Chapter – 2

LITERATURE REVIEW

2. Literature Review

2.1 Electrostatic discharge (ESD)

The generation and effect of static electricity, observed from ancient times, was initially characterized in the 1500's. The initial tribo-electric series, developed in the 1757 by Wilche, was interpreted as the transfer of electrons between two surfaces that are in contact with each other[27]. The "tribo-series", despite its 250-year existence, is still variable; dependent on the literature and a mechanistic explanation of its origins is still ongoing research subject[28-30].

2.1.1. Static electricity

The term `electrostatic' or `Static electricity' refers to the phenomenon associated with the build up of electrical charges generated, for example, by contact/rubbing of two objects. Static electricity (SE) and electrostatic discharge (ESD) are naturally occurring phenomena. Hebeish AA et al. have defined static electricity as electrical energy at rest on a surface[31]. At its simplest, SE is an electrical charge that cannot move.

If charges don't have a path to the ground, they become "static". If Static electricity is not rapidly removed, the charge will build up. It will eventually develop enough energy to jump as a spark to some nearby grounded or less highly charged object in an attempt to balance the charge.

2.1.2. How objects become charged?

Charging that generates when two solids come into contact has been referred to as frictional charging, contact charging, tribo-electric charging and tribo-electrification.

Most static electricity is generated by tribocharging. Tribocharging occurs when two materials contact with each other and are then separated[32-34]. One material gives up electrons and becomes positively charged; the other takes on these electrons and becomes negatively charged.) (Fig.2.1). Since an object has many billions of electrons, charge on objects grow to significant amounts. This is the most common way static charge is accumulated.

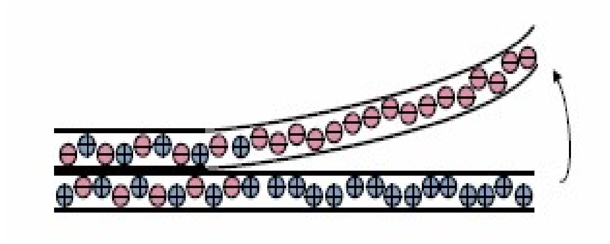


Fig. 2.1 ─ Triboelectric effect

Rubbing is not always necessary for charge generation. It usually increases the amount of charge produced. Experiment results have shown that, when an insulating surface is rubbed either by a conductor or another insulator, charge transfer may be several orders of magnitude greater than in a simple touching contact.

Gonzalez JA, Rizvi SA, Crown EM, et al. have found that objects have possibility to charge with any of the following modes: triboelectrification, induction, polarization & conduction[35].

2.1.3. What is ESD?

ESD is the sudden discharge of this electrostatic potential from one body to another. A good example is the shock we receive when touching a metal door knob after walking across a carpeted floor. Electrostatic charge, or static potential, is usually measured in volts (Table 2.1). Its magnitude and polarity are affected by humidity, the type and speed of motion, the level of friction, and the types of materials involved.

Table 2.1 – Human activity and generation of static charge (in voltage)

TYPICAL VOLTAGE LEVELS		
Means of Generation	10% to 25% RH	65% to 90% RH
Walking across a carpet	35,000V	1,500
Walking across vinyl tile	12,000V	250
Working at an ungrounded bench	6,000V	100
Picking up a polybag from a bench	20,000V	1,200
Sitting in a chair with urethane foam	18,000V	1,500

Occurrence of electrostatic discharge (ESD) has been around since the beginning of time. However, this natural phenomenon has become a significant issue with the widespread use of electronics in the world (Fig. 2.2).

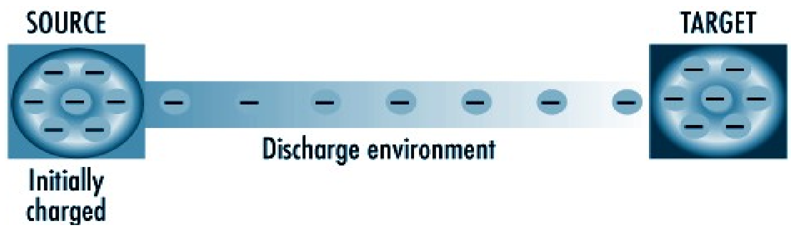


Fig. 2.2 ─ Schematic of electrostatic discharge problem

Many years ago the problems arising from static charges were relatively small with natural fibres in high humidity environments, but these problems became recognized as serious when synthetic fibres of a hydrophobic nature were introduced.

2.1.4. Causes & hazards of ESD

The age of electronics brought with it new problems associated with static electricity and electrostatic discharge. As electronic devices, became smaller and faster their sensitivity to ESD increased. Electrostatic discharge (ESD) is known as "the invisible threat".

The discharge can be caused by a variety of sources, most commonly a direct discharge from a person or equipment into a sensitive object.

The modes in which ESD damage occurs are:

- ❖ Discharge to the device
- ❖ Discharge from the device and
- ❖ Field-induced discharge.

There are basically two categories of damage from ESD:

- ❖ Catastrophic damage
- ❖ Latent damage

The main hazard of Static electricity is the creation of sparks in an explosive or flammable atmosphere. These sparks can set off an explosion or fire. The danger is greatest when flammable liquids are being poured or transferred. In many environments, ESD problems go beyond the minor irritation of a mild shock on a dry winter day. It can damage or destroy sensitive electronic components, erase or alter magnetic media, or set off explosions or fires in flammable environments.

ESD impacts productivity and product reliability in virtually every aspect of today's electronics environment. ESD affects production yields, manufacturing costs, product quality, product reliability, and profitability. Industry experts have estimated average product losses due to static range from 8-33%. Brown L and Burns D. have estimated actual cost of ESD damage to the electronics industry as running into the billions of dollars annually[36]. Examples of ESD indicators/labels are shown in Fig. 2.3.

Fig. 2.3 – Examples of ESD indicators/labels

2.1.5. ESD control

Basic principles of static control:

- ❖ Design in immunity
- ❖ Eliminate and reduce
- ❖ Dissipate and neutralize
- ❖ Protect products from ESD

ESD protection can be divided into two different, but often complementary goals:

- ❖ 1st goal: to prevent static charge build up (triboelectric charge) (Fig. 2.4).
- ❖ 2nd goal: to eliminate existing static charges[37]

Lehmicke (1949)	Henry (1953)	Ballou (1954)	Hersh and Montgomery (1955)	Henniker (1962)	Adams (1987)
		More positive (+)			
Glass	Platinum	Wool	Wool	Nylon 11	Nylon
Human hair	Formvar	Nylon	Nylon	Nylon 6.6	Wool
Nylon yarn	Filter paper	Silk	Viscose	Wool, knitted	Silk
Nylon polymer	Cellulose acetate	Viscose	Cotton	Silk, woven	Paper
Wool	Cellulose triacetate	Cordura®	Silk	Polyethylene glycol	Cotton
Silk	Polyethylene	Human skin	Acetate	Cellulose acetate	Wood
Viscose	Aluminum	Fiber glass	Lucite®	Cotton, woven	Hard rubber
Cotton	Polystyrene	Cotton	Polyvinyl alcohol	Polystyrene	Acetate, rayon
Paper	Copper	Glass	Dacron®	Polyisobutylene	Polyester
Ramie	Nature rubber	Ramie	Dynel®	Polyvinyl butyral	Styroform®
Steel		Dacron®	Velon®	Natural rubber	Orlon®
Hard rubber		Chromium	Polyethylene	Polyacrilonitrile	Saran®
Acetate		Orlon®	Telfon®	Polyethylene	Polyethylene
Synthetic rubber		Polyethylene		Polyvinyl chloride	Polypropylene
Orlon®					Polyvinyl chloride
Polyethylene					Telfon®
		More negative (–)			

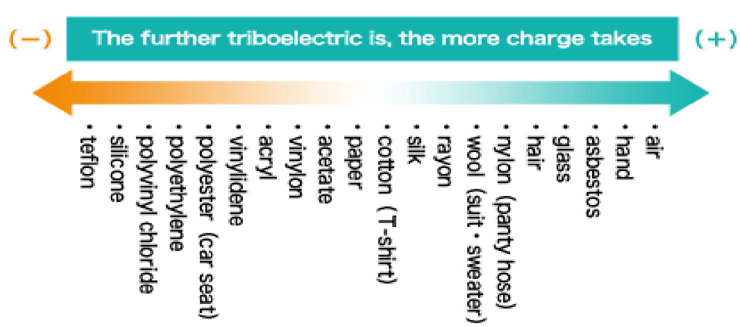


Fig. 2.4 – Triboelectric series

Lesniewski T and Yates K have studied evaluation of materials for cleanliness and ESD protective fabrics. They have proposed that ESD protective materials are desirable to since they have at least one of the following properties: they prevent the generation of static, dissipate electrostatic charges or provide shielding from electrostatic fields/ESD. Among the various solutions offered, Cheng KB, Perumalraj R, Chen HC, et al. have found that textile products and textile-based composite materials have caught the attention of researchers due to the versatility and conformability these textile structures provide[38-43].

Most Static electricity control measures suggest ways for the static charges to dissipate harmlessly before sparks occur (Half decay time is the time that is required to dissipate half magnitude of the developed static charge[44]). Some ways to prevent static charges from accumulating on materials are:

- ❖ Bonding and Grounding (Fig 2.5)
- ❖ Static collectors
- ❖ Humidification
- ❖ Additives

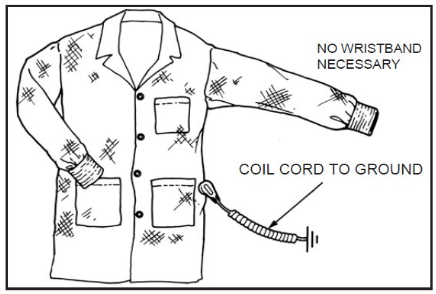


Fig. 2.5 – Grounding of premium jacket with snaps.

2.1.6. Material classification

Materials can be classified as anti-static, dissipative, conductive and insulative.

According to material, ESD Protection levels are shown in Fig. 2.6 :

- ❖ Conductive material : Excellent
- ❖ Static dissipative/antistatic : Good
- ❖ Insulator : None

Fig. 2.6 — Type of materials

2.1.7. Surface resistivity

For thermoplastic materials intended to dissipate electrostatic charges, Surface resistivity is the most common measurement of a material's ability to do so. Owen J. has confirmed that surface resistivity is a concept commonly used in industry, and typically specifies electrostatic properties[45].

To assess the performance of the ESD structures, different methods were used to analyze the properties of ESD fabrics. One of the most used methods is Surface resistivity measurement, which consists in placing two electrodes at certain distances on the tested fabric and measuring the resistivity between them[46-49]. Surface resistivity - A mathematical representation of a material's ability to resist the passage of electricity across its surface. Surface resistivity is defined as the electrical resistance between two electrodes pressed against a surface and forming the opposite sides of a square of any size[50]. It is expressed in ohms/square. A widely accepted Surface resistivity test method is ASTM D257.

2.2 Electric and magnetic fields (EMFs)

Since the mid-twentieth century, electricity has been an essential part of our lives. Electricity powers our appliances, office equipment, and countless other devices that we use to make life safer, easier, and more interesting. Use of electric power is something we take for granted. However, some have wondered whether the electric and magnetic fields (EMF) produced through the generation, transmission, and use of electric power [power-frequency EMF, 50 or 60 hertz (Hz)] might adversely affect to the working environment & our health.

2.2.1. Basics of EMF

A field describes the influence of an object on its surrounding space. within nature, a number of electric and magnetic fields occur. The earth is itself an immense natural magnet with magnetic poles near the north and south poles.

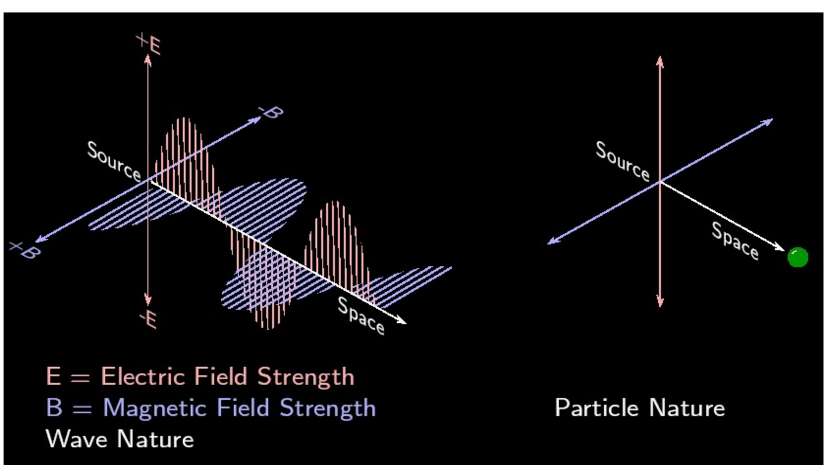


Fig. 2.7 – Electric and magnetic field

EMF refers to the two types of fields associated with any kind of electricity—electric fields and magnetic fields (Fig. 2.7). Electric and magnetic fields are produced by both natural and man-made sources that surround us in our daily lives.

An electric field is produced within the surrounding area when voltage is applied to a conductor (or wire). Just as the area around a hot water pipe is affected by the temperature of the pipe, the area surrounding an electrical conductor is influenced by the conductor voltage. The strength of an electric field at a given location depends on two factors — the level of voltage applied to the conductor and the distance from it. (Electric fields are related to voltage. Voltage is analogous to pressure in a water pipe. Higher voltages produce stronger electric fields.)

The piezo effect is related to electrical fields. Piezo actuators don't produce magnetic fields nor are they affected by magnetic fields. They are specially well suited for applications where magnetic fields cannot be tolerated.

Magnetic fields are produced where electric current is present. The strength of a magnetic field at a given location depends on the level of current flowing in the conductor or wire and the distance from it. (Magnetic fields are related to the amount of current that is flowing. Current is analogous to the rate of fluid flow in a water pipe. Higher currents produce stronger magnetic fields.) For example, the magnetic field generated by a hair dryer is higher when the dryer is operated on its "high" heat setting than on the "low" setting because the high setting draws more current. Electric and magnetic fields (EMFs) are invisible areas of energy, often referred to as "radiation".

2.2.2. Characteristics of EMF

- Wavelength
  (distance between a peak on the wave and the next peak of the same polarity)
- Frequency (Hz)
  [1 Hz = 1 cycle/second]
  (the number of cycles that occur in one second)
- amplitude (strength)

The direction of the field alternates from one polarity to the opposite and back to the first polarity in a period of time called one cycle.

- EMF in general sense - fields at extremely low frequencies such as those associated with the use of electric power.
- EMF in a much broader sense - fields with low or high frequencies (Fig. 2.8).

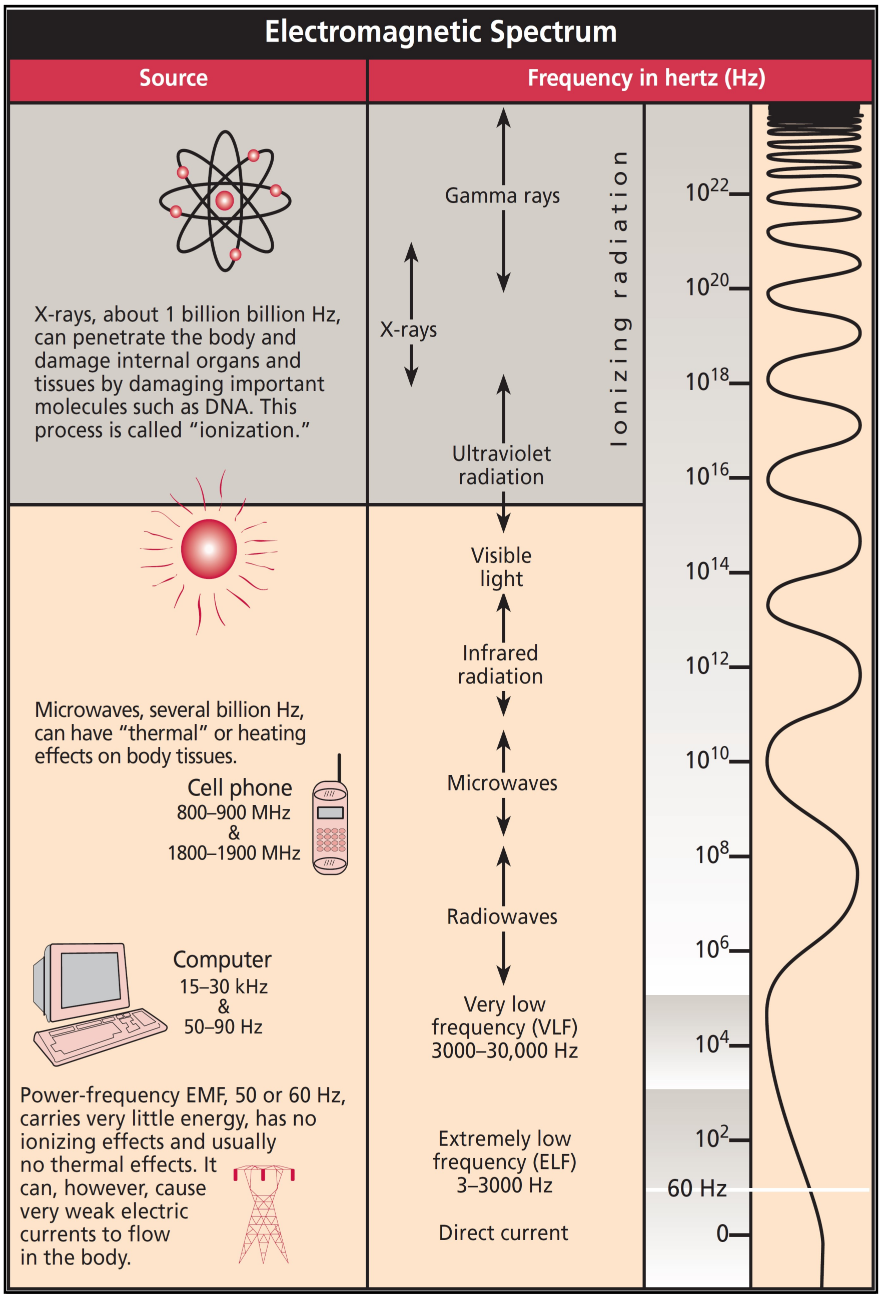


Fig. 2.8 – Electromagnetic spectrum

Two categories of radiations typically characterized by wavelength or frequency are (Fig. 2.9 & Fig. 2.10):

- Non-ionizing: which is generally perceived as harmless to humans (low-level radiation)
- Ionizing: which has the potential for cellular and DNA damage (high-level radiation)

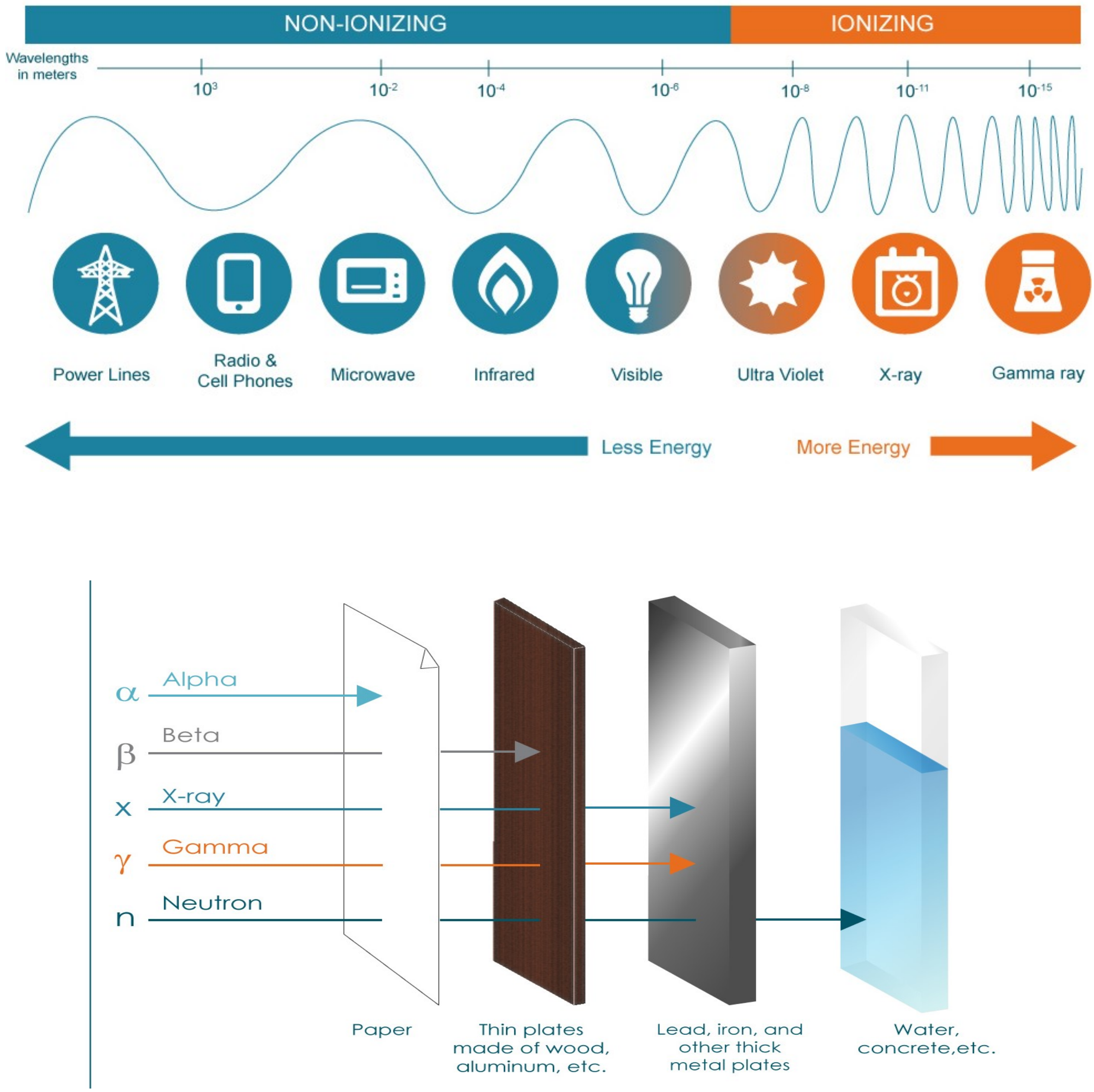


Fig. 2.9 – Non-ionizing and ionizing radiation & penetration

TECHNOLOGIES IN THE ELECTROMAGNETIC SPECTRUM

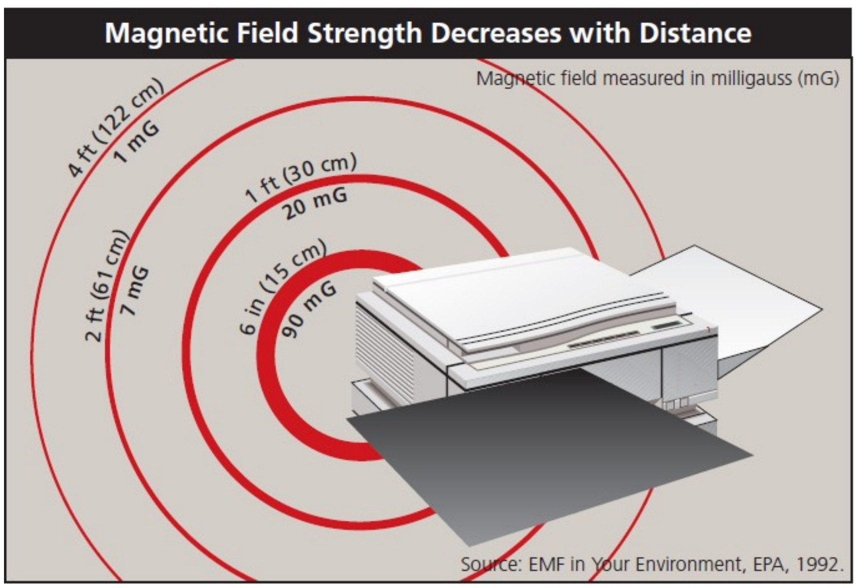
	NONIONIZING RADIATION RADIO FREQUENCIES AND MICROWAVES						IONIZING RADIATION X-RAYS AND GAMMA RAYS		
	Extremely Low Frequency	Very Low Frequency	Radio Frequencies	Microwaves	Infrared	Visible Light	Ultra-violet	Soft X-ray	Hard X-ray Gamma Rays
	Power lines Hydro lines Computer terminals Electric appliances Telephones Mobile phones Cell phones	Navigation Computer terminals Pagers Mobile phones Cell phones	Radio / CB Television Computer terminals Mobile phones Pagers Cell phones	Radar Computer terminals Microwave ovens Mobile phones(@2.5GHz) Cell phones	Sunlight Computer terminals		Sunlight Computer terminals	Medical X-rays Television Computer terminals	Nuclear fall out
Possible Health Effects Associated With Overexposure Based On Scientific Studies	Blood disorders Leukemia Cancer Cell growth Embryonic effect	CNS effects Central Nervous System Immune System Cell Membrane Effects	Cataracts Miscarriages Birth defects Blood disorders Embryonic effect CNS effects Central Nervous System	Cataracts Miscarriages Birth defects Genetic damage Birth deffects CNS effects Central Nervous System	Cataracts		Skin cancer Cataracts	Cancer Genetic damage Premature aging	

Fig. 2.10 – Technologies in the electromagnetic spectrum

2.2.3. Sources of EMF

As a result of all types of electrical equipment and building wiring as well as a result of nearby power lines, complex EMF exposures exist in the workplace.

EMF is found wherever electricity is generated, delivered or used. Power lines, wiring in homes, workplace equipment, computers, appliances and motors all produce EMF. Our exposure to EMF varies throughout the day depending on the sources of fields we encounter and how close we are to them (Fig. 2.11). The strength of the electric field depends on the voltage, while the strength of the magnetic field depends on the size of the current carried. The strengths of the fields reduce rapidly with distance from the sources.



You cannot see a magnetic field, but this illustration represents how the strength of the magnetic field can diminish just 1–2 feet (30–61 centimeters) from the source. This magnetic field is a 60-Hz power-frequency field.

Fig. 2.11 – Magnetic field strength & distance

The magnetic fields around the electrical source can effect sensitive equipment, especially those that use electron beams. Examples are electron microscopes and e beam lithography equipment. The electron beams are controlled and focused with magnets. Unwanted and uncontrolled magnetic fields in close proximity to the equipment results in reduced performance of the instrumentation.

Another important issue to be addressed by King R, Gandhi OP, Hocking B, et al. with EM (Electromagnetic) waves is their possible health effects on humans[51-53]. The World Health Organization (WHO) suggests that a wide range of environmental EM influences cause biological effects. There is also increasing concern that EMI adversely affects the operation of biological devices such as pacemakers[54].

Semiconductor Industries :

A wide variety of technologies are used in semiconductor manufacturing and testing. These technologies utilize a broad range of radiation sources. Common RF/Microwave radiation producing devices used by the semiconductor industry and RF/Microwave penetration in muscle, skin and other tissues are shown in Table 2.2 & Table 2.3[55].

Table 2.2 – RF wave producing devices & frequency range

Equipment	**Frequency (MHz)**
Plasma Etchers (some)	<0.5
Epitaxial Reactors	<0.5
Sputterers	13.56
Plasma Ashers	13.56 and 2450
Plasma Etchers (most)	13.56
X-ray Lithography Sources	50–55
Mold Preheaters	70–110
Handheld Radios*	460–470
Microwave Ovens	2450

Table 2.3 – RF wave depth of penetration in muscle, skin and other tissues

Frequency (MHz)	Depth of Penetration (cm)
1	91
27	14
40	11
433	3.6
915	3.0
2450	1.7
5800	0.72
10,000	0.34

2.2.4. EMF protection

Electromagnetic shielding is nothing but the protection against electromagnetic radiations/ waves (EMR) is also called as protection against EMI/RFI[56-59]. Perumalraj et al. have suggested that shielding effectiveness is a key parameter which often determines the scope for application of a given material[60]. Wu F, Xu Z, et al. have proposed electromagnetic shielding (Figure 2.12) used to prevent electromagnetic signals such as radio signals from leaving or entering a box or enclosure[61]. In the past, metals were the candidates for EMI shielding since they could reflect or conduct the free electrons[62].

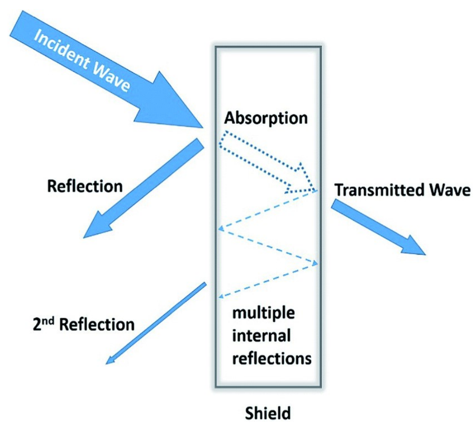


Fig. 2.12 – Transmission of electromagnetic waves

2.2.5. Field strength

The most accurate way to express WiFi field (signal) strength is with dBm, which stands for decibels relative to a milliwatt. Received signal strength indicator (RSSI) is a common measurement as well, but most WiFi adapters handle it differently, so it's common for applications to convert it to dBm. The important thing to understand about dBm is that we're working in negatives. -40 is a higher signal than -70, because -70 is a much lower number.

2.3 Cleanroom contamination

Cleanroom is a controlled workplace where different products are manufactured. It is closed work area in which concentration of airborne particles is controlled to specified limits. The basic purpose of a cleanroom is to protect the manufactured product from contamination. A cleanroom is designed in a contained space and controls strict atmospheric parameters such as humidity, pressure and temperature.

2.3.1. Basics of contamination

The contaminations are generated mostly by people, processes, facilities, and equipment. At the workplace, they must be continually removed from the air. The level of air cleanliness in the cleanroom must be regulated by standards. Kitain M. has stated that most frequently used standard is the ISO 14644[63].

A normal human hair is about 75-100 microns in diameter. A particle 200 times smaller (0.5 micron) than the normal human hair can cause major disaster in a cleanroom (Fig. 2.13-2.14)[64]. Undesired level of contamination can lead to expensive downtime and increased production costs. In fact, the billion dollar NASA Hubble space telescope was damaged and did not perform well because of a particle smaller than 0.5 microns. Two broad categories of surface contaminants are film type and particulates. These contaminants can produce a "killer defect" in a miniature circuit.

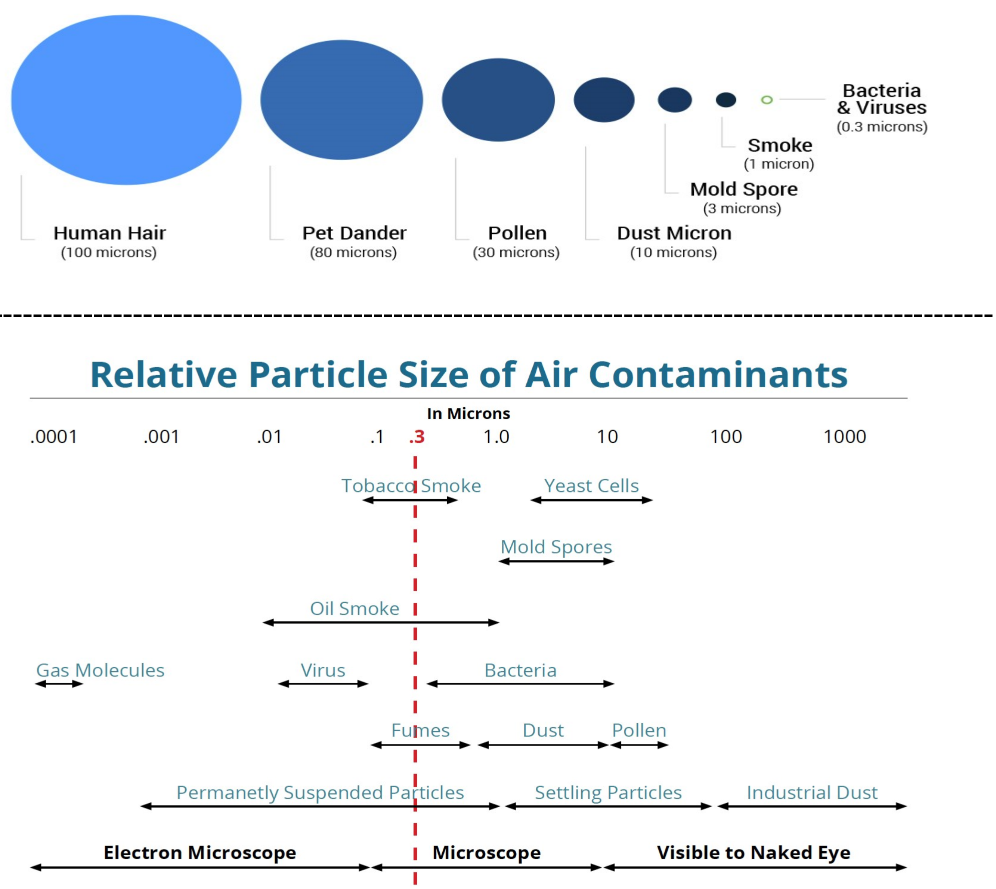


Fig. 2.13 – Different particle sizes in micron & relative particle size of air contaminants

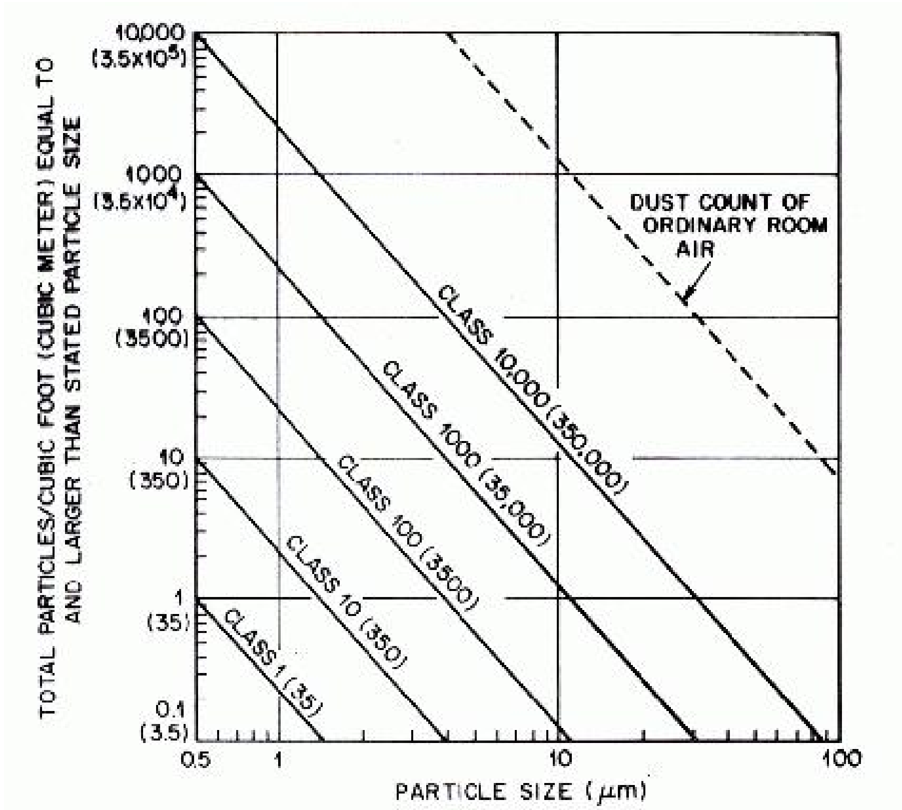


Fig. 2.14 – Particle size & total particles/cubit foot relationship

2.3.2. Nature of contamination

Contamination can be considered as anything which has an adverse effect on the quality or performance of something being created. It is a process or act that causes materials or surfaces to be soiled with contaminating substances.

Contaminates can take the form of particulate, chemical cross-contamination, bio-pollutants or electrical charges, which can have individually or collectively adverse effect on product or process performance. Here, airborne particles - skin, bacteria, fibres - pose the greatest challenge.

2.3.3. Different contaminants

❖ **Dust** – For cleanroom, this can be considered as skin shed by person or particulate matter brought into the working area from outside either by person or through poorly filtered purging air.

❖ **Chemicals** - Potential cross-contamination from production processes or from bodies, garments or equipment entering into the controlled environment.

❖ **Bacteria** - In the wider context, this embraces not only particulate and chemical pollutants likely to affect production quality but also the health of operators. Thus production plant chemicals and incoming air must be strictly controlled. This is mainly a problem associated with pharmaceutical and food processing industries.

❖ **Static charge** – static electricity is also a contaminant causing possible problems in all areas of cleanroom activity. Polyester or nylon cleanroom garments produce static electrical charge as fabric is in contact with fabric or with garments worn under the cleanoom garments. Static charges of many thousands of volts may be present on the garments during use.

2.3.4. The human component

In general, between 40 - 80 % of contamination can be traced to human operatives working into the cleanrooms (Fig. 2.15 & Table 2.4).

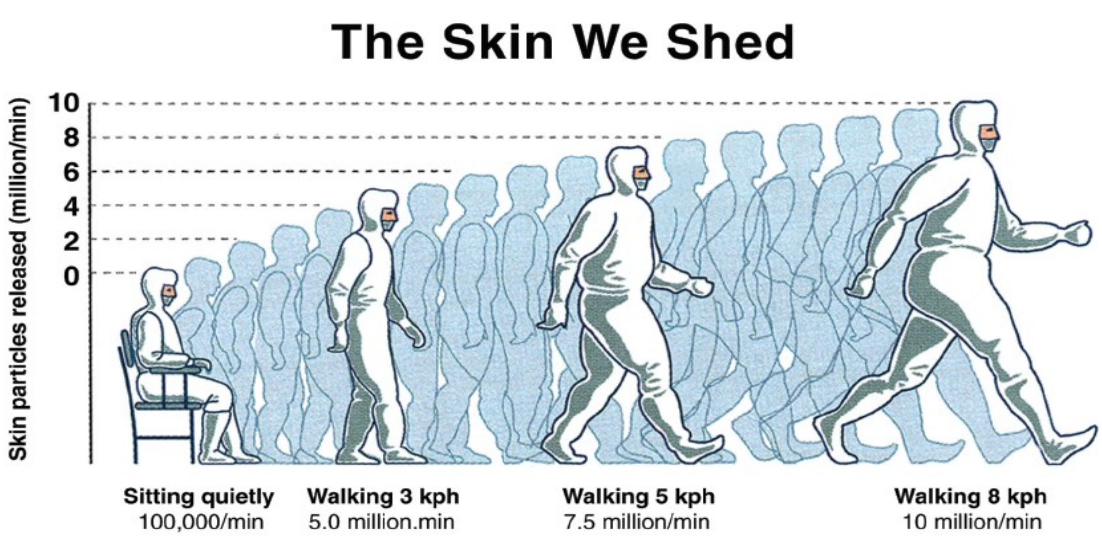


Fig. 2.15 – Human activity and particle generation

Table 2.4 – Particulate shed by humans during a range of activities

Action	Particles generated / minute (0.3 µm or larger)
Standing or sitting with no movement	100,000
Sitting or standing, light head, hand and forearm movements	500,000
Sitting or standing, average body or arm movement, toe tapping	1,000,000
Changing positions, sitting to standing	2,500,000
Slow walking (2 mph)	5,000,000
Average walking (3.5 mph)	7,500,000
Fast walking (5 mph)	10,000,000
Climbing stairs	10,000,000

2.3.5. Modern cleanroom concepts

Different modern cleanroom concepts are described in Table 2.5 and shown here in Fig. 2.16.

Table 2.5 – Types of cleanroom

Cleanroom type	Format	Characteristic
1. Unidirectional flow method	There are horizontal and vertical types	For high quality cleanrooms
2. Non-unidirectional flow method	There are turbulence and replacement/displacement types	For medium grade cleanrooms
3. Combined method	Combination of both.	Easy to obtain high "cost vs. Performance"

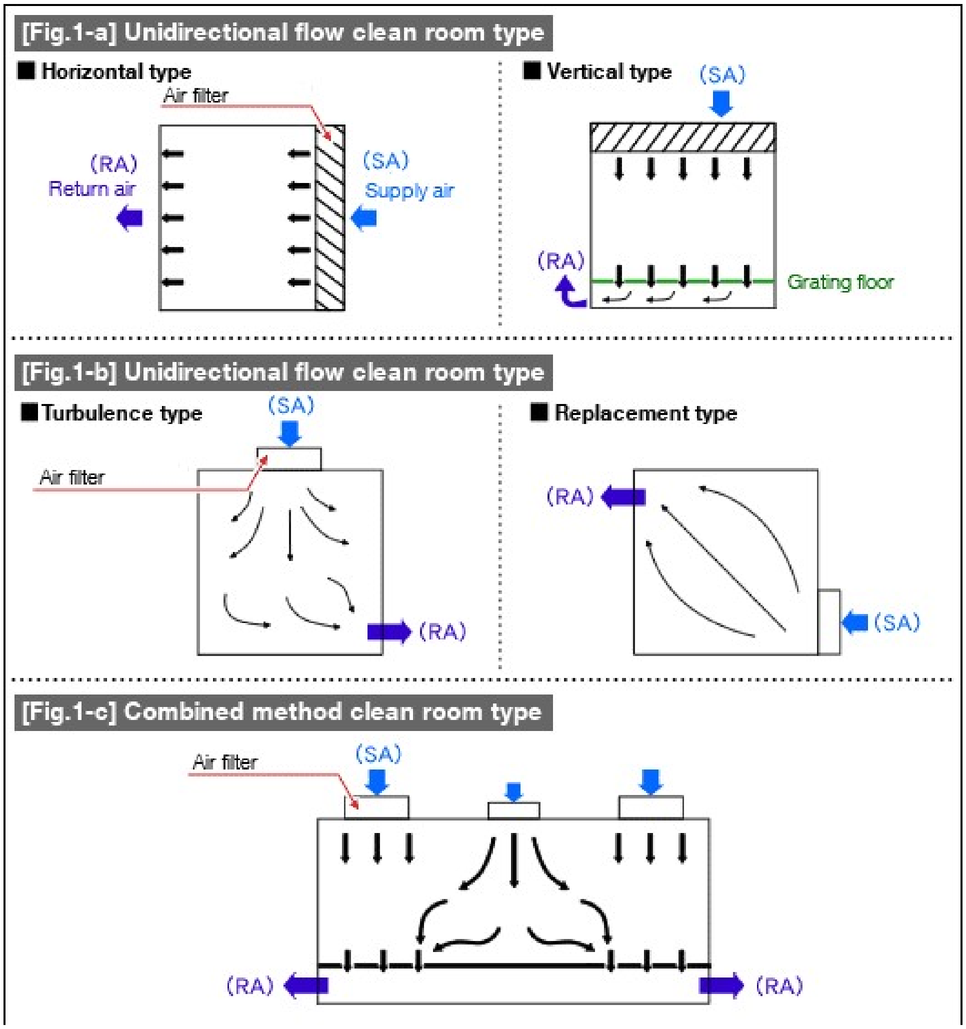


Fig. 2.16 – Various cleanroom designs

2.3.6. Cleanroom standards

In standard practice, cleanrooms are categories by how clean the air is (Table 2.6 to Table 2.9 & Fig. 2.17). As per Federal standard 209 (A to D) of the USA, the number of particles equal to and greater than 0.5mm is measured in one cubic foot of air, and this count is used to classify the cleanroom. This metric nomenclature is also accepted in the most recent 209E version of the standard. Federal standard 209E is used domestically.

The cleanroom classification standards FS 209E and ISO 14644-1 require specific particle count measurements and calculations to classify the cleanliness level of a cleanroom or clean area.

Table 2.6 – ISO 14644-1 Cleanroom standards

Class	maximum particles/m³						FED STD 209E equivalent
	>=0.1 µm	>=0.2 µm	>=0.3 µm	>=0.5 µm	>=1 µm	>=5 µm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room Air

Table 2.7 – Possible cleanroom requirements for various tasks

ISO Class (FS 209E)	Tasks
ISO Class 3 (Class 1)	Integrated circuit manufacturers manufacturing sub-micron geometries only use these rooms.
ISO Class 4 (Class 10)	Semiconductor manufacturers producing integrated circuits with line widths below 2 µm use these rooms.
ISO Class 5 (Class 100)	Used with a bacteria-free or particulate-free environment is required in the manufacture of aseptically produced injectable medicines. Required for implant or transplant surgical operations.
ISO Class 6 (Class 1000)	Manufacture of high quality optical equipment. Assembly and testing of precision gyroscopes. Assembly and testing of precision gyroscopes. Assembly of miniaturised bearings.
ISO Class 7 (Class 10000)	Assembly of precision of hydraulic or pneumatic equipment, servo-control valves, precision timing devices, high grade gearing.
ISO Class 8 Class 100000)	General optical work, assembly of electronic components, hydraulic and pneumatic assembly.

Table 2.8 – BS 5295 Cleanroom standards

	maximum particles/m³				
Class	>=0.5 µm	>=1 µm	>=5 µm	>=10 µm	>=25 µm
Class 1	3,000		0	0	0
Class 2	300,000		2,000	30	
Class 3		1,000,000	20,000	4,000	300
Class 4			20,000	40,000	4,000

Table 2.9 – The Federal standard FS 209D

Class	Measured Particle Size [µm]				
	0.1	0.2	0.3	0.5	5.0
1	35	7.5	3	1	NA
10	350	75	30	10	NA
100	NA	750	300	100	NA
1000	NA	NA	NA	1000	7
10000	NA	NA	NA	10000	70
100000	NA	NA	NA	100000	7000

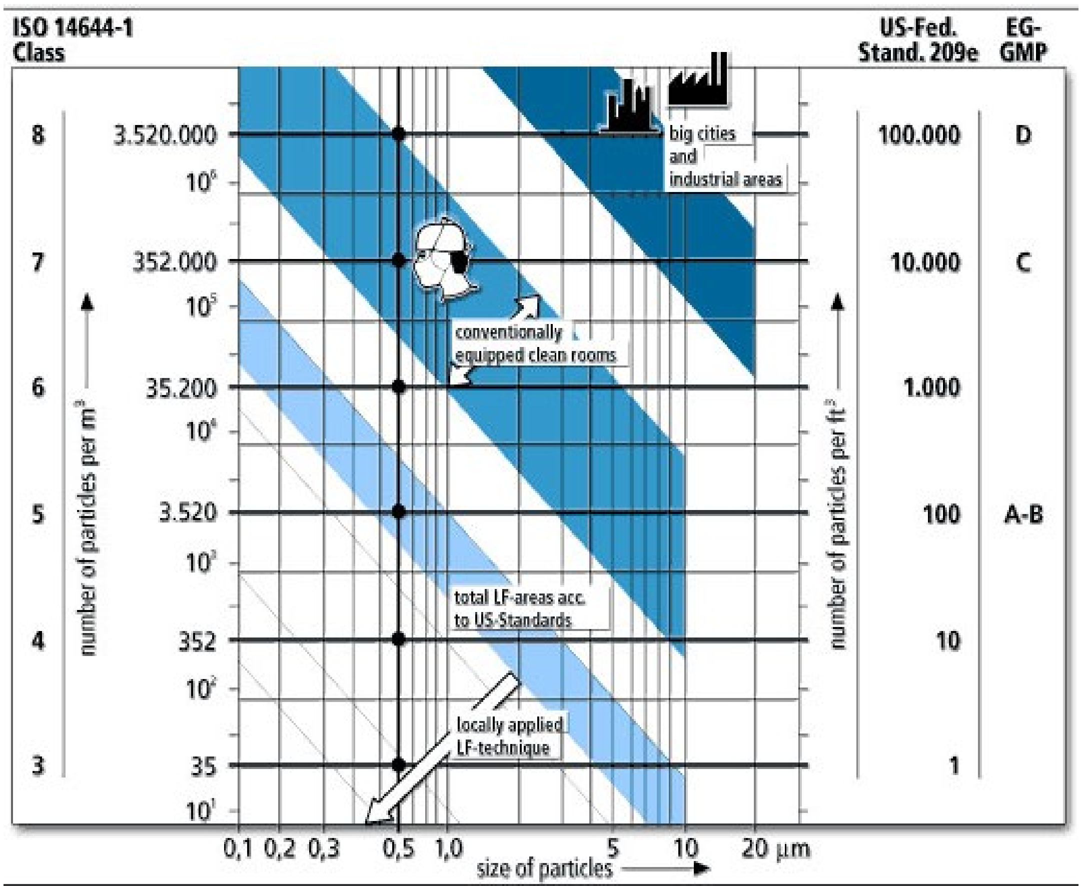


Fig. 2.17 – Comparison of standards

2.3.7. Contamination control (C^2)

Contamination control, or C^2 for short, covers all the different elements that are used to protect products, process equipment and personnel from being negatively affected by contaminants. The use of cleanrooms is today incorporated as a modern part of contamination control (Fig. 2.18)[65].

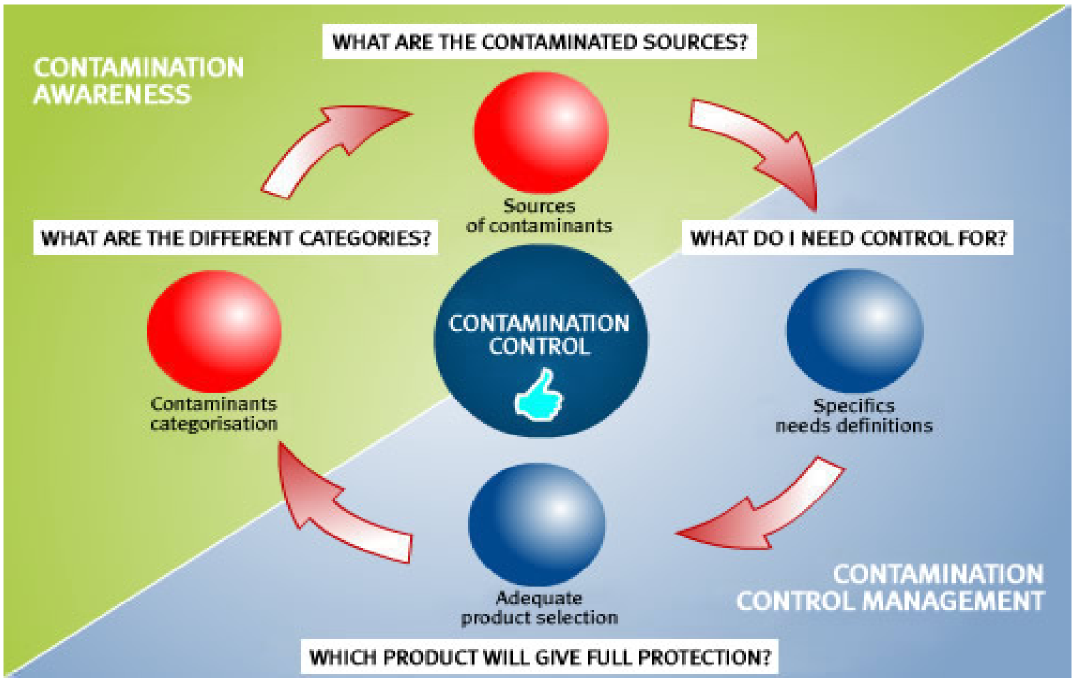


Fig. 2.18 – Contamination control

Cleanroom operators generate millions of particles throughout the day. Even more, it is matter of the operators' behaviour as well as the garment that have great influence on contamination.

Woven or re-usable fabrics are the most commonly preferred fabrics in cleanroom garments.. As the name implies, they are woven on sophisticated looms from yarns of continuous filaments of polyester/nylon. The thickness of the yarns and filaments is important (the finer the yarn the tighter the weave can be made and the better the filtration), but also pattern and tightness of the weave is important to reduce the pore size to a minimum. The use of continuous filament polyester/nylon means that there are few loose ends from which particles may be shed.

Plain weave generate a tighter fabric and good results under test but tight bending of the yarns can lead eventually to damage and particulate flaking[66]. Twill weaves are featured by a strong diagonal pattern[67]. Twill does not retain particles as well as the plain weave, but does not tend to blind as fast. Compare to plain weave with the same yarns, twill weave fabrics are more flexible, and therefore easier to fit into the filter[68].

The garments used in cleanrooms are shoe covers, cap, hood, face mask, coveralls, boots, safety glasses, gloves etc. (Fig. 2.19).

George et al. (1990) have studied particle release from fabrics during the process[69]. They compared particle release from fabrics likely to be worn under cleanroom coveralls. Measurements made near the openings in a cleanroom garment worn over cotton clothing showed that some leakage of particles occurred at the neck. Some parts of the cleanroom garments are prone to a high level of contamination (Fig. 2.20).

Fig. 2.19 – Different cleanroom garments

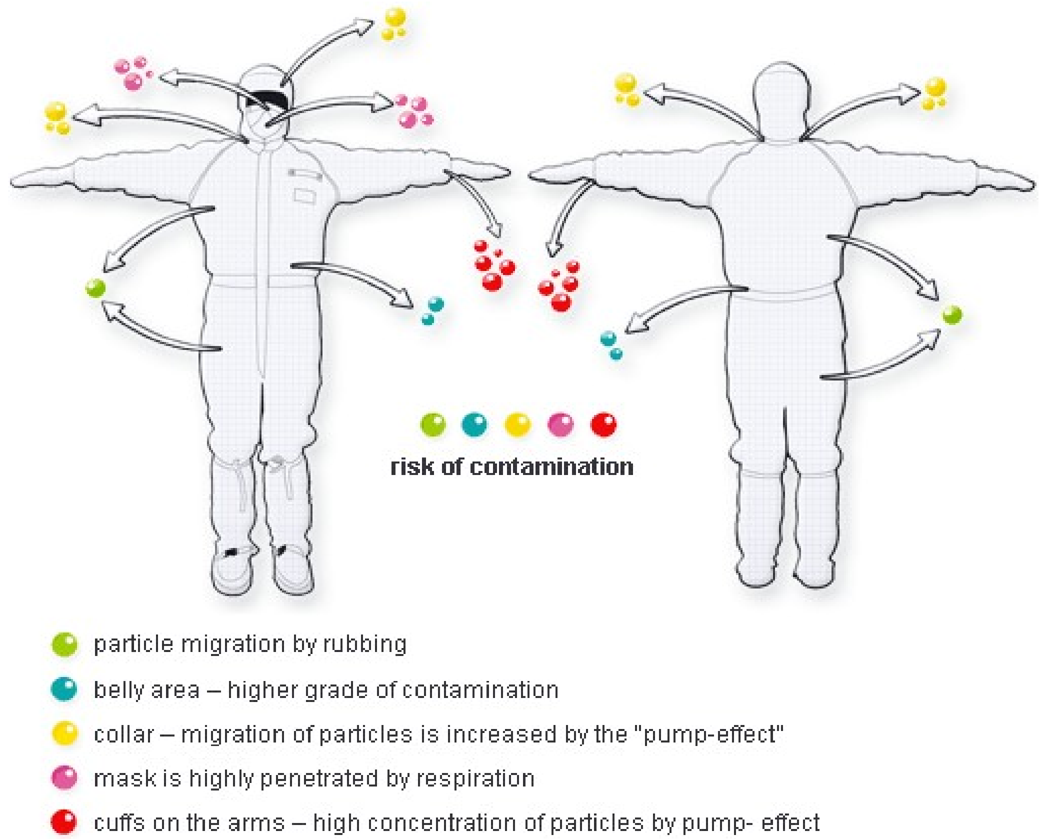


Fig. 2.20 – Garments & contamination

The design of the cleanroom and the activities performed there will greatly influence the requirements of the cleanroom garment needed for a specific application. Due to these demands, characteristics such as a modern design, color and comfort should not be the main focus while setting up the garments. Criteria should rather be filtration efficiency, ESD-properties and the so called 'pump-effect'.

2.3.8. Cleanroom test parameters

2.3.8.1. Air permeability

The Air permeability of a fabric is expressed as the amount of air passed over a surface under a certain pressure difference in a unit time. It is the rate of airflow through a fabric under differential pressure between the front and back surface. It has significance with respect to the usage area[70-71].

It is an important factor of a fabric as it plays a role in transporting moisture vapour from the skin to the outside atmosphere. The logic is that vapour travels mainly through fabric spaces by diffusion in air from one side of the fabric to the other[72]. These measurements have a direct correlation to the conductive fabric's breathability. High values of air permeability may indicate poor resistance to particle filtration.

2.3.8.2. Fabric particle density transfer rate (F-PDTR)

Cleanroom fabric particle density transfer rate (F-PDTR) is a very important parameter for cleanroom environment to measure particle density transfer rate from fabrics at fixed and variable flow from lower to higher speed range.

In this test, as per the capacity of instrument, air borne particles can be detected and flow rate in density and voltage can be displayed for the fabric sample varieties. This parameter is useful to measure micro particle density transfer rate from fabrics. It is also important for filter fabric test.

2.4. High functional conductive textiles

2.4.1. Introduction

Whether we call it "soft tech" or "wearables," we can all agree that there has been great advancements in recent years with merging of textiles and electronics. The interest in conductive textiles was renewed when the concept smart textiles emerged some fifteen years ago[73].

In the electronic industry, today electrostatic discharge control/protective products need to meet various requirements[74]. Electronic equipmentss that are electrostatic discharge sensitive (ESDS) must be protected throughout the entire manufacturing process cycle[75-77]. Development of products through woven or knitted process for electrostatic discharge control is greatest need of present market to avoid hazardous malfunctions in working area.

(Conductive and static dissipative terms typically related to resistance or resistivity ranges used in the evaluation of electrostatic discharge control materials & products.)

Category of conductive textiles[78]

- High performance
    - Made with improved performance i.e. properties etc.
- High tech
    - Made by superior method
    - Made by different method than ordinary method
- High functional
    - Developed according to needs
        - Health/protection
            - electrostatic discharge control
            - electromagnetic field control
            - contamination control etc.
        - Comfort etc.

The area of high functional conductive textiles can be viewed as an smart integration of electronics and textiles in order to create a new generation of flexible, comfortable, multifunctional textile structures with conductive capabilities[79]. These structures can be developed from new type of yarns (or hybrid yarns) and fabrics with conductive characteristics, which can be produced using existing machine set up or with adoption of new technologies.

High functional conductive textiles cater various needs in form of fabrics, laminates or composites which include applications for electrostatic discharge control, electromagnetic field control, contamination control etc. High functional conductive textiles also have their applications in –

- Electronic monitors,
- Telephone components,
- Computer and other modem enclosures,
- Medical devices,
- Navigation equipment,
- Laser calibration or testing equipments,
- Oscilloscope housings,

- ❖ Packaging,
- ❖ Grounding,
- ❖ Conductive gaskets,
- ❖ Bonding straps,
- ❖ Cables & connectors,
- ❖ Screens etc.

2.4.2. Conductive materials[80-83]

2.4.2.1. The 20th century guard

Traditionally, the materials used for ESD applications have been metals—a metallic strip or wire included within a non-conductive bulk material, forming a network—or carbon-filled materials such as plastics containing carbon black or carbon fibers[84] (Fig. 2.21). There have also been metal oxides—ITO and other tin oxides, mostly—used where transparency is important.

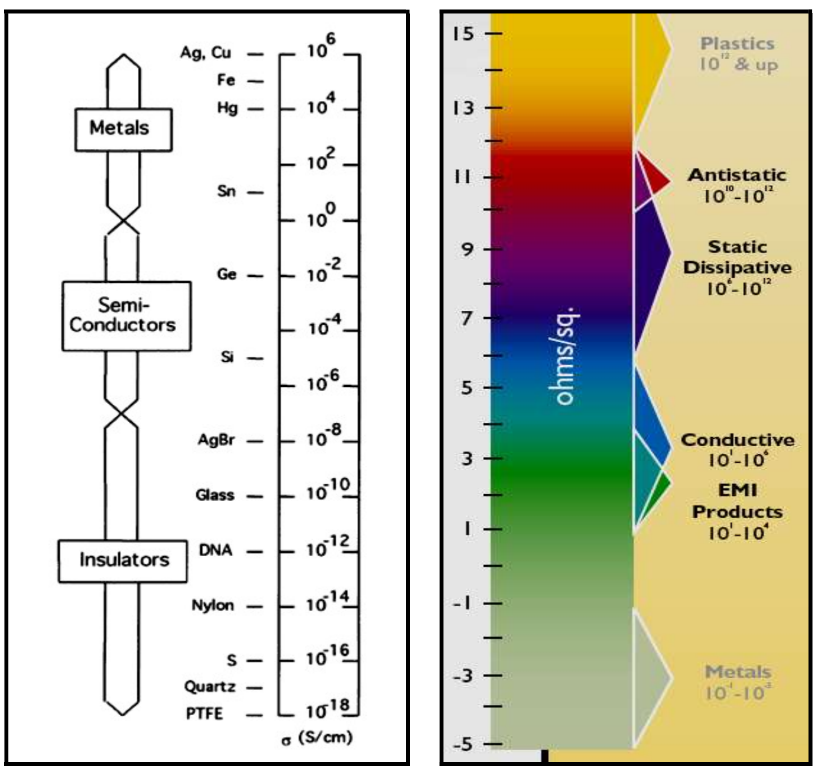


Fig. 2.21 – Classification of common materials based on volume conductivity (S/cm) & spectrum of solution (antistatic, static dissipative, conductive & EMI products)

2.4.2.2. Conductive/metal threads & inks

Metal threads are made up of metal fibres which are very thin metal filaments (diameters ranging from 1 to 80 micron).

Conductive inks - A layout can be screen-printed using conductive inks to add conductivity to specific areas of a garment. Carbon, copper, silver, nickel and gold may be added to conventional printing inks to make them conductive.

2.4.2.3. Nanometals

Metal nanoparticles can be applied as the main ingredient in a coating or as a conductive filler in a bulk material like a plastic that is otherwise insulating. The small size of nanoparticles combined with the low conductivity requirements of ESD materials offers the potential to use such small amounts of metals that even an expensive metal like silver is not cost prohibitive.

2.4.2.4. Carbon nanomaterials

Also promising is carbon in the form of carbon nanotubes (CNTs) or other carbon nanostructures, which can be used in even smaller quantities and which are not inherently expensive. CNTs are also very compatible with the fabrication of diffuse conductive networks. And graphene, as it becomes easier to produce, will also find its way into applications that take advantage of its electrical conductivity.

2.4.2.5. Inherently conductive polymers (ICPs)

ICP’s were discovered about thirty years ago, but it is only in the past decade that they have found widespread use in a variety of applications. The "old guard" materials is now supplemented with more advanced materials like inherently conductive polymers.

The use of inherently antistatic materials—metals, certain polymers, etc.—designed to be less prone to triboelectric charge buildup is one way around the problem. ICP’s are generally synthesized either chemically or electrochemically, each having its own advantages and disadvantes[85]. Kang YS, Lee HJ, Namgoong J, et al. have suggested recently discovered air-stable conducting polymers. These include doped polypyrrole, and polyaniline[86].

Some commonly known ICPs include polyacetylene, polypyrrole (PPY), polyaniline (PANI), and polythiophene (PTh) (Fig. 2.22)[87-89]. Intrinsically conductive polymer composites (ICPs) have been replacing metals sheets for various shielding applications in the electrical and electronic industries, especially for the electronic housing materials[90]. However, ICPs, mostly polyaniline (PANI) and polypyrrole (PPY), have rigid characteristics owing to their chemical conformation of benzene rings[91].

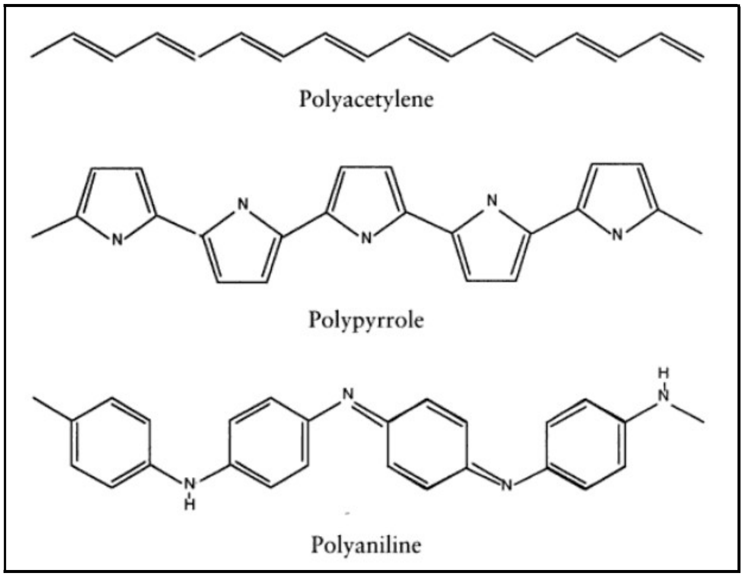


Fig. 2.22 – Conjugation paths of some inherently (or intrinsically), electrically conductive polymers (ICP's)

2.4.3. Methods to introduce conductive nature in textiles

Various methods-processes to introduce conductive nature in textile materials at fibre, yarn or fabric stages suggested by Gong RH, Lin JH, Chen HC, Cheng K, et al. are discussed below[92-100]:

2.4.3.1. Fibre stage

- ❖ Blending of metal and textile slivers
- ❖ Metallic salt
- ❖ Galvanic coating
- ❖ Fiber coating with conductive particles suspended in a resin
- ❖ Vacuum spraying process etc.

2.4.3.2. Yarn stage

- Yarn made with core spun process
    - *Ring spun yarn*
    - *Rotor spun yarn*
    - *Friction (DREF) spun yarn etc.*
- Yarn made with wrap spinning
- Yarn made from bicomponent fibers
    - *Concentric sheath/core*
    - *Eccentric sheath/core*
    - *Side-by-side*
    - *Pie wedge and*
    - *Islands/sea types of bicomponent fibers etc.*
- Cord yarns made with braiding
- Plied or cabled or composite yarns
- Fancy-novelty yarns etc.

2.4.3.3. Fabric stage

- Lamination
- Addition of conductive fillers
- Incorporating conductive fibres or yarns into the fabric
- Coating etc.

Conductive woven fabrics because of their structural order and ability to flex and conform to most desired shapes offer a great opportunity to develop a new generation of multifunctional and interactive textiles. Conductive fabrics have been considered for EM shielding and electrostatic dissipation (ESD) applications in the defense, electrical, and electronics industries[101-102].

Passi J, Goletti G, Fast L, et al. have stated that there several variations in both fabric and yarn structures, using wholly conductive fiber, surface conductive fiber, core conductive fiber and hybrid conductive fiber[103].

Hebeish et al. studied major factors affecting the performance of ESD-protective fabrics[31]. The raw materials used were synthetic fibers or mixed fibers (98% polyester fibers and 2% conductive fibers) which were taken to reduce or eliminate the build up of electrical charges.

Lin JH and Lou CW worked on electrical properties of laminates made from a new fabric with PP/Stainless steel comingled yarn[97]. In this work, they have added stainless steel filaments to commingled yarns.

Perumalraj R & Dasaradan BS studied electromagnetic shielding effectiveness of doubled copper cotton yarn woven materials[60]. The 30 tex cotton yarn and copper filament (of 0.1 mm, 0.11 mm, and 0.12 mm wire diameter) were used to produce 2 and 3 ply of cotton copper yarn on the ring doubling machine.

Cheng KB et al. worked on electrostatic discharge properties of stainless steel/polyester woven fabrics[59]. In this work, stainless steel staple fibers are incorporated into fabrics as conductive fillers to promote the electrostatic discharge properties of the woven fabric.

Saini P and Choudhary V studied electrostatic charge dissipation and electromagnetic interference shielding response of polyaniline based conducting fabrics[12]. Here, dispersions were coated over cotton fabrics by dip coating technique so as to impart electrical conductivity making them useful for antistatic and electromagnetic interference (EMI) shielding applications.

Xuf P, Tao XM, et al. worked on electromechanical behaviour of fibers coated with an electrically conductive polymer (Polymer fibers are coated with an intrinsically conductive polymer i.e. polypyrrole (PPy). PPy-coated PA6 fibers and PPy-coated lycra fibers are prepared by chemical vapour deposition using pyrrole)[104].

Maclaga B, Fisher WK studied static dissipation mechanism in carpets containing electrically conductive fibers (made from nylon conductive yarn) as isolated conductors[105].

Bhat NV, Seshadri DT and Radhakishnan S worked on preparation, characterisation and performance of conductive cotton+PANi fabrics (Washed and dried cotton fabric samples were allowed to soak in an aniline solution. Later on after cooling, a precooled solution of ammonium persulphate was added gradually to polymerize the aniline)[106]. Muthukumar N. and Thilagavathi G also worked on development and characterisation of electrically conductive polyaniline coated fabrics (cotton, polyester and nylon fabrics have been prepared from conductive polyaniline (PANI) polymer by in situ chemical oxidative polymerization of aniline)[89].

The literature survey carried out for research indicates following limitations of previous work:

- Specific to any one or two problems (electrostatic discharge, radiation or contamination)
- Use of limited variety of conductive materials
- Not fit to cleanroom requirements

Hence, significant efforts are desirable for cleanroom to develop high functional textile fabrics that can provide effective solution for electrostatic discharge, electromagnetic field and contamination control. Producing these types of functional conductive fabrics for cleanroom is one major aspect for researchers and manufacturers.

In this work, research is carried out to develop heterogeneous high functional textile fabrics with primary aim of electrostatic discharge control and secondary aim of electromagnetic field & contamination control for cleanroom environment.