareness and on licensed and non-licensed work with asbestos. However, it is important to understand that simply attending a training course will not make an operative competent. Competence is a combination of training, learning on the job, instruction and assessment. The HSE website provides information on competency.

Myths
Some electricians feel that they are adequately protected from breathing in asbestos fibres by using a dust mask.

Many types of disposable masks are not suitable for use against asbestos fibres (for example, very simple and looser-fitting masks, such as those used in medical situations). A type FFP3 disposable dust mask to EN 149 should be used. Half-masks with a P3 filter would also be suitable. Anyone using respiratory protective equipment (RPE) must be properly trained and competent in the fitting and wearing of it. In addition, as we don't all have the same shape or size of face, a face-fit test is required to ensure that the mask selected correctly fits the wearer.

It is also important to understand how to use the equipment. A mask may provide little or no protection if the person has stubble or a beard, as the fibres will be breathed in through the sides of the mask where it does not fit tightly to the face.

There are many other things to consider, such as protecting the work area, clothing and shoes from contamination. Personal protective equipment (PPE) should be worn when asbestos work is carried out.

Further information on PPE and RPE can be found on the HSE website.

Summary
As an electrician, you are likely to encounter asbestos during your career. It's important to know how to identify it and how to deal with it, should it be disturbed. Asbestos awareness courses provide valuable information, which you will retain and hopefully pass on to others, helping to keep us all safe from asbestos.

Don't be afraid to challenge an asbestos report. You should understand the limitations of the report and if you feel it does not provide sufficient information to allow you to carry out the work safely, you must not start work.

With regard to working with asbestos, electricians can only work with lower hazard (i.e. non-licensed) asbestos materials, provided they are properly trained and apply adequate controls. Therefore, in many situations, a specialist licensed asbestos contractor will be better suited to carry out work on asbestos. However, if you do work with or near asbestos, you must ensure the HSE guidance is strictly followed and the correct PPE and RPE is used.

Further sources of information

HSE: Control of Asbestos Regulations 2012
HSE: Asbestos: The survey guide
HSE: Managing and working with asbestos
HSE: Asbestos information, instruction and training
HSE: What is competence?
HSE guide em1 asbestos essentials: What to do if you discover or accidentally disturb asbestos during your work
HSE guide a26 asbestos essentials: Drilling and boring through textured coatings
HSE guide a33 asbestos essentials: Replacing an asbestos-containing fuse box or a single fuse assembly
Association of meter operators: Asbestos (guide to asbestos in the vicinity of electricity and gas meters)
Asbestos Information Centre: Storage Heaters Containing Asbestos

We would like to thank the following for providing images for this publication:

- The Health and Safety Executive (This article contains public sector information published by the Health and Safety Executive and licensed under the Open Government Licence)
- Armco Asbestos Surveys
- KNE Ltd