



الجمهورية الجزائرية الديمقراطية الشعبية

People's Democratic Republic of Algeria



وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Scientific Research

جامعة محمد الصديق بن يحيى - جيجل

Mohammed Seddik Benyahia University of Jijel

Faculty of Natural and Life Sciences

Department of Molecular and Cellular Biology

كلية علوم الطبيعة والحياة

قسم البيولوجيا الجزيئية و الخلوية

Organization, Risks, and Safety in Biology Laboratories (ORSL)

Course polycop

Intended for 2nd year Master student of Molecular and
Cellular Biology

Presented by Dr Arbia ABBES

MCA



Table content

List of figures.....	IV
List of table.....	V
Learning Objectives	01
Content of the material.....	01
Chapter I: Safety and hygiene standards.....	03
I.1. Introduction.....	03
I.2. Safety and hygiene standards in the molecular and cellular biology laboratory.....	06
I.2. 1. Recommended Strategies and Actions for Different Roles.....	06
I.2.2. Fitness for laboratory work.....	07
I.2.3. Accident prevention.....	08
I.2.4. Types of risks... What can we expect?.....	09
I.3. Classification of biology laboratories.....	10
I.4. Fire hazard.....	12
I.5. Floods in biology laboratories	12
Chapter II: Best laboratory practices and signaling.....	14
II. Best laboratory practices and signaling.....	14
II.1. Laboratory Safety.....	14
II.1.1. Personal Protective Equipment (PPE).....	14
II.2. Operational Practices.....	15
II.2.1. Basic Practices.....	15
II.3. Signage.....	17
II.4. Preparing for Laboratory Work	17
II.4.1. What Should I Know?.....	17
II.4.2. Before Leaving the Laboratory What Should I Remember?.....	18
II.5. Hygiene Rules.....	19
II.6. Work with Laboratory Animals.....	19
II.6.1. Healthy Animals.....	20
II.6.2. Infected Animals.....	20
II.7. Work with Human Pathogens.....	20
II.8. Decontamination.....	21
II.8.1. Chemical Decontamination for Surfaces and Devices.....	21
II.8.2. Steam Sterilization (autoclave).....	22
II.8.3. Ultraviolet Light.....	22
II.9. Basic Safety Rules in a Molecular Biology Laboratory.....	23
Chapter III Radioactivity.....	25
III.7. Radioactivity.....	25
III.7.1. What is a Radioisotope?.....	25
III.7.2. The Atom: The Foundation of Matter.....	27

III.7.3. Understanding Isotopes.....	28
III.7.4. The Stable Isotope.....	28
III.7.5. The Unstable Isotope.....	30
III.8. Selection of Radioisotopes.....	31
III.9. Production of Radioisotopes.....	32
III.10. Labelling techniques of biomolecules for radiotherapy.....	33
Chapter IV:Physical Risk Assessment.....	34
IV. Physical Risk Assessment.....	34
IV.1. Physical Risk Prevention.....	36
IV.1.1. Electrical Risks.....	37
IV.1.2.Noise	37
IV.1.3. Cryogenics — Liquid Nitrogen.....	37
IV.1.4. Risk of Cold Burns.....	38
IV.1.5. Risk of asphyxiation.....	39
IV.1.6. Risk of Explosion Due to Overpressure.....	39
IV.1.7. Risk of Explosion Due to Oxygen Condensation.....	40
IV.1.8. Extreme Temperatures.....	42
IV.2. Preventive Measures.....	42
IV.3. Radioactivity and Half-Life of a Radioactive Atom.....	43
IV.3.1. Ionizing Radiation.....	44
IV.3.2. Principles of Radiation Protection Against Ionizing Radiation.....	45
IV.4. Protective Measures.....	46
IV.4.1. Duration of exposure.....	46
IV.4.2. Distance from the Source.....	46
IV.4.3. Shielding.....	46
IV.4.4. Substitution.....	48
IV.5. Rules to Follow.....	48
IV.5.1. Radiation Area.....	49
IV.5.2. Lab Bench.....	49
IV.6. Radioactive Waste.....	49
IV.6.1. Emergency Procedures.....	49
Chapter V ; Chemical Risk.....	50
V.Chemical Risk.....	50
V.1. Major Components of Chemical Risk.....	50
V.1.1. Hazard	50
V.1.2. Exposure	51
V.2. Laboratory Work and Chronic Health Effects.....	52
V.3. Laboratory Work and Cancer Risk.....	52
V.3.1. Carcinogenic Substance.....	53
V.4. Chemical mutagens.....	54
V.4.1. Chemical mutagens, genotoxic substances and carcinogens.....	

V.5. Risk or danger? Strategies for managing flammable products.....	54
V.6. Corrosive Chemicals.....	54
Chapter VI. Biological Risks.....	55
VI. Biological Risks.....	55
VI.1. Biological Risk Assessment.....	55
VI.1.1. Prevention of Biological Risk.....	55
VI.1.2. Biosafety.....	55
VI.1.3. Infectious Substances.....	56
VI.2. Safe Laboratory Practices.....	56
VI.2.1. Decontamination.....	56
VI.2.2. Management of Biological, Cytotoxic, and Pharmaceutical Waste.....	57
VI.3. Biological Agents and Risks.....	57
VI.3.1. Classification of Biological Agents (Natural Microorganisms).....	58
VI.3.2. Biological risks (pathogenic bacteria and viruses)	58
VI.3.2.1.Pathogenic bacteria	58
VI.3.2.2.Virus	60
VI.3.3. Cell Cultures.....	60
VI.3.4. Genetically Modified Organisms (GMOs).....	61
References	

List of figures

Fig. 01. The central dogma of molecular biology.....	05
Fig. 02. DNA sequencing.....	06
Fig. 03. The three roles and their associated tasks in chemical laboratory safety.....	07
Fig. 04. Hydrogen isotopes	25
Fig. 05. Carbon isotopes.....	26
Fig. 06. Types of radioactive decay.....	27
Fig. 07. Different warning pictograms for identifying potential causes of physical risks.....	30
Fig. 08. Types of radiation used in various applications.....	35
Fig. 09. Hazard pictograms.....	41
Fig. 10. Schematic representation of the concepts of substance fate and exposure to an organism in the environment.....	43
Fig. 11. The risk assessment framework.....	52
Fig. 12. A schematic representation of a biosafety concept and four biosafety levels (BSLs) with their risk intensity.....	53
Fig.13. Sources of laboratory-acquired infections : the outer circle shows a possible chain of infection transmission.....	54
Fig. 14. Lab safety protocols	55

List of tables

Table 01. The different types of hazards and corresponding risks.....	09
Table 02. Classification of laboratories.....	11
Table 03. Main radioisotopes.....	28
Table. 04. Different hazard classes.....	39
Table 05. Mode of contamination of chemical products and prevention.....	40
Table 06. The different types of hazards and corresponding risks.....	42
Table 07. Types of Risk Related to Biological Agents.....	58



Organization, Risks, and Safety in Biology Laboratories (ORSL)

Learning Objectives:

Molecular Biology, like any new discipline, generates new risks. This course aims to review current knowledge regarding risks and safety standards in order to enable students to strictly apply best practices when working in Molecular Biology laboratories. Biology laboratories, particularly those involved in molecular biology research, present significant risks to laboratory personnel, the environment, and public health if not properly managed. This manuscript addresses the fundamental concepts of risk assessment, prevention, biosafety, and biosecurity within laboratory settings. The manuscript also discusses preventive strategies, including laboratory design, staff training, personal protective equipment, vaccination, and medical surveillance, as well as the safe handling of infectious materials. By integrating risk assessment principles with biosafety and biosecurity measures, this work highlights the necessity of a comprehensive and systematic approach to minimizing laboratory-acquired infections and ensuring safe working conditions in biological laboratories.

Recommended prior knowledge:

Students should have the required knowledge in Biology, General Toxicology, Physical Chemistry.

Content of the material:

Radioactivity (principles, methods and units of measurement) and radioisotopes used in biology (^{32}P , ^{33}P , ^{35}S , ^3H , ^{125}I , ^{12}C) and techniques for labeling macromolecules. Different types of risks: chemical risks (mutagenic, carcinogenic, corrosive and flammable substances), physical risks (ionizing radiation, radioactivity, UV, etc.), fire, flooding, biological risks (pathogenic bacteria and viruses). Organization and classification of biology laboratories Safety and hygiene standards, best practices and signage in the laboratory

Practical Work Programme

- Tour and observation of the various components involved in running a molecular biology laboratory.
- Practical exercises in good laboratory practice to prevent or minimize various risks in the laboratory.
- Taking blood smears

Assessment method: Individual work, EMD

This course material sets out the rules that biology laboratories must follow to ensure the reliability of results, whilst safeguarding staff safety and protecting the environment.

Chapter I will cover general aspects of laboratory organization and management, molecular biology tools, and general health and safety guidelines.

Chapter II will describe best laboratory practices and safety, personal protective equipment, basic practices, hygiene and some basic rules.

Chapter III will describe radioactivity

Chapter IV will describe the assessment of physical risk, preventive measures, non-ionizing and ionizing radiation, and radioactive activity.

Chapter V will focus on the major components of chemical risk, the management of chemical agents, and measures to manage their effects on humans and the environment, highlighting the carcinogenic risk of certain chemicals.

Chapter VI will focus on biological risk assessment, prevention, biosafety, and finally a description of safety practices within the laboratory.

Presentation – Master II BMC

PCR amplification, Sequencing , Cloning, DNA extraction, RNA extraction, Northern Blot, Southern Blot, Radiation risk, Biological risk (pathogenic viruses), Risk from mutagenic substances, Risk from carcinogenic substances

Assessment: Individual work, EMD



Molecular and Cellular Biology Laboratory Organization and Management



I.1. Introduction

Biological processes have been used by humans since prehistoric times; in medicine, biological techniques were employed long before the underlying mechanisms were understood (for example, the Chinese used antibiotics extracted from fungi). The history of molecular biology really began in the mid-19th century, with the systematisation of this knowledge and these observations. This period was marked by the abandonment of vitalism and the principle of spontaneous generation. The former sought to distinguish living beings from the rest of inert matter by attributing to them a ‘vital force’, which would explain their physical (movement) and chemical (fermentation by microorganisms) properties. Spontaneous generation, for its part, posits the spontaneous emergence of life, for example the spontaneous appearance of microorganisms on a fermentable medium.

According to Michel Morange, molecular biology is “the body of techniques and discoveries that have enabled the molecular analysis of the most fundamental processes of life, those that ensure its survival and reproduction”. This introduction provides a historical overview of the events that contributed to its emergence and development. Molecular biology remained for a long time the preserve of highly specialised institutions due to the complexity of its implementation. Indeed, the techniques available were delicate, could not be automated and required extremely restrictive spatial arrangements.

A laboratory is a facility equipped with the installations and apparatus necessary for procedures and experiments carried out in the context of scientific research, medical or materials analysis, technical testing, or scientific and technical education. The term “laboratories” is the generic term used for analytical laboratories, diagnostic laboratories, medical laboratories, public health laboratories or any other type of laboratory, including

those that carry out analyses on animals or environmental analyses for the purposes of diagnosis, screening or prevention, to aid decision-making regarding medical treatments, or for monitoring or public health.

Biology laboratories are primarily focused on handling biological agents, whether pathogenic or not. Work involving pathogenic substances is carried out in so-called containment laboratories. The quantities handled are small (in the order of a few millilitres). Within these laboratories, there is a risk of fire due to the handling of alcohol, the use of open flames and laboratory equipment. The coexistence of these products and materials can be dangerous. Researchers most often handle relatively small quantities of liquid, solid or gaseous products (ranging from a few milligrams to a few hundred grams...). However, the large number of procedures carried out simultaneously can result in a relatively large quantity of products on the premises (up to 100 kg).

It is not uncommon to find more than a thousand different products in a single laboratory, each with very different physical, chemical and toxic properties, some of which may be incompatible and lead to reactions that can be violent. It is evident that all types of hazardous products are present in these laboratories.

The fire safety risk stems mainly from products used as solvents, the majority of which have significant flammable properties (particularly oxygenated solvents, such as ethers, ketones, aldehydes, alcohols, etc.).

These tools are of particular interest for environmental microorganisms, as they are rarely isolable and cultivable on synthetic media. Indeed, it is observed that nearly 99% of the microorganisms present in an environmental sample (e.g., soil) are generally not cultivable and are therefore completely overlooked in studies using conventional microbiological methods based on culturing these microorganisms on synthetic media. Molecular biology tools will make it possible to overcome this limitation, as they do not require the microorganisms to be cultured and isolated in order to be studied. Their strength also lies in the fact that all the microorganisms present in a sample can be studied and analysed in a single step. However, a review of the scientific literature shows that these tools are still underutilised (Fig. 01).

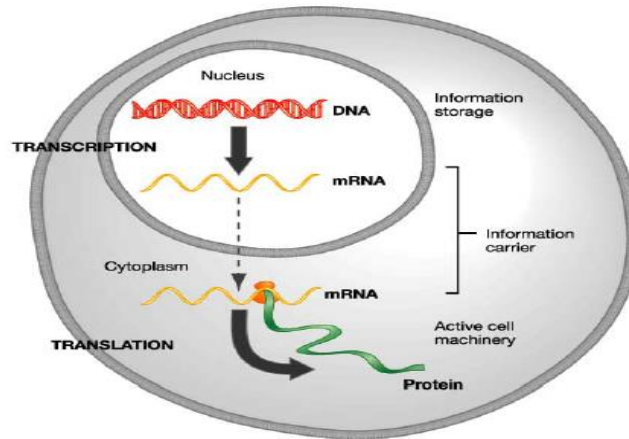


Fig. 01. The central dogma of molecular biology, formulated by Crick in 1960. It describes how genetic information is expressed, from its carrier, DNA, to proteins.

DNA (deoxyribonucleic acid) carries an individual's genetic information and constitutes their genome (the complete set of genes). When an individual expresses a gene (i.e. the gene is active), DNA is transcribed into RNA.

RNA (Ribonucleic Acid) is the molecule used to transfer the genetic instructions encoded in DNA. RNA, which reflects the activity of the bacterium, is then translated to form proteins. Proteins can have a structural role (as cell components) or a functional role (as enzymes). Fatty acids are constituents of the cell and can be used to differentiate between organisms. Analyses are typically carried out following a stage of extraction and purification of the cells' molecular components within the analytical sample processing chain.

Taking DNA as an example, every organism contains thousands of genes (the genome), each with its own unique size and order of the constituent bases A, C, G and T (the sequence).

Since Sanger's description in 1977, sequencing techniques have undergone innovations that have improved their efficiency, reliability and cost-effectiveness. Grouped under the generic name of high-throughput sequencing or next-generation sequencing (NGS), the available strategies are based on three steps (Fig. 02): library preparation: the DNA is cut into fragments linked by adapters; clonal amplification: a PCR reaction using primers that target the adapters allows the number of template fragments to be multiplied; parallel sequencing: the DNA fragments are read and translated into nucleotide sequences.

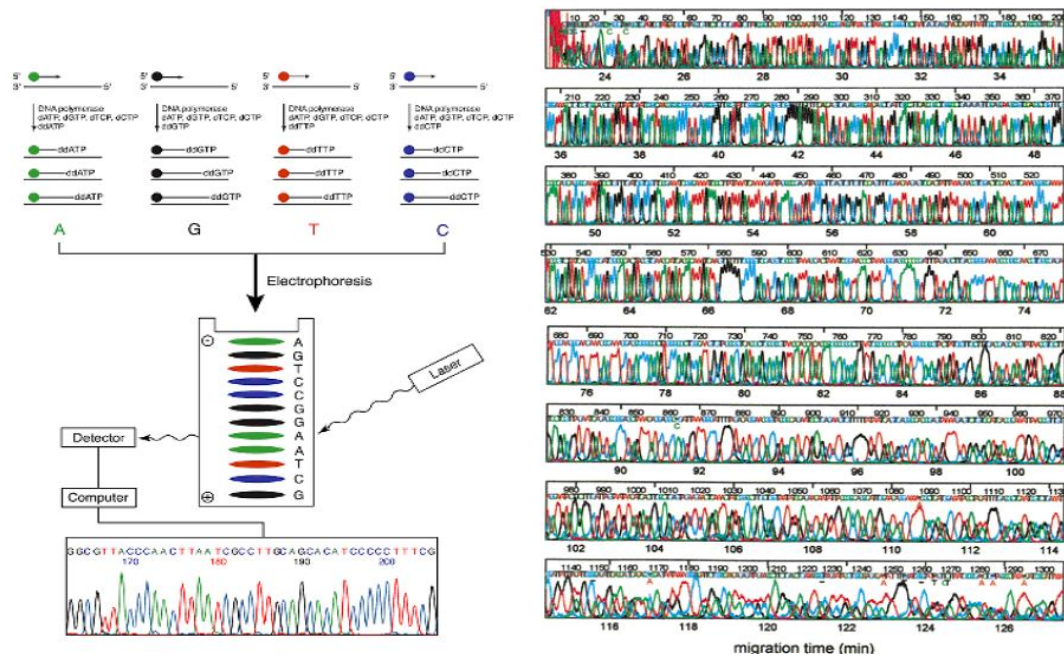


Fig. 02. Left: Principle of DNA sequencing using the modernised Sanger method. Four polymerisation reactions are carried out in parallel. Each contains the four nucleotides, a specific coloured marker, and a small amount of one of the nucleotides modified to halt polymerisation (dideoxynucleotide). An ultra-high-resolution gel is then run to distinguish fragments differing by a single base pair; Right: Analysis of sequence B (Alberts et al., 1994).

I.2. Safety and hygiene standards in the molecular and cellular biology laboratory

Everyone must be mindful of their own safety, that of their colleagues, and the protection of the environment. Be aware of good working practices, the measures to be taken in the event of an accident or incident, and the responsibilities involved.

I.2. 1. Recommended Strategies and Actions for Different Roles

The frequent occurrence of safety accidents in chemical laboratories nowadays is the consequence of multiple factors acting together(Zhang et al., 2021), including the employment of hazardous reagents, non-standardized operations, unreasonable procedures, imprudent behaviors of individuals, and the absence of supervision. Achieving the objectives of laboratory safety is not a task that can be accomplished by an individual or through solitary action; it necessitates a mutual effort and communication among various roles, including experimental personnel, laboratory director, and institutional administrators. It is through this multifaceted collaboration that the likelihood of chemical laboratory safety accidents can be

significantly reduced, the severity of accidents can be mitigated, and the well-being of the individuals involved and the environment are safeguarded. In the context of experimental activities, these three entities assume divergent roles and are guided by varied considerations when addressing laboratory safety (Fig. 03). As such, they shoulder their respective responsibilities and duties within the overarching objective of safeguarding laboratory security. In the ensuing sections of this comprehensive review, we will delve into an academic dissection of the roles and responsibilities assumed by these three key constituents in the reduction in safety incidents within chemical laboratories. Furthermore, we shall delineate a comprehensive set of protocols and strategic initiatives that are imperative for all stakeholders to implement in their quest to augment the safety standards within laboratory settings(Reidy et al., 2023).

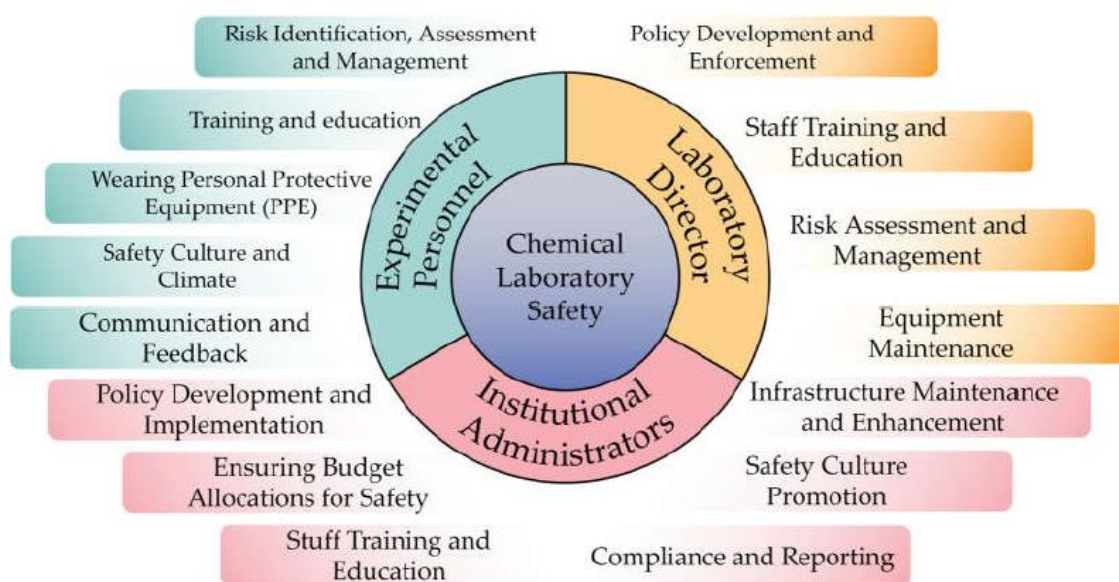


Fig. 03. The three roles and their associated tasks in chemical laboratory safety (Wang W et al., 2025)

I.2.2. Fitness for laboratory work

Anyone must inform the occupational health service in the event of a serious health problem, a known allergy to a product, asthma or pregnancy. The occupational health doctor will determine the conditions under which the person may work.

I.2.3. Accident prevention

The most common causes of accidents are:

- lack of experience
- lack of familiarity with the facilities and the organisation of procedures
- rushing

It is therefore necessary to:

Be informed and be trained: by consulting colleagues, your line manager, or the health and safety officer; by consulting publications that describe the hazards of handling, product safety data sheets (SDS), catalogues, etc.

Be informed: by marking hazardous operations (markings must be clear, concise, not excessive, and removed as soon as the hazard no longer exists)

Verify: the good condition of the equipment to be used (electrodes, rotor, etc.); follow the instructions on chemical labels or safety data sheets (see ‘chemical risk’); check the quality of products (dispose of any products that are suspect, contaminated, old, or have been stored for a long time, etc.)

Protect yourself: by learning how to use collective protective equipment (fume cupboards, extractor hoods, detection devices, etc.); by taking personal protective measures: gloves, lab coat, goggles, mask, face shields, etc.

Take particular care with your eyes (if there is a risk of splashes, explosions, etc.) and your hands (when using corrosive products, glassware, etc.)

Organise yourself and identify hazardous situations: potentially hazardous situation: several independent procedures at the same workstation, procedures involving steps carried out at different workstations; recreate the ‘safety environment’ required for each procedure; restore the area to its original condition after each procedure: tidying away equipment, proper waste disposal and cleaning Do not place personal belongings on or under the workbenches

Remove your lab coat in communal areas (office, break/coffee room, meeting room, toilets): leave your lab coat in the laboratory areas

I.2.4. Types of risks... What can we expect?

A quality management system can be defined as the ‘coordinated actions that direct and control an organisation’s activities with regard to quality’. This definition is used by the International Organization for Standardization (ISO) and the Clinical and Laboratory Standards Institute (CLSI). Both of these bodies are internationally recognised as standardisation organisations for laboratories. In a management system for quality, all aspects of the laboratory’s operations, including organisational structure, methods and procedures, must be examined to ensure quality (table 1).

➤ **Table 01.** The different types of hazards and corresponding risks(Wang W et al., 2025)

➤

Types of Hazards	Subcategories	Characteristics and Risks
Chemical hazards	Flammable and pyrophoric substances	These reagents can spontaneously ignite when exposed to air or water; improper storage or use may lead to fires.
	Toxic reagents	Exposure to toxic substances can result in acute or chronic health hazards, potentially leading to pain, liver and kidney damage; certain special reagents may even be carcinogenic, teratogenic, have reproductive or cumulative toxicity.
	Corrosive substances	Contact with such substances may cause harm to the skin and mucous membranes, leading to skin corrosion, edema, or congestion.
	Allergens	Such substances may cause allergic reactions in certain individuals, leading to symptoms such as itching, swelling, and subcutaneous bleeding.
	Psychoactive substance	These substances directly act upon the central nervous system, causing either stimulation or inhibition, and their continuous use can lead to dependence.
Physical hazards	High/low temperature	Improper use of equipment providing high or low temperatures can lead to burns or frostbite.
	High pressure or vacuum	High-pressure gas cylinders, gas steel bottles, pressure reactors, and vacuum equipment may lead to explosions.
	Electrocution	In chemistry laboratories, if a large number of instruments and equipment are not maintained in a timely manner, it may lead to electrical shock accidents.
	Laser and radiation harm	Some chemistry laboratories may use laser equipment or radioactive materials, and extreme caution is required when using them.
	Mechanical injury	Improper handle of heavy objects, high-speed rotating equipment, and sharp instruments can cause injury.
Biological hazards	Microbes	Some microorganisms are pathogenic or infectious. Relevant experiments must be carried out in strict accordance with the standard operating procedures (SOP) to avoid the occurrence of biosafety accidents.
	Macromolecular Allergens	Certain biological macromolecules may possess sensitizing effects among specific populations. Therefore, experiment operators are obliged to take proper personal protective measures.

Various factors must be taken into account in the quality management of buildings and safety:

- Safety: a process designed to prevent unwanted risks from entering the laboratory.
- Containment: a process designed to minimise risks and prevent the community from being exposed to hazards originating from the laboratory.
- Safety Measures: guidelines and procedures to prevent any risk to staff, visitors and the community. Depending on the results of the risk assessment, appropriate preventive measures

I.3. Classification of biology laboratories

The laboratory classification approach takes into account three types of structures, depending on their nature of activity; human and animal health laboratories (L), animal facilities and greenhouses. Human and animal health laboratories are structures that collect and analyze various fluids and biological tissues of human or animal origin.

Animal facilities are areas of a laboratory where animals are used for experimental or diagnostic purposes. They can be located in the laboratory or in a side room. Greenhouses are closed or semi-open translucent structures made of glass or plastic, supported by a metal or wooden structure, for the cultivation of plants used for experimental purposes. laboratories develop strategies to prevent the risk of contamination and propagation. Laboratories are thus classified according to Biosafety Level (BSL). The biosafety level is a composite index that takes into account the type of organization, the construction method, the means of containment, the equipment of the laboratory as well as the practices and procedures to be observed to work on agents belonging to the various risk groups. There are four levels of biosafety grouped into three classes of laboratories (Table2); basic security (BSL1 and BSL 2), containment (BSL 3) and high security containment (BSL4).

To determine what level of laboratory biosecurity applies to a given agent, a risk assessment is necessary. For this, one must take into account not only the risk group but also a number of other factors. For example, an agent in risk group 2 will generally require facilities, equipment, practices, and procedures that correspond to biosecurity level 2 if the work is to be done with minimal risk. However, if certain manipulations involve the production of highly concentrated aerosols, it will be better to go to biosecurity level 3 so that the safety conditions are met because, at this level better confinement of the aerosols will be ensured in the laboratory (Table 1).

The determination of the biosecurity level required for a given manipulation therefore, consists of assessing the risk "on a professional level" rather than automatically adopting the

level of safety corresponding to the risk group to which the pathogen belongs. Biology laboratories are classified by their safety protocols, field of study, and intended purpose. They are organized into **four Biosafety Levels (BSL-1 to BSL-4)** to manage risk, and structured through specific **clinical governance** to ensure accurate **diagnostic and research testing**. The organization and classification of biology laboratories are detailed in comprehensive manuals that outline safety procedures, risk management, and facility design. Key guidelines include **Biosafety Levels (BSL)**

- **BSL-1:** Suitable for **basic teaching and research** using well-characterized agents not known to cause disease in healthy adults
- **BSL-2:** Geared toward **primary health services and clinical diagnostics**. Handled via specific procedures defined in the
- **BSL-3:** Focuses on **special diagnostics and research special diagnostics and research** involving indigenous or exotic agents that may cause serious or potentially lethal disease through inhalation.
- **BSL-4:** The highest level of **maximum containment** reserved for dangerous and exotic agents that pose a high risk of life-threatening disease.

Table 02. Classification of laboratories WHO(2005) .

Risk group	Containment level	Laboratory Practices and Safety Equipment
I	ABSL-1	Limited access protective clothing and gloves.
II	ABSL-2	In addition to the NSBA-1 recommendations, include biohazard panels: Class I or II ESB for aerosol generating activities. Decontaminate waste and cages before washing.
III	ABSL-3	In addition to the ABSL-2 recommendations, note that access is regulated. BSC and special protective clothing recommended for all activities.
IV	ABSL-4	In addition to the ABSL-3 recommendations, note that access is strictly limited. Change clothes before entering. Use Class III BSC or pressurized suits. Take a shower before going out. Decontaminate all waste before leaving.

Biosecurity guidelines are cumulative, that is, at each level of safety apply all the guidelines that are valid for the lower levels.

I.4. Fire hazard

Fire presents a risk of loss of life and property, injury that must be taken into account, possibly to decide whether it is better to extinguish the fire or circumscribe it. It is important to have fire prevention and fire management measures.

To this end:

- Staff members must be trained on fire prevention and fire management measures;
- A fire safety plan must be available in the laboratory;
- The contact list (standard telephone numbers) of fire and emergency services, the number of the biosafety officer and that of the laboratory manager must be available;
- Fire management gear such as fire extinguishers, masks, an alarm system, etc. must be available;
- Emergency exits must be present and not congested;
- A laboratory plan with visible exits must be available;
- The meeting point must be well materialized;
- A simulation programme must be documented and available;
- Signs, judiciously placed prominently in each room, in corridors and halls, should warn personnel and indicate the proper action to be taken as well as emergency exits to use.
- Fire-fighting gear should be placed near room doors and at various strategic points in corridors and halls

I.5. Floods in biology laboratories

Floods in biology laboratories pose severe risks, including **electrocution**, **equipment damage**, and the **release of hazardous bioagents**. Contaminated water can spread infectious pathogens and disrupt critical research, requiring immediate containment, spill disinfection, and adherence to established **biorisk management** procedures.

- **Biosafety & Contamination:** Flooding can wash away or release Risk Group pathogens, leading to dangerous exposure for personnel and the wider environment.
- **Equipment & Infrastructure Damage:** Waterlogging destroys sensitive incubators, centrifuges, and refrigerators, resulting in a total loss of research materials.
- **Electrical Safety:** Standing water combined with live laboratory equipment significantly increases the likelihood of deadly shocks or fires.

- **Safety first:** If hazardous laboratory materials are compromised or threatened, the local HAZMAT team should be involved in the response. Laboratory staff may also need to shut off the electricity in water-exposed areas, as electricity flows easily through water and poses a lethal risk. In some cases, trained laboratory personnel may need to be called in to shut off sensitive laboratory instruments. Mass spectrometers, for example, have potentially hidden high voltage lines that power overhead vacuums. Trained laboratory staff know where those voltage lines are, while first responders may overlook them. In any case, from a policy standpoint, first responders may be reluctant to touch laboratory instrumentation.

Note: If deemed safe, do not unplug refrigerators and freezers. Laboratories have found that refrigerators and freezers can actually withstand a good amount of water exposure (including water “gushing from ceilings”) without suffering damage or compromising stored items.

- **Triage:** If water threatens immediate damage — such as in a laboratory-wide event involving a burst overhead sprinkler system — safeguard priority items as much as possible. For example, use plastic biohazard bags to cover expensive laboratory instruments and computers, close doors, remove paper files from desktops, etc.
- **Locate the source:** Of course, it is paramount to stop the flow of water, if you can. In one situation, for example, laboratory maintenance workers were able to manually shut off the valve allowing water to spew from a 2,000-gallon rooftop storage tank. Even if the worst damage is already done by the time the flood is discovered, it is necessary to identify the source of the water, so measures can be taken to avert a similar crisis in the future.

II. Best laboratory practices and signaling

Routine or research laboratories encompass a wide variety of working situations. Laboratory work involves the implementation of techniques and the handling of substances that may differ. The sector of activity may also vary: routine activity, public or private activity, public research in universities/university hospital centers, specialized organizations, and private industrial research activity.

II.1. Laboratory Safety

Users must adopt security practices to minimize the likelihood of unauthorized persons entering laboratories or storage areas, or of infectious materials leaving the laboratory without authorization.

Incidents, such as the disappearance of infectious substances, unauthorized entry of an individual, or a spill of biological material (among others), must be reported without delay to biosafety officers. Self-experimentation is prohibited.

II.1.1. Personal Protective Equipment (PPE)

It is mandatory to wear PPE when working in the laboratory (lab coat, gloves, and safety glasses, if required). This PPE must be removed when leaving the laboratory area where infectious material is handled. When material or an organism carrying biological risks is handled, gloves must always be worn when performing procedures involving risk of splashing or skin contamination. Wearing gloves is mandatory for any handler with skin lesions on their hands. Gloves must always be worn when working with biological fluids and human or animal tissues that may be contaminated by various pathogenic microorganisms. Gloves must be removed when contaminated, once work with biohazardous material is finished, or before using the telephone or opening a door. Hands must be washed immediately after gloves are removed and discarded along with single-use materials intended for incineration.

Biological fluids, samples, and human or animal tissues must always be considered potentially contaminated by various pathogenic agents transmissible via blood: hepatitis B or C, HIV, or pathogens that may be transmitted via animal blood to humans. The use of personal protective equipment to protect the face from splashes, such as glasses, gloves, and a mask, is necessary as required by the Laboratory Biosafety Manual.

II.2. Operational Practices

Laboratory-acquired infections are relatively rare events, as several requirements must be met for a pathogen to be transmitted. These requirements, known as the "chain of infection," include: the presence of a pathogen of sufficient virulence; a relatively high concentration of the pathogen (infectious dose); a mechanism for the pathogen to be transmitted from the environment to the host; the appropriate entry point to the host; and the presence of a susceptible host. Operational practices apply to all users of biohazardous material or organisms, regardless of the associated risk group. Practicing safe containment rules provides an adequate safety margin in situations where the risk is unknown, and protects both the user and the biological material

II.2.1. Basic Practices

Laboratories handling biohazardous materials and organisms must comply with the following basic practices :

1. Eating, drinking, smoking, and storing food, personal items, or utensils are prohibited. Wearing jewelry is also not recommended;
2. Mouth pipetting is prohibited, regardless of the substance, in all laboratories. Use pipetting instruments;
3. Access to the laboratory and support areas is limited to authorized personnel;
4. Laboratory doors must be closed at all times (this rule does not apply to open areas within a laboratory);
5. Open wounds, cuts, scratches, and abrasions must be covered with waterproof dressings;
6. The laboratory must be kept clean and orderly. Excessive storage in work areas can hinder evacuation and increase the risk of accidents. Everything unrelated to work that is difficult to decontaminate (newspapers, books, correspondence) should be restricted; writing and report drafting should be done in spaces separated from the areas where materials and organisms involving biological risks are handled;
7. Staff members, as well as visitors, trainees, and other persons entering or working in the laboratory, must wear properly buttoned protective clothing and closed-toe shoes;

8. Procedures providing for face and eye protection must be carefully determined, and the choice of protective means must be adapted to the risk: safety glasses and protective masks must be worn if it is necessary to protect the eyes and face against liquid projections (e.g., handling liquid nitrogen) and the impact of objects;
9. Wearing gloves (latex, vinyl, copolymer, etc.) is mandatory when a procedure risks causing direct skin contact with materials or organisms involving biological risks. Gloves must be removed before leaving the laboratory. Chainmail gloves may be worn under the gloves to prevent cuts;
10. Protective clothing must not be worn outside the laboratory (do not go to the library or the cafeteria with a contaminated lab coat!). Laboratory clothing must not be stored with street clothes;
11. In case of possible or certain exposure, contaminated clothing must be decontaminated by autoclaving or bleach before being cleaned;
12. The use of needles, syringes, and other sharp objects should be minimized. Personnel handling syringes and needles must take great care to avoid self-inoculation and producing aerosols during their use and disposal. During these operations, needles should not be bent, cut, removed from the syringe, or recapped, but rather promptly placed in a puncture-proof container before disposal;
13. Handwashing. Individuals handling potentially contaminated materials must wash their hands before leaving the laboratory, even if they have worn gloves;
14. Decontamination. Work surfaces must be cleaned and decontaminated with appropriate disinfectant products after every spill of potentially hazardous substances, as well as at the end of each day;
15. Contaminated devices and equipment must be properly disinfected and labeled as such before leaving the laboratory for repair or disposal;
16. The effectiveness of autoclaves used for decontamination must be regularly checked using indicators. The results and cycle logs (time, temperature, and pressure) will be recorded in a file;
17. Disposal of biological waste. Contaminated materials must be placed in appropriate and clearly identified containers;
18. Disinfectants effective against the agents handled must be available at all times in handling or storage areas;

19. Moving infectious materials or toxins is done using closed and labeled containers. Use a cart if necessary. Movement occurring between containment areas located within the same building should be done with labeled, leak-proof, and impact-resistant containers. This also applies to waste;
20. When stored outside the containment zone, infectious materials or toxins must be labeled, kept in leak-proof and impact-resistant containers, and placed in a locked storage area restricted to authorized personnel;
21. Incident and accident reports. The laboratory supervisor must be immediately notified in the event of a spill, accident, exposure to infectious materials, or breach of containment. A written log of these incidents and accidents must be kept up to date by the supervisor..

II.3. Signage

At the entrance of each laboratory, a sign must indicate:

-  The name of the laboratory and its contact information
-  Safety instructions, warnings, and hazards
-  The persons responsible

II.4. Preparing for Laboratory Work ...

II.4.1. What Should I Know?

Avec quoi je travaille :

- The hazards and risks related to my work and the hazardous materials used.
- The personal protective equipment to use.
- The safety rules and procedures applicable to my work.
- The operation and proper use of equipment

Knowing the premises and preventing accidents:

- The location and use of each piece of emergency equipment (fire extinguishers, emergency shower and eyewash station, first aid kit, and spill response kit) and how to obtain help.
- The evacuation route and the location of the assembly point.
- The procedures in the event of a spill or emergency.

Be responsible

- Follow the safety rules and procedures that apply to my work.
- Have new experiments and modifications to experimental protocols approved.
- Pay attention to others and do not disrupt their work.
- Stay focused: avoid music or multitasking involving cell phones, smartphones, electronic tablets, etc. (SMS, social networks, etc.).
- Perform work involving hazardous materials under a hood or a biosafety cabinet (BSC) and ensure their proper operation.
- Conduct good management of hazardous materials, as well as residual waste materials.

Be preventative

- Do not leave an experiment unattended unless it involves no risk.
- Ensure access to Safety Data Sheets (SDS).
- Treat unknown materials as hazardous.
- Exercise double caution with large quantities.
- Store hazardous materials or substances immediately after use.
- Identify the contents of all containers clearly and legibly.
- Wear appropriate attire, tie back long hair, and wear closed-toe shoes with non-slip soles. Sandals and fabric shoes are prohibited (risk of absorbing hazardous materials). Work without jewelry.
- Keep the area clean: put away what is not in use. Do not leave bottles on the floor, or cabinet doors or drawers open.
- Keep emergency equipment, entrances, and exits clear at all times.
- Comply with the rules regarding the transport of hazardous materials.

II.4.2. Before Leaving the Laboratory What Should I Remember?

Leaving the premises clean and functional::

- Identify any setup left unattended (description of the experiment, products used, and hazards) and leave your contact details nearby so you can be reached in case of a problem.
- Turn off heating appliances, electricity, water, gas, compressed air, and vacuum lines.
- Clean up the area: device or workstation.
- Store unused equipment and devices in their respective storage places.
- Label, pack, and dispose of all waste according to appropriate procedures.

- Remove or identify all damaged equipment (have it repaired or replaced).
- Leave protective equipment (glasses, lab coats, gloves, etc.) in the laboratory.
- Lock the laboratory door upon exiting.

II.5. Hygiene Rules

In general, you must:

- Respect hygiene and safety rules for your safety, that of the people working alongside you, and that of the environment;
- Respect other handlers, which implies cleaning the benches and doing your dishes after each procedure, putting things away, and respecting reservation schedules;
- Take care of the equipment;
- Correctly label what you want to keep. The label must indicate: the preparer's name, the product's name, its concentration, and its manufacturing date (or date of opening, or expiration date);
- Do not handle materials alone in the laboratory during evenings and weekends outside of laboratory opening hours.
- Laboratory equipment is expensive, take care of it! If you notice an equipment malfunction or if you break something, report it. This allows repairs to be initiated or the equipment in question to be replaced as quickly as possible.

II.6. Work with Laboratory Animals

Handling laboratory animals poses a certain risk to health and safety (bites, scratches, etc.) even if the animals handled are considered healthy. Furthermore, animals could also be naturally or experimentally infected. Therefore, animals must be handled with care and by using adequate personal protective equipment such as: lab coat, safety glasses, bite-resistant gloves, etc., as well as restraint facilities when the situation requires it.

Exposure to animals may pose a risk of developing allergies in the handler. In this case, the handler should minimize exposure to types of animals to which they are allergic and minimize contact with these animals. They must also ensure they have the necessary personal protective equipment (gloves, lab coat, mask, glasses) to reduce or eliminate this allergic reaction. Handling cages also poses risks. Cage bedding may produce aerosols potentially containing

microorganisms and dust. Handling techniques must attempt to minimize the production of these aerosols as much as possible. When applicable, handlers must wear the necessary personal protective equipment. In addition, handlers of infected animals and animals captured in the wild must request an assessment of the need for preventive vaccination against the relevant pathogenic organisms (when available).

II.6.1. Healthy Animals

Healthy animals can represent a biological risk when they develop zoonoses, which are diseases transmissible to humans. They can be asymptomatic carriers or not of organisms (parasites, viruses, bacteria, etc.) that render them potentially dangerous to humans. Attention must be paid to animals exhibiting unusual behavior and coming from an environment likely to have contaminated them. Adequate veterinary surveillance almost entirely reduces the risk of zoonoses in humans from these animal.

II.6.2. Infected Animals

The inoculation of animals with organisms classified into one of the four risk groups represents the same risk as that organism. It is necessary to apply the same work and containment precautions with these animals as with the agent itself. Certain in vivo experiments can increase the risk of the inoculated organism. In these cases, the perceived risk group must be applied in place of the existing risk group. It is important to use the appropriate equipment (e.g., bite-resistant gloves, cages with filters) to reduce the risk associated with handling these infected animals.

II.7. Work with Human Pathogens

If human material contains a viable pathogen, it must be considered a human pathogen with the power to infect and cause disease in another human. Among potentially infectious materials, we find: blood, body fluids containing blood, mucous membranes, vaginal secretions, cerebrospinal fluid, synovial fluid, pleural fluid, peritoneal fluid, pericardial fluid, and amniotic fluid. It is important to properly assess health risks for the worker and to offer them appropriate vaccination if applicable.

II.8. Decontamination

Decontamination is a process or treatment aimed at making it safe to work on a surface or with an instrument previously contaminated by a pathogenic agent. It includes sterilization and disinfection.

It is a process of eliminating microorganisms to such a low level that there is no longer any risk of infection, even for an unprotected individual.

Decontamination can range from simple cleaning with a detergent (disinfection) to as drastic a procedure as sterilization. Sterilization involves the use of physical or chemical processes that destroy all microorganisms, including bacterial spores. Disinfection is essentially the destruction and elimination of specific types of microorganisms. The aim of disinfection is to reduce the number of microorganisms to a level such that the risk of transmitting an infection is eliminated in a given application.

The effectiveness of disinfection is influenced by many factors: the nature and number of microorganisms, the amount of organic matter present, the nature of the surface or object to be disinfected, the disinfectant used, its concentration, the exposure time (contact time), and the ambient temperature. When should you decontaminate? At the end of each experiment involving the use of material and/or organisms carrying biological risks; as soon as an accidental spill of such a substance occurs; at least once a day for potentially contaminated surfaces and devices that have been used; every time you want to wash, store, have repaired, or discard a device.

The primary responsibility for complying with this procedure rests with each user and each laboratory supervisor, who must ensure that everyone in their laboratory is well aware of the nature and potential hazards of the material used. People working with materials and organisms involving biological risks must know the decontamination procedures related to their activities and the various factors influencing them.

II.8.1. Chemical Decontamination for Surfaces and Devices

Chemical disinfectants are used to decontaminate surfaces, devices, and any items or containers that cannot be decontaminated by heat. They are generally used to clean up spills and splashes of materials and/or organisms involving biological risks. The choice of disinfectant depends on the resistance of the handled microorganisms.

Some organisms are highly resistant to chemical disinfectants, such as protozoan spores or cysts, while others demonstrate high sensitivity, such as vegetative bacteria.

When using chemical disinfectants, in addition to their compatibility with the materials they will contact, one must consider their ease of use, stability, and the health hazard risk that each may represent (e.g., formaldehyde). Choosing a disinfectant can be difficult given the many products on the market. However, the active components of different chemical disinfectants belong to a limited number of chemical classes. To choose an effective disinfectant, one must understand the capabilities and limitations of each of these classes and unwanted side reactions. It is important for users to refer to the product's safety data sheet before any use.

II.8.2. Steam Sterilization (autoclave)

Glass Petri dishes, pipettes, culture tubes, glassware, culture media, etc., can be effectively decontaminated in a direct steam autoclave. The effectiveness of autoclave decontamination depends on the ease with which steam can penetrate into and between the objects to be decontaminated. Packaging must therefore allow steam to penetrate freely. Stacked and overloaded containers may result in sterilization failure. The duration of the decontamination cycle must be adjusted according to the load to be decontaminated. Routine checks (weekly, depending on frequency, etc.) of the sterilization process must be carried out and the results must be recorded in a register.

II.8.3. Ultraviolet Light

The use of ultraviolet (UV) rays is only necessary to decontaminate the work surface of certain microorganisms. The light emitted by UV lamps (with a wavelength of approximately 260 nm) exerts a germicidal effect and can reduce the number of microorganisms found either in the air or on the surface exposed to the light. However, the sterilization and decontamination power of UV is limited by several factors including: UV light has low penetrating power. Furthermore, UV irradiation can cause damage to the skin and eyes. Harmful effects are mainly at this level since UV rays do not penetrate deep into tissues. Although the glass in new enclosures is anti-UV, it remains impossible to work there when UV rays are being emitted.

A relative humidity higher than 70% reduces the germicidal effectiveness of UV. A temperature below 25°C (77°F), as well as air movements that can cool the lamp, will reduce its effectiveness. Cleanliness: UV lamps should be washed with alcohol weekly to remove

any dust that could reduce UV efficiency. The maximum effectiveness of UV decontamination is 20 minutes. It is not recommended to use UV over long periods, as this decreases the lifespan of the UV tubes.

II.9. Basic Safety Rules in a Molecular Biology Laboratory

1. Strict separation of living areas and laboratories. Respect the ban on smoking, eating, and drinking in laboratories, or storing food in the refrigerators and freezers of these rooms. Remove your lab coat and gloves before entering an office or going to the cafeteria, meeting room, secretariat, or documentation room. Remove your gloves to answer the phone, use a computer keyboard, open doors, etc. Also, avoid touching your face with your hands if you are wearing gloves, and do not put pens used in the laboratory into your mouth.
2. Use the personal and collective protective means at your disposal. These are lab coats, gloves, goggles, and protective visors/helmets (anti-UV).
3. Learn to recognize the different risks and respect instructions. Learn to identify the different risks from the marking (product labels, posters, etc.) and take them into account! Everyone must remain vigilant and responsible regarding the use of products and equipment.
4. Label! Any sample, product, manipulation result, waste, etc., must be correctly labeled. The label identifies the product and avoids any misunderstanding or manipulation error, especially if the flask containing the product is not the original one. Useful information that should appear on the label: product name, name of the person who prepared it, opening or manufacturing date, storage condition, concentration.
5. Clean and/or decontaminate the workstation after each procedure. Think of the people who will use it after you! Workstations must always be left clean and complete: washing benches with bleach, empty trash cans, complete pipette sets, boxes of tips available.
6. Management of hazardous products. Do not store flammable solvents (e.g., alcohol) in refrigerators that are not spark-safe. Vapors could ignite in the event of a spark. Do not dump hazardous chemicals into sinks, nor objects contaminated by these products (gloves, paper, tubes, etc.) into "normal" trash cans. There are special trash cans for liquid or solid waste: phenol, chloroform, EtBr (BET), formamide, etc.

7. In case of an incident or accident... In the event of a splash of a dangerous or potentially dangerous liquid (e.g., rodent blood) on the body or in the eye, wash thoroughly with water for at least 15 minutes. In case of ingestion of a hazardous product, do not induce vomiting and do not give the person anything to drink. Inquire about the nature of the product, its quantity, its concentration, the circumstances of the accident, possible mixtures, etc., so as to be able to inform the health and safety officer; in all cases, inform the health and safety officer immediately, even if it does not seem serious at the time.

8. Inform and train newcomers. Never leave newcomers unsupervised during their first manipulations. Explain the laboratory's operating rules to them and train them in techniques, specifying all safety rules



III.7. Radioactivity

When an isotope decays spontaneously, the excess energy emitted is a form of ionizing radiation. In other words, decay emits radiation, which is called activity. The isotope that transforms and emits radiation is called a radioisotope. Decay is expressed or measured in units called becquerels (Bq). One becquerel corresponds to one disintegration per second.

III.7.1. What is a Radioisotope?

Every atom of an element must have a specific number of protons and neutrons at its center (in the nucleus) to be stable, i.e. to remain in its initial form. Radioisotopes are elements that do not have the proton/neutron ratio necessary to remain stable. When its proton/neutron ratio is unbalanced, an atom tries to become stable and, in doing so, releases energy. For example: a stable carbon atom has six protons and six neutrons, while carbon-14, an unstable (and therefore radioactive) isotope, has six protons and eight neutrons. Carbon-14, like all other unstable elements, is a radioisotope. The stabilization process, during which energy is released in the form of radiation, is called « radioactive decay »

The radioactivity of radioisotopes decreases very quickly. The interval during which half of them disappear is called the half-life. This can range from a few hours to several days.

III.7.2. The Atom: The Foundation of Matter

All matter around us is composed of atoms. Atoms form elements such as oxygen, hydrogen and carbon. An atom is composed of protons and neutrons, which form the nucleus, and electrons, which orbit around the nucleus. The nucleus carries a positive charge; protons are positively charged, while neutrons are electrically neutral, as their name suggests. Electrons are negatively charged particles that move around the nucleus forming a peripheral cloud. The

negative electrons are attracted to the positive nucleus by an electric force. This is what maintains the structural integrity of the atom

The nuclide is an atomic entity characterized by the number of protons and neutrons that make up the nucleus, which corresponds approximately to the mass of the nuclide. The number that sometimes accompanies the name of the nuclide is the mass number (sum of protons and neutrons in the nucleus). For example, carbon-12 is a carbon nuclide with 6 protons and 6 neutrons.

III.7.3. Understanding Isotopes

Nuclides of an element that have the same number of protons but a different number of neutrons are called isotopes of that element. These are variants of the same basic element. For example, there are three isotopes (or variants) of hydrogen: hydrogen-1 (one proton and no neutron), hydrogen-2 or deuterium (one proton and one neutron) and hydrogen-3 or tritium (one proton and two neutrons). Other examples: uranium-235, which has 92 protons and 143 neutrons, and uranium-238, which has 92 protons and 146 neutrons. Uranium-235 and uranium-238 are both isotopes of uranium (Fig. 04).

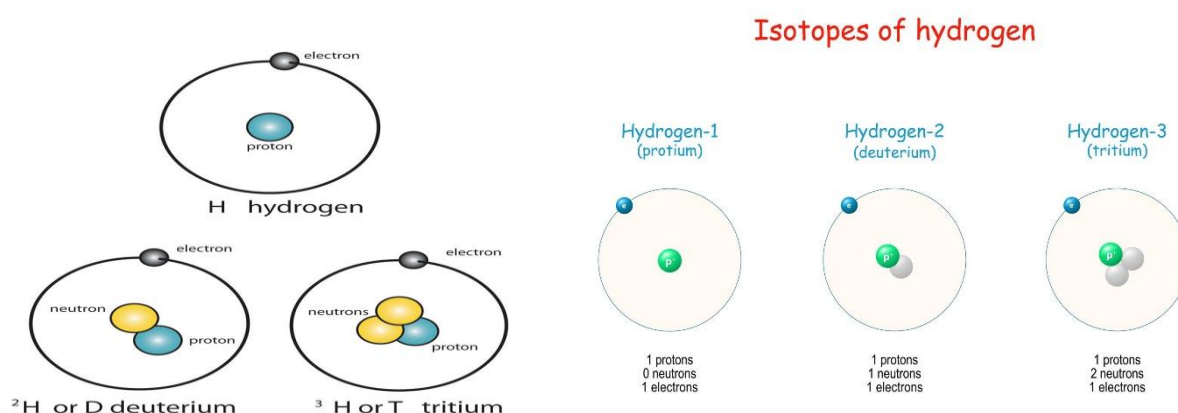


Fig. 04. Hydrogen isotopes (IRSN, 2012).

III.7.4. The Stable Isotope

Many isotopes are stable. They do not undergo radioactive decay and do not emit radiation. Other isotopes are unstable. An isotope is stable when there is a balance between the number of neutrons and the number of protons. When a stable isotope is small, it contains practically the same number of protons as neutrons. Larger stable isotopes have slightly more neutrons

than protons. Among stable isotopes is carbon-12, with six protons and six neutrons, for a total mass of 12 grams (Fig. 05).

III.7.5. The Unstable Isotope

When there is an imbalance between the number of protons and neutrons — usually when the neutron-to-proton ratio is too low — the isotope will want to transform into a more stable form, i.e. a different atom. When this occurs, the atom reduces its mass by emitting alpha particles, beta particles, positrons or gamma rays, but some may reach stability through spontaneous fission or electron capture. This is a spontaneous process called radioactive decay.

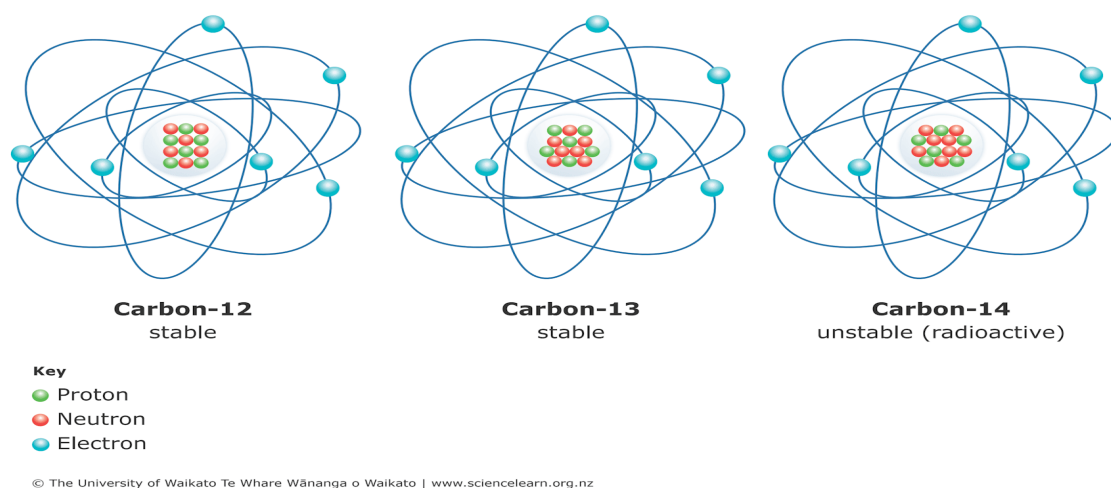


Fig. 05. Carbon isotopes (IRSN, 2012).

➤ There are three main types of radioactive decay:

Alpha decay: When an atom undergoes alpha decay, it ejects a particle composed of two protons and two neutrons from the nucleus, resulting in a decrease of the atomic number by two and a decrease of the mass number by four.

Beta decay: Beta decay occurs when a neutron in the nucleus of an unstable atom converts into a proton and an electron is ejected from the nucleus. The atomic number increases by one, but the mass decreases only slightly.

Gamma decay: Gamma decay is the release of excess energy present in the nucleus following alpha or beta decay, or after neutron capture in a nuclear reactor. The residual energy is emitted in the form of a gamma-ray photon. Gamma decay generally does not affect the mass number or the atomic number of the radioisotope (Fig. 06).

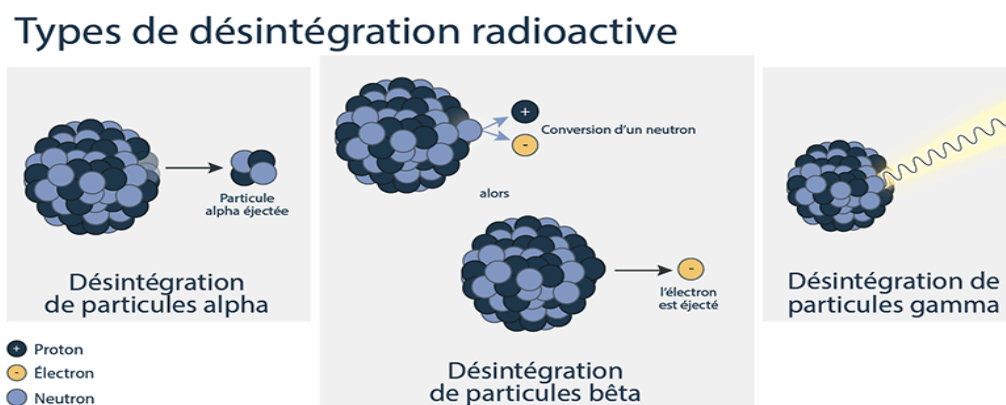


Fig. 06. Types of radioactive decay (IRSN, 2012).

III.8. Selection of Radioisotopes

A radioisotope or tracer is a radioactive atom with the same physicochemical properties as the stable atom of which it is the isotope. Thus, it has the same biodistribution as its "cold" analogue, and can be detected through the radiation it emits. This radioactive tracer is in most cases integrated into a vector that allows the radionuclide to be directed toward a region of interest. The combination of tracer and vector is called a radiotracer or radiopharmaceutical. However, not all radioisotopes can be used in scintigraphy. They are primarily selected according to their physical characteristics, and several parameters must be taken into account, including the energy of the photons emitted; the mode of production, cost and availability.

III.9. Production of Radioisotopes

Some radioisotopes are natural, others are artificial. Only those produced by nuclear reactors and cyclotrons are used for medical purposes, as they are easy to obtain, have the characteristics required for imaging and generally have a much shorter half-life than natural radioisotopes. The half-life is the time required for half of the radioisotopes to decay. It gives an indication of the lifetime of a radioisotope. Radioisotopes with a very long half-life are more stable and therefore less radioactive. The half-life of radioisotopes used in medicine

ranges from a few minutes to a few days. For example, rubidium 82, used in myocardial perfusion imaging, has a half-life of 1.26 minutes, while iodine 131, used to diagnose and treat thyroid conditions, has a half-life of eight days. There are approximately 1,800 radioisotopes in total, of which about fifty are used in medicine (Table 03).

Table 03. Main radioisotopes (L'Annunziata, 2012).

radioisotope	half-life	units	production route
^{11}C	20.4	minutes	$^{14}\text{N}(\text{p},\alpha)^{11}\text{C}$ (cyclotron)
^{13}N	9.9	minutes	$^{14}\text{O}(\text{p},\alpha)^{13}\text{N}$ (cyclotron)
^{15}O	122	seconds	$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ (cyclotron)
^{18}F	110	minutes	$^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$ (cyclotron)
^{62}Cu	9.74	minutes	$^{63}\text{Cu}(\text{p},\text{n})^{62}\text{Zn}$ (cyclotron) $^{62}\text{Zn} \rightarrow ^{62}\text{Cu}$ (generator)
^{64}Cu	12.7	hours	$^{64}\text{Ni}(\text{p},\text{n})^{64}\text{Cu}$ (cyclotron) $\text{Zn}(\text{various})^{64}\text{Cu}$ (cyclotron)
^{68}Ga	67.7	minutes	$^{69}\text{Ga}(\text{p},2\text{n})^{68}\text{Ge}$ (cyclotron) $^{68}\text{Ge} \rightarrow ^{68}\text{Ga}$ (generator)
^{76}Br	16.2	hours	$^{76}\text{Se}(\text{p},\text{n})^{76}\text{Br}$ (cyclotron)
^{124}I	4.15	days	$^{124}\text{Te}(\text{p},\text{n})^{124}\text{I}$ (cyclotron)
^{89}Zr	78.4	hours	$^{89}\text{Y}(\text{p},\text{n})^{89}\text{Zr}$ (cyclotron)
^{82}Rb	76	seconds	$^{82}\text{Sr} \rightarrow ^{82}\text{Rb}$ (generator)

III.10. Labelling techniques of biomolecules for radiotherapy

Radiotherapy using open radioactive sources has become an important and promising mode of treatment of cancer patients, particularly in conjunction with other modalities like surgery and chemotherapy. For this purpose therapeutic radiopharmaceuticals are designed to deliver high doses of radiation to selected target organs or tissues with an aim of minimizing unwanted radiation to surrounding healthy tissue. Several radionuclides have been developed and tagged into appropriate carriers for targeted radiotherapy. As radionuclide carriers, chelating

chemical agents, monoclonal antibodies, peptides, biodegradable particles, colloids, etc., have been investigated as radiopharmaceuticals for therapeutic nuclear medicine. In spite of the potential of targeted radiotherapy to treat a wide range of malignant conditions, the routine clinical use has been, hampered by the lack of suitable radionuclide carrier molecules which would adequately concentrate these radionuclides in target tissues of interest. Much higher and specific uptake of the radiopharmaceutical in the target tissue is needed for effective therapeutic applications than is possible with most of the diagnostic agents currently available. Following the recommendations of a group of experts in 1997, and in view of the realization that higher levels of targeting for therapeutic agents would be possible using biomolecules such as monoclonal antibodies, peptides and other receptor avid molecules as carriers of the radionuclide, in 1998 the International Atomic Energy Agency (IAEA) launched a Co-ordinated Research Project (CRP) on Labelling Techniques of Biomolecules for Targeted Radiotherapy. The CRP aimed at developing and optimizing existing procedures for radiolabelling of monoclonal antibodies and small peptides with therapeutic radionuclides, such as ^{90}Y , ^{188}Re and others.



IV. Physical Risk Assessment

Risks are assessed in relation to the harm they can cause to people. Risks can be of different types (Fig. 07):

- Asphyxiation – Sources: handling liquid nitrogen in a poorly ventilated room, fire;
- Electrocution – Sources: electrical fires, poorly maintained electrical equipment or installations, etc.;
- Burns – Sources: fire, electricity, Bunsen burners, non-ionizing radiation (infrared, UV), laser radiation, autoclaves, chemicals, low temperatures (e.g., liquid nitrogen), etc.;
- Genetic alterations/Cancer – Sources: ionizing radiation (radioactive materials), non-ionizing radiation (UV);
- Miscellaneous injuries (wounds, hemorrhages, contusions, fractures, etc.) – Sources: falls, falling objects, explosions (e.g., pressurized equipment such as autoclaves or



Fig. 07. Different warning pictograms for identifying potential causes of physical risks (Shematek and Wood, 2012).

IV.1. Physical Risk Prevention

Due to the wide variety of physical hazards, certain recommendations must be followed:

- Learn to recognize the different pictograms and comply with the instructions;
- Respect storage regulations (e.g., flammable products in fireproof and explosion-proof cabinets). Do not unnecessarily store flammable materials (e.g., cardboard boxes);
- Most of the time, these hazards correspond to restricted access areas. Do not enter unless you have a specific reason to be there, or if you have not received specific training or safety information (e.g., radioactivity);
- Use the specific protective equipment provided (hearing protection, safety goggles and shields, gloves for high and low temperatures, etc.);
- Follow the operating instructions for all laboratory equipment;
- Do not dismantle broken equipment (call a maintenance and repair service provider);
- Do not manually carry objects that are too heavy or bulky."

IV.1.1. Electrical Risks

It is essential that all electrical installations and equipment be checked and tested regularly, including grounding. Circuit breakers, including residual current devices (RCDs), must be installed on laboratory electrical circuits. Circuit breakers do not protect people; their role is to protect circuits from overload and thus prevent fires. Residual current devices are designed to protect people from electric shock.

All electrical equipment in the laboratory must be grounded, preferably through grounding outlets. All laboratory electrical equipment and circuits must comply with national electrical safety standards.



IV.1.2. Noise

The effects of long-term exposure to excessive noise are insidious. Certain laboratory equipment, such as some types of lasers, or facilities housing animals, can lead to significant exposure of this kind. Acoustic measurements can be carried out to determine the risk of noise exposure. If the resulting data justifies it, engineering controls can be considered, such as enclosing noisy equipment or installing noise barriers or screens around this equipment or

between noisy areas and other workspaces. If the noise level cannot be reduced and staff are continuously exposed to excessive noise, a hearing conservation program must be implemented, including the use of hearing protection devices for work in noisy environments, as well as medical surveillance of staff to monitor the effects of this hazard.

IV.1.3. Cryogenics — Liquid Nitrogen

To handle cryogenic liquids, the cryogenic liquid — liquid nitrogen training must be completed. It is available online as a refresher on filling, transporting and storing liquid nitrogen

IV.1.4. Risk of Cold Burns

- Avoid any contact with the liquid.
- Wear recommended PPE: safety goggles, lab coat, thermal gloves and if necessary, shoe covers.
- For tank filling: add a face shield and thermal apron.
- First aid: shower exposed areas with lukewarm water.

IV.1.5. Risk of asphyxiation

- Use in a well-ventilated area and avoid breathing in vapors.
- Large-scale use may require the presence of an O₂ detector.
- Handle large tanks with two people.
- First Aid: Move the person to a well-ventilated area.

IV.1.6. Risk of Explosion Due to Overpressure

- From liquid to gas, cryogenic liquids have a high expansion rate.
- Use a cryogenic container in good condition.
- Never use closed containers.
- Limit ice formation.

IV.1.7. Risk of Explosion Due to Oxygen Condensation

When using a trap connected to a vacuum system and cooled with liquid nitrogen, the introduction of ambient air through a seal defect can lead to the condensation of oxygen (a liquid characterized by a bluish color). Liquid oxygen presents an explosion risk



IV.1.8. Extreme Temperatures

a. Heat

There is a risk of burns when handling hot objects or open flames; wear heat-resistant gloves and any other PPE deemed necessary. There is a risk of hyperthermia when working in hot environments. Take regular breaks and drink plenty of water.

b. Cold

There is a risk of cold burns when handling objects at low temperatures and cryogenic liquids; wear thermal gloves, appropriate clothing and necessary PPE. There is a risk of hypothermia with prolonged cold exposure.

c. Non-ionizing radiation (laser, UV, and microwaves)

Radiation is the emission of energy from its source. In the case of non-ionizing radiation, the energy is insufficient to ionize atoms or molecules.

d. Laser

Lasers are characterized by a narrow and targeted beam, which allows a large amount of energy to be sent to a small surface area. The main risk associated with lasers is eye injury. There are seven categories of lasers: class 1, 1M, 2, 2M, 3R, 3B and 4.16.

IV.2. Preventive Measures

- ✚ Receive adequate training for laser use, according to its class and the emitted wavelength. Class 3B and 4 lasers are particularly dangerous.
- ✚ Wear appropriate protective eyewear and a cotton lab coat (for Class 3R, 3B, and 4 lasers), and remove reflective personal items such as watches, jewelry, pens, belt buckles, zippers, etc. The use of a laser emitting in the UV spectrum requires wearing a face shield, a lab coat, and disposable gloves.
- ✚ Laser safety glasses are specific and require careful attention and proper use; carefully read the manufacturer's instructions regarding compliance verification, maintenance, and lifespan.
- ✚ Never look directly or indirectly (via reflection from objects such as mirrors or stainless steel) into a laser beam.
- ✚ Undergo an optometric examination every five years.
- ✚ Restrict laboratory access, specifically when the laser is operating. Class 3B and 4 lasers require a controlled work area and specific signage. A light-up warning sign indicating that the laser is in operation, as well as an emergency stop button, must be located at the laboratory entrance.

IV.3. Radioactivity and Half-Life of a Radioactive Atom

The activity of a radioactive atom is defined by the number of disintegrations per second and is expressed in Becquerels (Bq). A disintegration is a microscopic event that is completely random and cannot be predicted. However, on a macroscopic scale, the average number of disintegrations follows a well-described law using an exponential function that decreases over time. The activity of the radioactive atom can thus be characterized by the radioactive period or half-life, which corresponds to the time necessary for half of the initially present radioactive atoms to have disintegrated.



IV.3.1. Ionizing Radiation

Ionizing radiation is invisible. It cannot be smelled, touched, or heard — it can only be measured. Ionizing radiation has enough energy to release electrons from an atom, producing a charged atom, whereas non-ionizing radiation, such as radio waves, visible light or ultraviolet light, cannot (Fig. 08).

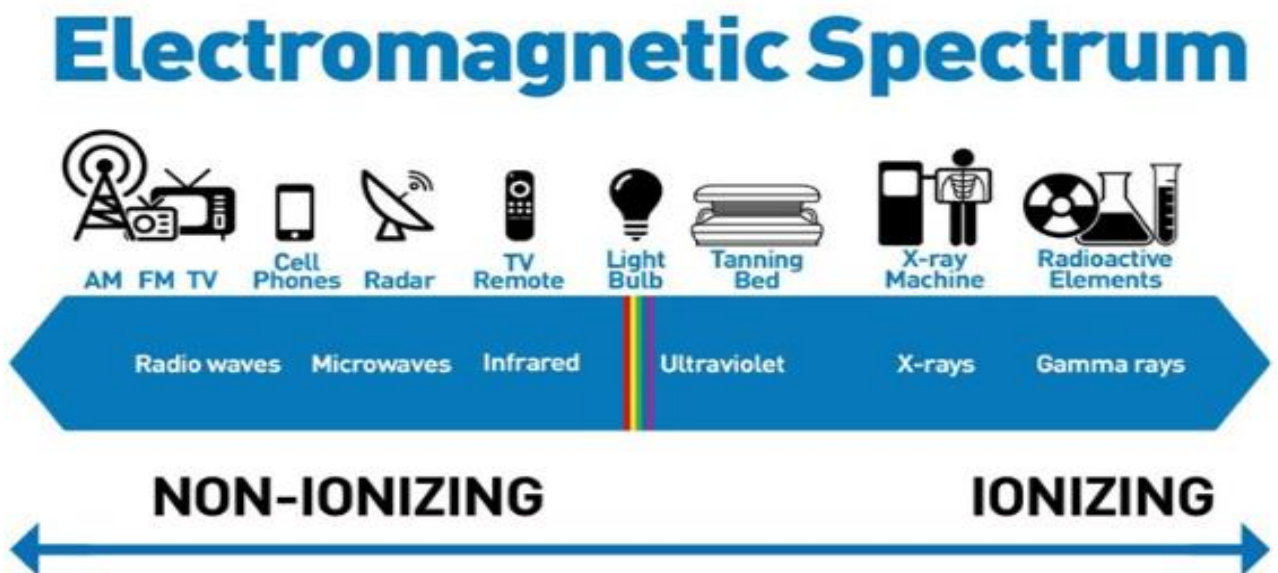


Fig. 08. Types of radiation used in various applications (d'Ariane, 2016).

The purpose of radiation protection is to shield human subjects from the harmful effects of ionizing radiation, which notably include:

- Somatic effects, e.g., observable clinical symptoms in exposed individuals. These particularly include radiation-induced cancers, such as leukemia or bone, lung, and skin cancers, which may only appear several years after irradiation. Other less severe effects can include minor skin lesions, alopecia, blood abnormalities, gastrointestinal tract lesions, or cataracts.

- Hereditary effects, e.g., symptoms observed in the offspring of exposed individuals. The hereditary effects of gonad irradiation notably consist of chromosomal abnormalities or gene mutations. High-dose irradiation of germ cells in the gonads can also lead to cell death, resulting in fertility disorders in both sexes and alterations in the female menstrual cycle.
- Fetal exposure during development, particularly between the eighth and fifteenth weeks of pregnancy, can increase the risk of congenital malformations, mental retardation, or radiation-induced cancers later in life

IV.3.2. Principles of Radiation Protection Against Ionizing Radiation

To limit the harmful effects of ionizing radiation, the use of radioisotopes must be regulated and must always comply with national standards in this area. The implementation of radiation protection is based on four principles :

1. Reduce the duration of exposure as much as possible
2. Stay as far away as possible from the radiation source
3. Place shielding around the radiation source
4. Substitute radioisotopes with other non-radiometric techniques

IV.4. Protective Measures

IV.4.1. Duration of exposure:. The duration of exposure during the handling of radioactive substances can be reduced by: practicing new and unfamiliar techniques without using radionuclides until they are perfectly mastered; using radionuclides only when needed, cautiously and without rushing; ensuring that once used, all radioactive sources are immediately returned to their storage location; frequently removing radioactive waste from the laboratory; spending as little time as possible in the area or laboratory where there is a risk of irradiation; and training to properly manage and plan radioactive substance manipulations and their duration. The less time spent in the radiation field, the lower the individual dose received, as shown by the following equation :

$$\text{Dose} = \text{Dose rate} \times \text{time}$$

IV.4.2. Distance from the Source

For most gamma or X-radiation, the dose rate varies as the inverse square of the distance from a point source. It can therefore be seen that if the distance between the radiation source and the operator is doubled, the exposure will be divided by four over the same duration. Various devices and mechanical systems are used to increase the distance between the operator and the source, such as various types of tongs, particularly long-handled ones, and remote pipetting devices. It should be noted that a small increase in distance can result in a significant reduction in dose rate.

IV.4.3. Shielding

By placing screens between the source and the operator or other personnel that are capable of absorbing or attenuating the radiated energy, their exposure can be limited. The choice of the type of screen and its thickness depends on the penetrating capacity of the radiation (i.e. its nature and energy). Acrylic resin, wood or light metal screens, 1.3 to 1.5 cm thick, protect against highly energetic beta particles, but to protect against high-energy gamma or X-radiation, it is necessary to use high-density lead screens.

IV.4.4. Substitution

Radionuclides should not be used if other techniques are available. If another technique cannot be substituted for a radioisotopic method, the radionuclide whose radiation is the least penetrating or least energetic possible should be used. There are four types of rules for working with radioactive substances: those concerning the irradiation zone, those concerning the bench where the handling takes place, those concerning waste management, and finally those concerning records and emergency procedures.

IV.5. Rules to Follow

Among the most important rules, the following can be mentioned:

IV.5.1. Radiation Area

Only use radioactive substances in areas specifically designated for this purpose. Only essential personnel should be present. Wear personal protective equipment, including

appropriate laboratory clothing, safety goggles and disposable gloves; wear a personal dosimeter to monitor radiation exposure.

Les laboratoires où sont manipulés des radionucléides doivent être conçus de manière à ce que le confinement, le nettoyage et la décontamination soient simplifiés. La zone de travail sur les radionucléides doit être située dans une pièce de petites dimensions contiguë au laboratoire principal ou dans un secteur spécial de celui-ci, à distance des autres zones de travail. Des panneaux portant le symbole international de risque d'irradiation doivent être apposés à l'entrée de la zone d'irradiation.

IV.5.2. Lab Bench

Use trays containing disposable absorbent materials to collect spilled liquids. Limit the quantity of radionuclide used. Place a protective screen around radiation sources, the bench and the areas where radioactive waste is placed. Mark the radioactivity symbol on radioactive product containers, also indicating:

- ✚ The nature of the radionuclide, its activity and the date of measurement.
- ✚ Use radiation dosimeters to check work areas, protective clothing and hands once work is completed.
- ✚ Use properly shielded transport containers

IV.6. Radioactive Waste

Frequently remove radioactive waste from the work area..

IV.6.1. Emergency Procedures

- ✚ Keep an accurate record of the use and disposal of radioactive products.
- ✚ Review dosimetric records to look for any possible exceeding of the dose limit for certain products.
- ✚ Develop action plans for emergency situations and conduct regular drills.
- ✚ In an emergency, first attend to the injured, thoroughly clean contaminated areas, if necessary seek assistance from security services, and write and file an incident report.



V. Chemical Risk

Work carried out in laboratories around the world continues to drive major scientific and engineering advances. Laboratories have become centers for the acquisition of knowledge and the development of new materials for future applications, as well as for the monitoring and control of chemical substances currently used in everyday life.

Most chemicals manufactured and used today are useful, but some can also endanger human health, the environment, and skew public perception of the usefulness of chemistry. Laboratories face a large number of threats; securing chemical products can mitigate this type of risk. A new culture of safety and safety awareness, the accountability it entails, its organization and learning have developed in laboratories that use chemical products, by developing special procedures and equipment for handling and managing these products in accordance with safety rules (Yang at al., 2022). The development of a safety culture results in promoting safer environments for teaching, learning and working (table 04) .

Table. 04. Different hazard classes (Persoons et al., 2005).

Symbol		Meaning & Use	Examples of Products	Safety Precautions
	Toxic	Fatal if swallowed, inhaled, or absorbed through skin.	Pesticides, methanol.	Wear gloves and protective clothing. Do not eat or drink while using. Wash hands thoroughly after handling.
	Irritant	Causes skin and eye irritation, dizziness, or allergic reactions.	Laundry detergents, antifreeze.	Use in well-ventilated areas. Avoid skin and eye contact.
	Flammable	Easily ignites when exposed to heat or flame.	Petrol, nail polish remover.	Keep away from heat and open flames. Store in cool, ventilated places.
	Explosive	May explode when exposed to heat or shock.	Fireworks, ammunition.	Handle with extreme care. Store in secure, designated areas.
	Corrosive	Causes severe skin burns and eye damage; may corrode metals.	Drain cleaners, strong acids.	Wear full PPE. Avoid direct contact with skin or eyes.
	Gas Under Pressure	Contains gas under pressure that may explode when heated.	Gas cylinders.	Store away from heat sources. Do not drop or mishandle cylinders.
	Health Hazard	May cause long-term health issues such as cancer or infertility.	Turpentine, benzene.	Use appropriate PPE. Avoid inhalation or skin contact.
	Oxidising	Can intensify fires or cause other materials to ignite.	Bleach, medical oxygen.	Keep away from flammable materials. Ensure good ventilation.
	Environmental Hazard	Very toxic to aquatic life and the environment.	Pesticides, turpentine.	Do not dispose of in drains or water sources. Follow proper disposal guidelines.

Laboratory work (whether research or routine) is associated with exposure to many chemical agents. Chemicals can cause fires and explosions with devastating consequences: injuries or deaths, property destruction, environmental pollution. Accidents (broken tubes, spills, handling errors...) can have more or less significant traumatic consequences for the individual, as well as an immediate risk of poisoning. The occurrence of a workplace accident may be indicative of dangerous situations (Leggett ; 2012). (explosion, ignition, heat release...) or of a toxic nature. Reactive chemicals are thus classified into different hazard classes: The use of reactive chemical products can lead to various risks of a physicochemical nature. The toxicity of a product also depends on the quantity introduced into the body (dose), the cumulative nature of doses or effects, the route of entry, the metabolic abilities of the individual, the condition of the subject and the circumstances at the time (fatigue, stress, etc.), and other products introduced into the body accidentally or otherwise (other toxicants, dietary habits, tobacco, alcohol, drugs, medications...) (Table 05).

Table 05. Mode of contamination of chemical products and prevention (Persoons et al., 2005).

MODE OF CONTAMINATION	CAUSATIVE AGENT	PREVENTION
Ingestion	Risk posed by: • Mouth pipetting • Improper use of gloves • Poor hygiene practices	• Do not eat, drink, or smoke in the laboratory • Wear gloves • Maintain strict hand hygiene • Use mechanical pipetting devices
Ocular Exposure	Risk posed by: • Splashes and aerosols	• Wear safety goggles • Avoid generating aerosols • Work under a fume hood or biosafety cabinet
Dermal Exposure	Risk posed by: • Splashes • Direct contact • Skin injuries	• Wear gloves • Avoid splashes • Protect damaged skin areas with appropriate dressings
Inhalation	Risk posed by: • Grinding and centrifugation procedures • Flaming and homogenization procedures	• Work under a fume hood • Centrifuge in sealed tubes or hermetically closed containers, then open them under a fume hood or BSC • Open ampoules under a fume hood or BSC

Before any handling, **it is essential to know the risks and precautions to take by reading** the Safety Data Sheets and, where applicable, the toxicological data sheets or at minimum the R & S risk phrases. There are nine pictograms, they consist of a black symbol on a white background within a red border thick enough to be clearly visible (Fig.09).

		
• Oxidizers	• Flammables • Self Reactives • Pyrophorics • Self-Heating • Emits Flammable Gas • Organic Peroxides	• Explosives • Self Reactives • Organic Peroxides
		
• Acute Toxicity	• Corrosives	• Gases Under Pressure
		
• Carcinogen • Respiratory Sensitizer • Reproductive Toxicity • Target Organ Toxicity • Mutagenicity • Aspiration Toxicity	• Irritant • Dermal Sensitizer • Acute toxicity (harmful) • Narcotic Effects • Respiratory Tract • Irritation	• Environmental Toxicity

Fig. 09. Hazard pictograms (Persoons et al., 2005).

V.1. Major Components of Chemical Risk

For frontline experimental personnel and laboratory administrators, the paramount task is to identify potential hazardous factors and conduct comprehensive risk assessments. This encompasses understanding the properties of various chemicals, the risks associated with the use of experimental equipment, and the unexpected incidents that may arise during experimental procedures. Subsequently, based on the assessment outcomes, targeted management measures should be formulated and implemented, such as refining experimental operation processes, upgrading safety equipment, and enhancing safety training (Chandra et al. , 2016).

This holistic risk management strategy is crucial for mitigating risks, ensuring the safety of laboratories and personnel, and forming the foundation for maintaining the normal functioning of laboratories and the smooth progression of scientific research. According to aspects such as the sources, nature, and destructiveness, the concealed hazards in chemical laboratories can be classified into the following categories (Table 06).

Table 06. The different types of hazards and corresponding risks (Kong at al., 2022)

Types of Hazards		Characteristics and Risks
Chemical hazards	Flammable and pyrophoric substances	These reagents can spontaneously ignite when exposed to air or water; improper storage or use may lead to fires.
	Toxic reagents	Exposure to toxic substances can result in acute or chronic health hazards, potentially leading to pain, liver and kidney damage; certain special reagents may even be carcinogenic, teratogenic, have reproductive or cumulative toxicity.
	Corrosive substances	Contact with such substances may cause harm to the skin and mucous membranes, leading to skin corrosion, edema, or congestion.
	Allergens	Such substances may cause allergic reactions in certain individuals, leading to symptoms such as itching, swelling, and subcutaneous bleeding.
	Psychoactive substance	These substances directly act upon the central nervous system, causing either stimulation or inhibition, and their continuous use can lead to dependence.

V.1.1. Hazard

A hazard is defined as the inherent capacity of a chemical substance or a mixture of chemical substances to cause adverse effects on humans or the environment under specific exposure conditions. The effects or damage caused by a chemical substance or mixture can be of various types. In humans, they may affect reproductive or neurological functions, or induce cancer, for example. In the environment, these effects may result in mortality or growth disturbances in animal and/or plant populations. Hazard characterization is carried out through the study of the behavior and interactions of the chemical substance or mixture at the level of the organism, tissues, cells, and genetic material.

V.1.2. Exposure

The concept of exposure can be simply defined, as suggested in a report by the Institute for Environment and Health (UK), as the 'contact between a chemical substance and a population

or an individual over time.' This definition calls for another, that of the 'exposure assessment' principle, which helps to understand the complexity of the exposure concept and its implications for measurement methods. The Risk Assessment Toxicology Steering Committee proposes the following definition: the quantification of the level of a chemical substance to which human populations, subpopulations, and individuals are exposed in terms of intensity, duration, and frequency. It involves measuring the quantities of substances and their transformation or degradation products in order to estimate the concentrations/doses to which human populations or environmental compartments are, or may have been, exposed (Fig. 10).

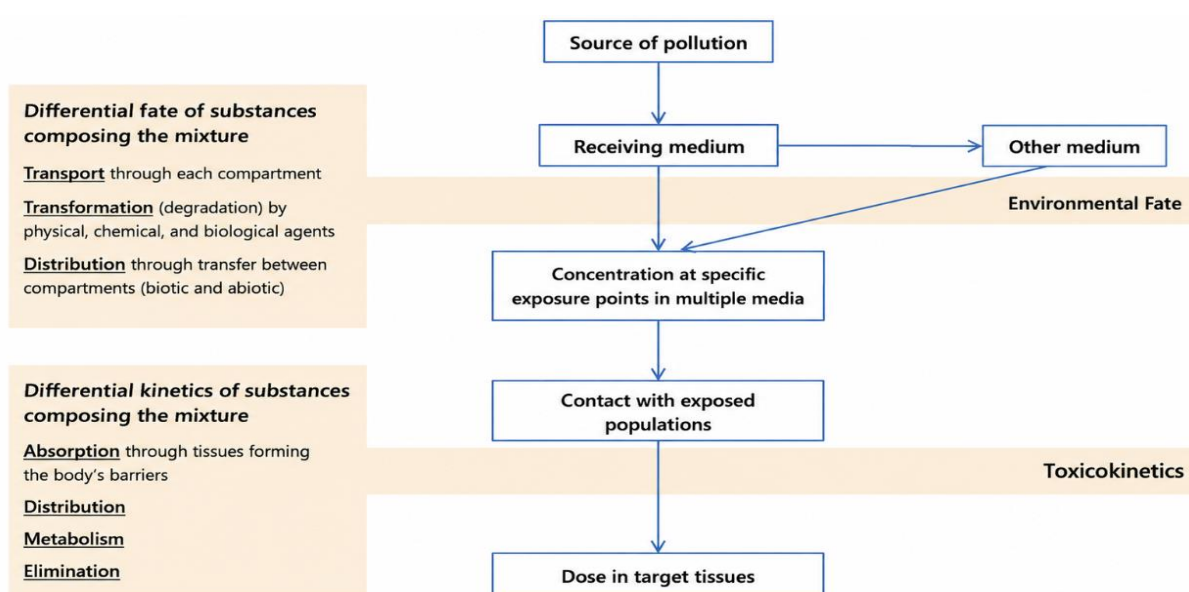


Fig. 10. Schematic representation of the concepts of substance fate and exposure to an organism in the environment, adapted from (Rice MacDonell et al., 2008).

Exposure models can be grouped into different categories: Exposure assessment related to modes of contact — these models focus on the modes of contact of the individual with the substance (route of exposure), including ingestion, inhalation, and dermal contact.

Chemical risk is therefore the combination of the potential hazard of a substance, an intrinsic characteristic, and its exposure to the environment or a living organism. Risk assessment therefore corresponds to the assessment of the magnitude of damage suffered by an environment or an organism, and thus constitutes an identification of the impact of the substance on the environment or organism. From a societal perspective, chemistry has

accompanied human evolution since antiquity and has experienced exponential growth since the 19th century. Therefore, the necessity of understanding chemical risk through science, and regulating it through law, has become essential.

V.2. Laboratory Work and Chronic Health Effects

Injuries are more or less severe depending on the nature of the product, its concentration, the duration of contact and its location. Bases penetrate tissues more deeply than acids. Damage from burns caused by alkaline solutions is therefore potentially greater (particularly for the eyes). There are also specific dangers associated with certain types of acids (hydrofluoric acid and hypocalcemia, for example). It should be noted that vapors from strong acids containing sulfuric acid are classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC).

In the event of an accident, the major risk is acute poisoning. The effects and severity of the poisoning depend on the nature and amount of the substance, making it impossible to compile an exhaustive list of the resulting symptoms. Acute effects include skin irritation and respiratory or ENT (Ear, Nose, and Throat) irritation, which can progress to acute pulmonary edema with Acute Respiratory Distress Syndrome (ARDS). The risks associated with high exposure to solvents (via dermal, respiratory, or digestive routes) depend on the severity of the poisoning. Most solvents are, to varying degrees, irritating to the skin and mucous membranes. Inhaling concentrated solvent vapors can cause irritation of the upper airways. Furthermore, the combustion of chlorinated solvents (such as chloroform) releases caustic gases such as hydrochloric acid and phosgene. At a higher intensity, inhaling solvents can cause nervous system damage with ebrio-narcotic symptoms

In cases of massive inhalation, disturbances of consciousness may occur. There are toxicities specific to each family of solvents (chlorinated and fluorinated solvents and cardiac arrhythmia, methanol and optic neuritis...). Allergic effects also exist in the form of hives, eczema and asthma for many products. These effects depend on the individual's predisposition but also on working methods and the individual's exposure to the product. Chronic poisoning results from prolonged or repeated exposure to low doses of a product. Disorders develop slowly: respiratory difficulties, fatigue, nervous, digestive, and blood disorders...etc.

The most commonly used products in laboratories, in addition to acids and bases, are solvents. Regular exposure to one or more solvents can, in the more or less long term, cause often irreversible damage to target organs. Penetration into the body occurs through the skin and respiratory tract. Poisoning via the oral route is exceptional in a professional setting (accident or suicide). Some effects are common to most solvents, while others are specific to certain substances. In terms of skin effects, solvents can cause irritation and dermatitis; but they can also cause neurological damage of the type of organic solvent psychosyndrome (fatigue, sleep disorders, difficulty concentrating, memory loss, mood disorders, depression, impairment of cognitive functions). Some may be responsible for neuropathies (hexane). Hematological damage is also described for benzene and certain glycol ethers. Finally, since solvents are partly metabolized by the liver and eliminated by the kidneys, these organs are prime targets. Solvents cause kidney and liver damage, which must be prevented.

V.3. Laboratory Work and Cancer Risk

In addition to these short-term effects, which generally have an easily identifiable cause, the occurrence of long-term effects (ophthalmological, respiratory, renal, hematotoxic, hepatotoxic) must be prevented.

Some products handled in laboratories are known or suspected to be carcinogenic, mutagenic or teratogenic. These include chemical agents (solvents, alkylating agents, intercalating agents, aromatic amines, hormones, heavy metals...), biological agents (hepatitis B and C viruses, HTLV virus, mycotoxins, genetically modified organisms) and radioactive compounds (radioisotopes, ionizing radiation).

Multiple simultaneous exposures to several chemical substances, as well as to biological and physical agents, are not uncommon

Most of the knowledge comes from historical occupational cohorts conducted over the past 20 years. The literature reviewed includes studies specific to research and biology laboratory workers; all epidemiological studies reviewed face methodological difficulties in assessing exposure. Laboratory personnel are exposed to a wide variety of chemical agents and at different levels of exposure. This explains why no study has quantified specific exposures. Exposure is estimated based on the job title of the individuals studied. Case-control studies, in which the cancer exposure of cases is compared to the exposure of controls to estimate the relative risk associated with these exposures, are rare.

Most authors note the significantly elevated frequency of cancers of hematopoietic tissues in laboratory personnel. Among other locations, brain, prostate, pancreatic and colon cancers are noted. There is also a significantly elevated frequency of breast cancers and malignant melanomas; the socio-occupational characteristics of this population may be a possible explanation.

V.3.1. Carcinogenic Substance

A carcinogenic substance is a substance or agent that can cause cancer or increase the risk of cancer. Known carcinogenic substances include viruses (hepatitis B virus), hormones (estrogens), chemicals (benzene), natural minerals (asbestos), alcohol and solar radiation (ultraviolet radiation)..

Warning: CMR Products!

Ethidium Bromide (EtBr) is labeled, depending on the safety data sheets (SDS) of different suppliers, as R40 (limited evidence of a carcinogenic effect), and/or R46 (may cause heritable genetic damage), and/or R68 (possible risk of irreversible effects, risk during pregnancy of adverse effects for the child).

Protective equipment: lab coat and over-coat, nitrile gloves, follow the recommendations below

Physical risks: skin and especially eye burns from UV, cuts from scalpel blades.

Recommendations :

- Use nitrile gloves to handle EtBr as it passes through latex gloves;
- When placing your gel for staining in the EtBr bath, be careful not to splash the bench and always replace the lid on the bath; never put your hands in the bath to retrieve your gel (even with gloves), tools are available for this purpose
- If the staining of the gel in EtBr seems insufficient after 15 to 20 minutes in the bath, do not touch the bath but ask the responsible permanent staff member to take care of it;
- Visualizing a gel using the BioPrint system: the UV lights remain on when you open the door, so a protective face shield must be worn;
- To visualize a gel using the UV transilluminator (UV table), always lower the glass shield over the table before turning on the UV lights, and turn them off before lifting

it. If you need to cut your gel with the UV lights on and the shield raised, you imperatively must wear the anti-UV protective face shield. Under no circumstances forget to lower the shield or wear the anti-UV face shield when looking at or cutting the agarose gel on the UV table, as you risk severe eye burns. Since gloves become contaminated with EtBr while handling the gel, always handle the face shield by the outside to avoid contaminating the inside (face side).

- After handling, clean the glass of the UV plate with water only (absolutely no alcohol!).

Waste Management:

- Solid waste contaminated with EtBr (agarose gels, gloves, paper) must be disposed of in the solid EtBr waste bin (white bucket)
- Do not pour any liquid containing EtBr (TBE or TAE from electrophoresis tanks, EtBr staining liquid, gel rinsing bowl water) down the sink. These liquids must be emptied into the large carboy reserved for this purpose, located under the benchtop, using the funnel."

V.4. Chemical mutagens

Chemical mutagens are substances that cause permanent changes in the DNA sequence of a cell. These changes, known as mutations, occur when a chemical alters the genetic code that cells use to grow, function, and reproduce. DNA contains the instructions that guide cellular processes. When a chemical mutagen interferes with this genetic information, it can alter DNA in several ways, including:

- changing individual DNA bases
- inducing DNA adducts
- causing strand breaks
- interfering with DNA repair enzymes
- inserting or deleting sections of genetic code
- disrupting how DNA is copied during cell division

If these changes are not repaired by the cell, they become permanent mutations. Some chemical mutagens act indirectly, requiring metabolic activation to form reactive species that

interact with DNA. While all mutagens are genotoxic, not all genotoxic substances cause gene mutations; some act primarily by inducing chromosomal damage or numerical chromosome changes.

V.4.1. Chemical mutagens, genotoxic substances and carcinogens

Chemical mutagens are closely related to two other important toxicological concepts: genotoxicity and carcinogenicity. While these terms are sometimes used interchangeably, they describe different types of hazards.

- **Chemical mutagens** are closely related to two other important toxicological concepts: genotoxicity and carcinogenicity. While these terms are sometimes used interchangeably, they describe different types of hazards.
- **Genotoxic substances** are chemicals that damage genetic material more broadly than chemical mutagens do. This damage can include DNA strand breaks, chromosomal abnormalities, or interference with DNA replication or repair processes. Some genotoxic effects lead to mutations, but others may not result in permanent DNA sequence changes.

In other words, **mutagenicity is a subset of genotoxicity**. All chemical mutagens are genotoxic, but not all genotoxic substances are mutagenic. For a broader explanation of how chemicals damage genetic material, see our article on Genotoxicity explained.

- **Carcinogens** are substances that can cause cancer. Some carcinogens act by causing mutations in DNA, which can trigger uncontrolled cell growth. However, other carcinogens cause cancer through non-genotoxic mechanisms, such as chronic tissue damage, inflammation or hormonal disruption. Learn more about how carcinogens are classified and assessed in chemical hazard frameworks.

Because these concepts overlap, regulators evaluate mutagenicity, genotoxicity, and carcinogenicity as distinct but complementary endpoints when assessing chemical hazards. Understanding the distinctions helps scientists determine the hazard associated with a chemical and how it should be classified, labelled, and controlled.

V.5. Risk or danger? Strategies for managing flammable products

Laboratory safety is an absolute priority, especially when handling flammable liquids. Understanding the difference between "risk" and "danger" is essential to ensure a safe and efficient working environment. A "danger" is a potential source of harm, while "risk" is the probability that harm will occur under certain circumstances.

Identifying and Assessing Dangers

The first step in managing flammable liquids is to identify and assess their dangers. Every substance must be properly labeled and accompanied by a Safety Data Sheet (SDS) that describes its characteristics and associated risks. It is crucial that all personnel are adequately trained and aware of the properties of each chemical substance used.

Prevention and Control Measures

We at Labor Security System are professionals in producing cabinets for chemical products. For many years, we have created safe and innovative solutions for storing flammable liquids, and we can certainly offer some good advice to improve laboratory safety. First, dangers must be identified, then prevention and control measures must be implemented to minimize risks.

Here are some key measures:

1. **Adequate Ventilation:** Ensure that the laboratory is equipped with an effective ventilation system to prevent the buildup of flammable fumes.
2. **Safe Storage:** use certified Labor Security System cabinets for storing flammable liquids, to ensure optimal protection against sources of heat and sparks.
3. **Use of PPE:** Wear personal protective equipment (PPE) such as gloves, safety glasses, and liquid-resistant lab coats.
4. **Emergency Procedures:** Have well-defined and easily accessible emergency plans in case of fires or accidental spills.

Training and Awareness

Continuous training is crucial to ensure that all workers are up to date on best safety practices. Regular refresher courses and emergency simulations can increase personnel awareness and

readiness. Managing flammable liquids in the laboratory requires a systematic and proactive approach.

Identifying dangers, implementing effective control measures, and ensuring continuous training are key elements to minimize risks. To help create a safe and productive work environment, Labor Security System has developed a wide range of safety cabinets suitable for every context and need.

V.6. Corrosive Chemicals

This guideline identifies general safety precautions that should be reviewed and followed when dealing with corrosive chemicals at Brandeis. They represent a significant hazard because skin or eye contact can readily occur from splashes, and their effect on human tissue generally takes place very rapidly.

Examples

Glycolic acid, Imidazole, 4-Methoxybenzylamine, Sodium hydroxide, Amines, Sulfuric acid, Bromine, Hydrogen peroxide

➤ How to protect?

Eye Protection

Safety glasses that meet the ANSI Z.87.1 1989 standard should be worn whenever handling corrosive chemicals. Ordinary prescription glasses will not provide adequate protection unless they also meet this standard. Safety glasses should also be equipped with side shields if there is a possibility of flying particles (i.e., glass, plastics).

Skin Protection

Gloves should be worn when handling corrosive chemicals. Nitrile gloves should be adequate for handling most of these in general laboratory settings. An MSDS should be reviewed if handling may involve extended or high exposure to lab personnel to ensure adequate skin protection is provided. In addition, a lab coat or apron is advised if exposure could involve more than normal handling operations would be expected. No open-toe shoes are allowed.



VI. Biological Risks

Biology laboratories, particularly those specializing in Molecular Biology, play a crucial role in scientific research, diagnostics, and biotechnological development. However, the manipulations performed in these laboratories whether involving microorganisms, cell cultures, or genetic material expose researchers to potential biological hazards. These risks can have consequences for the health of personnel, the environment, and sometimes even the general population, in the event of mismanagement or failure of safety measures. Biosafety involves the implementation of a number of containment principles, techniques and practices aimed at preventing the accidental exposure of personnel to pathogens or toxins, or the release of such substances. Biosecurity involves the establishment of administrative and personnel management measures to reduce the risk of loss, theft, misuse, diversion or deliberate release of agents or toxins. The true foundation of biosecurity lies in the application of biosafety practices in the laboratory.

VI.1. Biological Risk Assessment

How can we ensure a safe working environment to protect students, technicians, researchers, and the environment from biological hazards?

Biological risk is defined as the probability that exposure to a biological agent will cause an adverse effect, such as an infection, allergy, or intoxication. Given these dangers, it is essential to implement rigorous procedures for risk assessment, prevention, and biosafety, in accordance with international standards (WHO, European Union, etc.). This chapter aims to present the main steps in biological risk assessment, prevention and biosafety measures, safe laboratory practices, and the classification of biological agents according to their risk level. Particular attention will be paid to the management of biological waste and genetically modified organisms (GMOs), which are frequently used in molecular biology laboratories.

Biological risks are difficult to assess given that animals captured in the field are potentially infected with various parasites (nematodes, viruses, bacteria...) and that the risks to humans are not known a priori. Regardless, it is imperative to comply with certain preventive rules.

Many work activities include hazards to workers, and among these biological risk is particularly important, mostly because of different types of exposure, contact with highly dangerous agents, lack of limit values able to compare all exposures, presence of workers with defective immune systems and therefore more susceptible to the risk. Bioaerosols and dust are considered important vehicles of microorganisms at workplaces and interaction with other occupational agents is assumed. Moreover, biological risk can be significant in countries with increasing economic development or particular habits and some biological agents are also classified as carcinogenic to human. Specific emerging biological risks have been recently pointed out by Risk Observatory of the European Agency for Safety and Health at work, and we must consider the worker's attitude and behavior, influenced by his own perception of risk more than his real knowledge, that could over-underestimate the risk itself. Therefore, biological risk at work requires a complex approach in relation to risk assessment and risk management, made more difficult due to the wide variety of biological agents, working environments and working techniques that can determine the exposures. (Corrao, Candal. 2012) (Fig. 11).



Fig. 11. The risk assessment framework. (EDITION, 2020).

VI.1.1. Prevention of Biological Risk

- Protective equipment must be used mandatorily in order to limit the risks of disease transmission from animals to humans. They include: lab coat, gloves, protective goggles, and a mask.
- Handling must take place in a suitable room, isolated from the rest of the laboratory. Indeed, it is preferable that sampling be carried out outside the Molecular Biology laboratory. Contaminated waste must be disposed of in appropriate bins: sharps boxes for needles and sharp objects, incinerator for biological waste.

VI.1.2. Biosafety

Research work involving the handling of biological material can present a risk of infection or contamination for the individual, but also for the community and the environment. The use of infectious substances requires the implementation of several control measures, such as regulations, safe working methods, and specialized equipment. These measures aim to ensure protection against pathogens, toxins, and infected animals (Fig. 12)

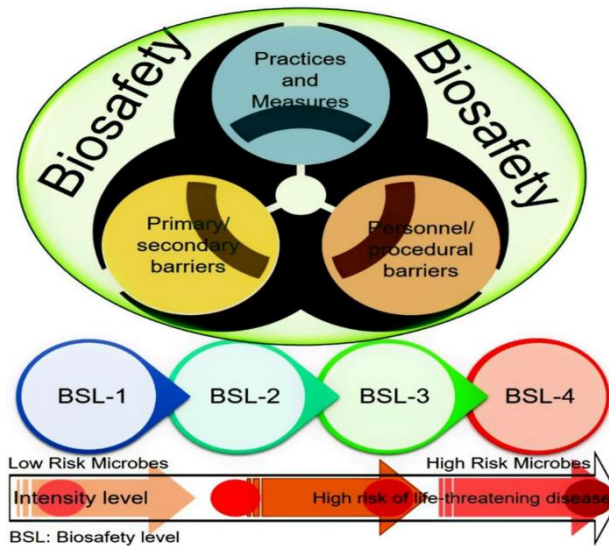


Fig 12. Schematic representation of a biosafety concept and four biosafety levels (BSLs) with their risk intensity (Peng et al., 2018).

VI.1.3. Infectious Substances

Infectious substances are categorized into four risk groups based on their toxicological properties on the individual and the community within a laboratory handling context. Risk factors include pathogenicity, infectious dose, mode of transmission, host range, and the availability of effective preventive measures and treatments. They can enter the body through four routes :

- ✚ Inhalation in aerosol form (the most significant route of infection)
- ✚ Skin or eye absorption
- ✚ Ingestion
- ✚ Injection (accidental) from needle sticks or soiled sharp objects

Unlike chemical risks, where the effect of a product generally depends on the dose, a small amount of biological material can multiply within the host and have adverse effects on it or the environment. (Fig. 13)

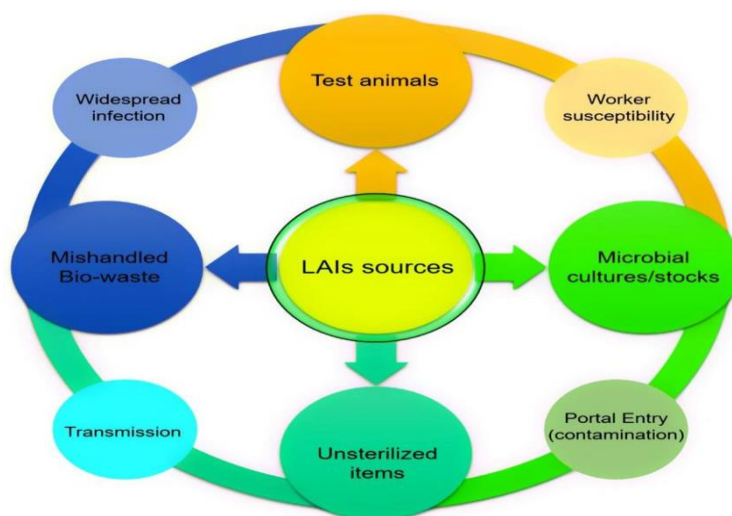


Fig.13. Sources of laboratory-acquired infections : the outer circle shows a possible chain of infection transmission (Peng et al., 2018).

VI.2. Safe Laboratory Practices

Laboratory safety requires awareness of the potential hazards associated with handling hazardous materials, knowledge of exposure mechanisms, and the use of protective equipment and techniques that minimize the likelihood of exposure. This includes disinfecting work surfaces, materials, and equipment before washing and after each workday. Safe practices also encompass technical procedures to reduce exposure to hazards, such as slow handling to avoid aerosols, prohibiting food consumption, containing work under biosafety cabinets, adhering to procedures in case of equipment failure or accident, and vigilance against intrusion and error. The risk assessment used to determine the categories of experiments assigned to each containment level, and to select safe laboratory practices, containment equipment, and protective equipment for facilities that describe the safety requirements for each level, is based on scientific knowledge and experience gained in laboratories. Many routine laboratory processes can easily become sources of infection, necessitating vigilance to prevent intrusion and error (Barkley et al., 2007) (Fig. 14).



Fig. 14. Lab safety protocols (Shutterstock ; 2021).

All laboratories involving work of a biological nature must adhere to basic good practices. In addition to the principles mentioned in the section on Good Laboratory Practices, the following can or must be included:

- Handle all body fluids and blood products as if they were infectious. Never minimize danger.
- Never mouth-pipette.
- Protect open wounds, scratches, and others with a waterproof bandage.
- Contaminated clothing must be decontaminated.
- Limit the use of sharp or puncturing objects.
- Work surfaces, materials, and equipment must be decontaminated before being washed, and this must be done after each workday.

VI.2.1. Decontamination

The decontamination of laboratory material, equipment, and work areas allows for the control of accidental pathogen release into the community or environment, as well as protecting its users. It is essential to use effective decontamination methods before disposing of or reusing material. This can be done by sterilization (autoclave) or disinfection.

Laboratory disinfection procedures are an essential component of biosafety protocols. This process involves the systematic cleaning and disinfection of all work surfaces, equipment, and frequently touched areas to eliminate any potential biological hazards. The first step in disinfecting surfaces involves removing visible dirt and organic materials using appropriate cleaning products. This is followed by the use of chemical disinfectants that are effective against the specific pathogens that are dealt with in the laboratory, such as sodium hypochlorite (bleach), hydrogen peroxide, and quaternary ammonium compounds. The choice of disinfectant depends on factors such as the type of pathogens present, material compatibility, and the duration of contact required for effective disinfection.

VI.2.2. Management of Biological, Cytotoxic, and Pharmaceutical Waste

The disposal of biological, cytotoxic and pharmaceutical waste is subject to specific rules on a weekly basis or upon request during periods of reduced activity. This waste is generally managed by a specialized company. No recycling is possible; waste is either incinerated or disinfected by autoclave and landfilled.

-  **Animal anatomical waste** is disposed of frozen in specific containers (fiber boxes or barrels with two plastic bags), clearly labeled and bearing the word "Incinerate"..

-  **Preservation liquids for animals**, vertebrates, and invertebrates must be separated from the specimens by collecting them in a labeled container carrying the description of the supplier's preservative and ensuring an available SDS; these fluids will be treated as chemical residues. Animal specimens, vertebrates and invertebrates, without their preservation liquids, will be treated as animal anatomical waste..

-  **Non-anatomical waste** (sharp, puncturing, or soiled objects; biological tissues, cell cultures, or material that has been in contact with them; live strain vaccines; blood or soaked material) is disposed of in special containers, as appropriate (plastic bin,

cardboard box); they will be autoclaved and landfilled or incinerated. Liquid waste that can be chemically or thermally decontaminated and no longer falls into hazard categories can be discharged into the environment.

- ✚ **Non-anatomical waste from the microbiology teaching sector** (agar, culture media) must be autoclaved and disposed of at the local landfill site; a log with the date, description, and weight must be maintained for statistical compilation and to meet a regulatory requirement.
- ✚ **Pharmaceutical waste** includes drug residues (non-toxic, toxic, and cytotoxic), products used for the preparation or administration of drugs, as well as certain hazardous products. Containers that enclose or have come into contact with a pharmaceutical product fall into this category. These products must be identified by a visible label, such as this one on the container.
- ✚ **Expired or discarded controlled drugs** (e.g., narcotics) are also pharmaceutical products that must be kept in a registry with their residual volumes and kept under lock and key until they are collected. They will be incinerated at high temperatures.
- ✚ **Cytotoxic waste** consists of expired or discarded drugs, as well as their containers, whose role is to inhibit or prevent the proper functioning of cells. They are mainly used to treat cancer, often as part of chemotherapy. These drugs sometimes treat specific diseases. These drugs are used on animals or culture media. They will be incinerated at high temperatures and must bear this label on the collection container.

VI.3. Biological Agents and Risks

Workers can be exposed to five types of risks related to biological agents. The table defines these types of risk and provides the various associated symptoms. Pathogenic biological agents: microorganisms, including genetically modified microorganisms, cell cultures, and human endoparasites capable of causing infection, allergy, or intoxication (table 07).

Table 07. Types of Risk Related to Biological Agents (CNRS, 2017)

Types of risks related to biological agents	Definition	Examples of diseases and symptoms
Infectious risks	Infections due to the intrusion and multiplication of a biological agent in the body. This is the most common risk in the workplace	Tuberculosis, Hepatitis B, Pneumonia, Skin lesions, Tetanus, Aspergillosis
Immuno-allergic risk	Reaction of the immune system to a biological agent (molds).	Rhinitis, Asthma, Pneumopathy, Various allergic reactions
Intoxication risks	Intoxication that occurs through exposure to a toxin produced by a biological agent (e.g., <i>S. chartarum</i> (mold), <i>E. coli</i>).	Fever and body aches, Respiratory failure, Digestive reactions (nausea, diarrhea)
Carcinogenic risk	Cancerous tumors caused by the disordered multiplication of cells when the biological agent comes into contact with the body (e.g., Hepatitis B and C viruses).	Liver cancers, Other cancers
Infestation risks	Invasion of the organism by parasites (e.g., scabies, lice, bedbugs, fleas).	Skin lesions, Itching

VI.3.1. Classification of Biological Agents (Natural Microorganisms)

A microbiological entity, cellular or non-cellular, capable of replicating or transferring genetic material. Cell culture: the result of the *in vitro* growth of cells isolated from multicellular organisms. This classification concerns bacteria, viruses, parasites, and fungi. They are divided into four groups according to their pathogenicity and the existence or absence of effective prophylaxis or treatment. Knowledge of biological agents and their classification determines prevention rules, notably biosafety levels 2, 3, or 4 required for their handling. Furthermore, certain pathogenic biological agents are associated (or suspected to be

associated) with the occurrence of certain cancers. These agents have been classified by the International Agency for Research on Cancer (IARC) based on their carcinogenic effect in humans.

VI.3.2. Biological risks (pathogenic bacteria and viruses)

VI.3.2.1. Pathogenic bacteria

Pathogenic microorganisms represent only a small proportion of the biological hazards of concern in laboratory investigations. Their control importance is based on their potential threat to humans, animal populations, and also agriculture. In addition, they can be responsible for large-scale infections with huge economic costs and environmental consequences (Bosia, 2008). In addition, new viruses are constantly emerging that threaten the lives of humans and animals. All laboratory staff who work with biological samples are exposed to a number of infectious materials and subject to risk from clinical specimens and cultures. Since hazardous agents can be transmitted in the laboratory by inhalation, inoculation, or through the skin, among others, it is necessary to know the characteristics of the agents in study according to their risk to the health of laboratory staff, and to the human and animal population in case of an outbreak (Corrao et al., 2012).

The World Health Organization developed a system to classify microorganisms based on their danger to laboratory staff and the public. Biological agents of risk group 1 include those unlikely to cause disease in man, biological agents of risk group 2 include those that can cause disease in humans and pose a danger for workers with little chance of spreading among them or to the community. In addition, there is prophylaxis and effective treatment available to the community. Biological agents of risk group 3 include those that can cause serious illness in humans, represent a serious danger to workers with risk of spreading to the community, and there is an effective treatment or prophylaxis. Finally, the biological agents of risk group 4 include those that can cause severe disease in humans and represent a serious danger to workers, with likelihood of being spread to the community and there is usually no effective prophylaxis or treatment (WHO, 2004).

However, there are other biological risk classifications by country, based mainly on national policies. In the European Union, Directive on the protection of workers from risks through

exposure to biological agents, the agents are classified into four risk groups based on the risk level of infection. In the United States, biological hazards are also classified into four risk groups, from minimal hazard (risk group 1) to those responsible for very serious diseases (risk group 4), as described by the Centers for Disease Control and Prevention (CDC) (Center for Disease Control and Prevention). In other countries such as Canada or Australia, pathogenic agents are also classified into four risk groups.

VI.3.2.2. Virus

Today, virus research is associated with wide applications, such as viral diseases, new vaccines, or GMOs. The potential risk with virus has been previously described regarding vaccine production, GMOs, or xenotransplantation. Research about LAI via virus is scarce, although infections with human immunodeficiency haemorrhagic virus, West Nile Virus, Dengue, or Marburg virus, among others, have been. Thus, appropriate biosafety and biosecurity measures, immune control strategies, training and education, and specific laboratory facilities are necessary to decrease the potential risk of LAIs and/or viral outbreaks (Gaidamovich al.,).

VI.3.3. Cell Cultures

The risk can come from the cells but also from the techniques related to their culture (medium, immortalization, quantities used...). The risk presented by primary cultures is very comparable to that of biological samples: an example is the risk related to the presence of contaminating pathogenic microorganisms. The risk of cell lines is that of accidental re-implantation in the handler, thereby inducing the development of a tumor.

VI.3.4. Genetically Modified Organisms (GMOs)

These are living organisms whose genetic material has been modified in a way that does not occur naturally by multiplication and/or natural recombination. Like natural biological agents, GMOs are classified into 4 groups based on the risks they present to public health or the environment. Each group defines the containment class (in its guidelines, the High Council of Biotechnologies uses the term "containment" rather than "biosafety level") in which the GMO must be handled. The 4 classes of biosafety level (C1 to C4): Class C1 covers operations

using Group I GMOs with zero or negligible risk to human health and the environment. Class C2 covers Group II GMOs with low risk. Class C3 covers Group III GMOs with moderate risk.

Evaluation of the hazard of a GMO

The hazard evaluation of a GMO must take into account the hazard of each element of the triad: recipient or host organism, vector, insert. In the event that risk levels differ between the recipient, vector, and insert, the highest risk level is retained. However, the evaluation of the hazard conferred by a construct is not necessarily a simple juxtaposition of the hazards presented by its components: the combination of the three elements of the triad can indeed cause an increase or a decrease in the hazard

Recipient Organism

A non-pathogenic recipient organism may become hazardous after the introduction of an exogenous sequence (e.g., the sequence may enable toxin expression or modify organism characteristics such as increased environmental survival). In most cases, a pathogenic recipient organism remains pathogenic. The hazard of viral vectors relates to their potential capacity to integrate into the host cell genome, recombine with host sequences, or be complemented by host sequences.

Insert

The inserted sequence, if it poses no hazard, is referred to as category A. It belongs to category B if it can be a hazard factor: DNA encoding a biologically pathogenic protein (toxin, etc.), DNA derived from a pathogenic microorganism, or DNA whose expression is directly linked to the cell immortalization mechanism or capable of increasing the expression, integration and/or replication capacity of the vector.

References

- AFNOR, N. (2004). X50-151,” Value management and its tools, functional analysis, value analysis, design for objective design”, French National Standards, Ed.
- Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts, and J.D. Watson. Molecular Biology of the Cell, 3rd. Garland Publishing Inc., New-York, 1994.
- Ariane, F. Environmental Protection Review Report: Cameco Fuel Manufacturing
- Boucher, M., Deguire, S., Giroux, D., Malo, S., & Fleury, N. (2002). Health and safety guide for laboratories. (4th ed.). Montreal: Quebec Order of Chemists.
- Boucher, M., Deguire, S., Giroux, D., Malo, S., & Fleury, N. (2002) Health and Safety Guide for Laboratories. (4th ed.). Montreal: Quebec Order of Chemists.
- Carbonneau, S., Tremblay, D., & Sévigny, C. (2014). Guide des bonnes pratiques de laboratoire en cytologie. Association des cytologistes du Québec.
- CEA-LNHB (2016). Radiation-matter interactions. http://www.nucleide.org/Gamma_spectro/interactions.htm.
- Center for Disease Control and Prevention (CDC). (2009). “Section II—Biological Risk Assessment,” in Biosafety in Microbiological and Biomedical Laboratories, 5th Edn, eds Chosewood L., Wilson D. (Washington, DC: U.S. Government Printing Office;), p. 10–13.
- Chaffey, N. (2003). Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P. Molecular biology of the cell. 4th ed.
- Chandra, T.; Zebrowski, J.P. Hazards associated with laboratory scale hydrogenations. J. Chem. Health Saf. 2016, 23, 16–25.
- Collins, C., Fryer, M., & Grosso, A. (2006). Plant uptake of non-ionic organic chemicals. *Environmental science & technology*, 40(1), 45-52.
- Corrao C. R. N., Mazzotta A., Torre G. L., Giusti M. D. (2012). Biological risk and occupational health. Ind. Health 50, 326–337 10.2486/indhealth.MS1324
- EDITION, F. (2020). *Laboratory biosafety manual fourth edition*.
- Eisenstein B, (1990) The polymerase chain reaction: a new method of using molecular genetics for medical diagnosis. N Engl J Med 322: 178–183. Nouvelles techniques de biologie moléculaire
- Fleming, D. O., & Hunt, D. L. (2006). Biological safety: principles and practices (No. Ed. 4). ASM Press.

Geneva, 2005, ISBN 92 4 254650 X, 219 pages. <https://www.who.int/csr/resources/>

Good laboratory practice training manual for the trainee: a tool for training and promoting good laboratory practice (GLP) concepts in disease endemic countries 2 ed (2008)

Harkness-Brennan, L., D. Judson, A. Boston, H. Boston, S. Colosimo, J. Cresswell, P. Nolan, A. Adekola, J. Colaresi, J. Cocks, and W. Mueller (2014). An experimental characterisation of a broad energy germanium detector. *Nuclear Instruments and Methods in Physics Research, Section A : Accelerators, Spectrometers, Detectors and Associated Equipment* 760, 28–39.

Inc. 2016.

J. L. (2012). Radiological risk in post-accident situations - Guide to good practices for radioactivity measurement laboratories.

Jacob, F. (1976). *The Logic of Life*, coll. Tel, Gallimard editions, Paris.

L'Annunziata, M. F. (Ed.). (2012). *Handbook of radioactivity analysis*. Academic press.

Leggett, D.J. Identifying hazards in the chemical research laboratory. *Process Saf. Prog.* 2012, 31, 393–397.

Leleu, J., & Triolet, J. (2002). Dangerous chemical reactions. (INRS) National Institute for Research and Safety. Retrieved from www.inrs.fr.

Maisant, S. C., Hasni-Pichard, H., Langrand, J., Cavezza, S., Villa, A., & Garnier, R. (2015). Chemical risk assessment resulting from accidental contamination of a biology laboratory. *Archives of Occupational and Environmental Diseases*, 76(3), 262-268.

Norme internationale ISO 15189, 2007, relating to specific requirements concerning quality and competence in medical biology analysis laboratories

OMS (2005). *Laboratory Biosafety Manual* (3rd ed.). World Health Organization. Retrieved from www.who.int/fr/

Peng, H., Bilal, M., & Iqbal, H. M. (2018). Improved biosafety and biosecurity measures and/or strategies to tackle laboratory-acquired infections and related risks. *International journal of environmental research and public health*, 15(12), 2697.

Persoons, R., Dumas, L., Bonnetterre, V., Dumas-Kern, A., Stoklov, M., & Maitre, A. (2004). New methodology for assessing chemical risks: application in hospital laboratories. *Archives of Occupational and Environmental Diseases*

Persoons, R., Dumas, L., Stoklov, M., & Maître, A. (2005). Development of a new method for assessing chemical risks: application in hospital laboratories. *Archives of Occupational and Environmental Diseases*, 66(4), 326-334.

Peter Galison, *Image and Logic. A material Culture of Microphysics*, Chicago, University of Chicago Press, 1997.

Piccolo, j. L., Demongeot, s., Girard, v., Quinio, c., Scapolan, s., & Tillie, Publications/biosafety/labbios-man3rdfrenchweb.pdf

Reidy, J.; Guzman, J.; Vleck, S.; Ahmad, I.; Patel, H. Addition to “A Laboratory Accident of Acryloyl Chloride, Its Consequences, Treatment, and Safety Measures: An Arduous Lesson to All Researchers”. *ACS Chem. Health Saf.* **2023**, 30, 98–99.

Rice, G., MacDonell, M., Hertzberg, R. C., Teuschler, L., Picel, K., Butler, J., ... & Hartmann, H. (2008). An approach for assessing human exposures to chemical mixtures in the environment. *Toxicology and Applied Pharmacology*, 233(1), 126-136.

Segondy, M. (2019). Bonnes pratiques de laboratoire: un système d’assurance qualité pour les laboratoires d’essais non cliniques. *Revue Francophone des Laboratoires*, 2019(515), 20-24.

Série sur les principes de bonnes pratiques de laboratoire et vérification du respect de ces principes Numéro 1 : Les Principes de l’OCDE de bonnes pratiques de laboratoire (tels que révisés en)

Sheehan, W. F. (1976). Periodic table of elements with emphasis. *Chemistry*, 49(3), 17-18.

Shematek, G., & Wood, W. (2012). *Laboratory Safety: Guidelines from the SCSLM*. (7th ed.). Hamilton: Canadian Society for Medical Laboratory Science.

Shematek, G., & Wood, W. (2012). *Laboratory Safety: Guidelines from the SCSLM*. (7th ed.). Hamilton: Canadian Society for Medical Laboratory Science.

van Leeuwen, C. J., & Vermeire, T. G. (Eds.). (2007). *Risk assessment of chemicals: an introduction* (Vol. 94). Dordrecht: Springer.

van Leeuwen, CJ et Vermeire, T. (éd.). (2007). *Évaluation des risques liés aux produits chimiques : une introduction* (Vol. 94). Dordrecht : Springer.

Voet D, Voet JG. 1995. *Biochemistry*, 2nd edn. New York, NY, USA: Wiley, Chapter 19: Citric Acid Cycle, 538–562

Wang, W., Su, Y., Cao, H., & Li, D. (2025). Enhancing Chemical Laboratory Safety with Hazards Risks Mitigation and Strategic Actions. *Laboratories*, 2(1), 5.

WHO(2005)Laboratory Biosafety Manuel. – 3rd edition. World Health Organization, World Health Organization. Laboratory biosafety manual. Third edition. Geneva: World Health Organization; 2004

Yang, J.; Xuan, S.; Hu, Y.; Liu, X.; Bian, M.; Chen, L.; Lv, S.; Wang, P.; Li, R.; Zhang, J.; et al. The Framework of Safety Management on University Laboratory. *J. Loss Prev. Process Ind.* 2022, 80, 104871

Zhang, B.; Zhang, L.; Wang, H.; Wang, X. Lessons Learned from the explosion that occurred during the synthesis of diaminomethanesulfonic