RÉPUBLIQUE ALGÉRIENNE DÉMOCRATIQUE ET POPULAIRE

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITÉ YAHIA FARÈS DE MÉDÉA

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Faculté de Technologie
Département de Génie des Procédés et Environnement

Polycopié de cours — Licence

Filière : Génie des Procédés / Hygiène et Sécurité Industrielle

Niveau : 2^{e} année Licence — Semestre 3 — UE Découverte UED 2.1

HSE FOR INDUSTRIAL INSTALLATIONS

HSE Installations industrielles
Cours dispensé en anglais — 22h30, 1 crédit, coefficient 1

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About these lecture notes

These notes support the course **HSE Installations industrielles**, a discovery-unit course of the third semester of the Licence in Process Engineering (GP) and in Industrial Hygiene and Safety (HSI). They are written in English because the course is taught and examined in English, and because the international literature of this discipline — standards, guidance, safety data sheets, technical reports — is read in English. A bilingual glossary at the end of the volume gives the French equivalent of every technical term used, since the legal texts that the graduate will actually apply are written in French and in Arabic.

Status of the document

This is a *polycopié*: a complete written support that follows the official national programme (canevas) of the Licence *Hygiène et Sécurité Industrielle* chapter by chapter and week by week. It does not replace attendance: roughly one third of the material — the workshops on cause trees, the numerical drills, the discussion of the case studies — only exists in the lecture room. It does, however, contain everything that will be examined.

How to use it

- Read the section announced in the semester plan *before* the corresponding session. The sessions are built on the assumption that the vocabulary is already known.
- Do the exercises with a pen and a calculator before opening the solution. A solution read is a solution forgotten.
- Treat every framed box marked WARNING as an examination question in disguise. They mark the points where students lose marks year after year.
- Keep the formula sheet of Appendix A beside you during the numerical sections; it is the only document you are expected to memorise in substance.

Rule of evidence applied throughout this course. Every legal reference — law, executive decree, ministerial order — and every standard reference given in these notes must be verified by the reader against the official source: the *Journal officiel de la République algérienne démocratique et populaire* for national texts, the publisher's own catalogue for standards. A reference quoted from a third party is a lead, not a proof. Where these notes state the object and the date of a text without its number, that is deliberate: the number is to be read from the official text, not copied from a lecture. Students who bring a verified correction to class will see it recorded here, dated, in the next version.

Prerequisites

General chemistry and unit operations of the first year; the ability to handle a unit conversion without hesitation; elementary probability at the level of "a frequency is a count divided by an exposure". Nothing else is assumed.

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Version of 15 August 2026. Comments, corrections and reports of a broken reference are welcome and will be attributed.

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Identity card of the course

Item	Value fixed by the national programme
Title in the canevas	HSE Installations industrielles
Title used in class	HSE for Industrial Installations
Degree and level	Licence, second year, semester 3 — Process Engineering (GP) and Industrial Hygiene and Safety (HSI)
Teaching unit	Unité d'enseignement découverte — UED 2.1
Weekly load	1 h 30 of lecture; no tutorial class, no laboratory session
Total student workload (VHS)	22 h 30 over 15 weeks, plus 2 h 30 of complementary personal work
Credits and coefficient	1 credit, coefficient 1
Assessment	Final written examination, 100 % of the mark, 1 h 30
Chapter split imposed	Chapter 1 over 7 weeks; Chapter 2 over 8 weeks
Stated objectives	Identify and assess risk; implement the appropriate prevention methods; verify the reality and the effectiveness of the measures put in place
Language of instruction	English, with a bilingual glossary and French legal terminology

Reading of the workload. One credit and twenty-two hours and a half is a small envelope for a large subject. The pedagogical consequence is explicit in these notes: the course does not attempt to teach the formal methods of risk analysis — HAZOP, FMECA, fault tree analysis, layers of protection analysis — which belong to later semesters. It teaches the vocabulary, the indicators, one complete accident-analysis method, the hierarchy of prevention, and the elements of occupational health and environmental protection that a process engineer meets in the first week of professional life. Everything in this volume is examinable; nothing in it is decorative.

Foreword: what this course is, and what it is not

This is a **discovery course**. It carries one credit, and it is the first place where a process engineer meets safety as a discipline rather than as a slogan. Its ambition is therefore precise and limited: at the end of the semester you must be able to look at an industrial installation — a pumping station, a boiler room, a chlorination unit, a tank farm, a thermal spa — and do the three things the national programme states explicitly.

1. **Identify and assess the risk.** Not to feel that something is dangerous, but to name the hazard, describe the exposure, estimate the severity and the likelihood, and write the result down in a form that another person can read, check and contest.
2. **Implement the appropriate prevention methods.** Not to hand out helmets, but to choose in a defensible order: eliminate, substitute, engineer, organise, and only then protect the individual.
3. **Verify the reality and the effectiveness of what has been put in place.** This third objective is the one students underestimate. A barrier that exists on paper and not on site is worse than no barrier at all, because it consumes the confidence that should have gone to a real one.

What this course is *not*: it is not a course on formal risk-analysis methods, and it is not a law course — the companion course *Regulation and Standards*, taught in the same discovery unit, carries that load. The two courses are designed as a pair. This one gives the technical grammar of prevention; the other gives the authority behind that grammar. A student who masters only one of the two is either an engineer who cannot justify a decision, or a clerk who cannot make one.

Why a process engineer, and not only a safety specialist, must own this material

Three quarters of the decisions that determine the safety of an installation are taken before any safety specialist is consulted: the choice of a reagent, the choice between a gaseous and a liquid form of the same active substance, the position of a sampling point, the decision to bury a pipe or to run it in a visible trench, the decision to make a pump serviceable from the surface or only from the bottom of a dry well. Each of these is a process engineering decision, taken for reasons of cost, yield or footprint, and each of them fixes for thirty years the exposure of the people who will operate the plant. The safety specialist arrives afterwards and can only add barriers to a design already frozen. That asymmetry is the reason this course exists in a process engineering curriculum.

> **A discipline of measurement, not of impression.** Throughout this course, any statement of the form "this installation is safe" is refused unless it is accompanied by three elements: *what* was measured, *with which method*, and *against which threshold*. The same demand applies to your examination answers, and later to the reports you will sign.

Learning outcomes

By the end of the semester the student is able to:

Domain	Outcome	Assessed in
Vocabulary	Distinguish rigorously *hazard*, *exposure*, *risk*, *hazardous event* and *damage*, and use each word in its own place	Question 1 of the paper
Organisation	Name the internal and external actors of prevention in an Algerian industrial establishment and state what each may legally require	Question 1 and case
Quantification	Compute and interpret the frequency rate, the severity rate, the frequency index and the mean duration of absence; explain why two plants with the same frequency rate may show very different severity rates	Question 2
Quantification	Compute a time-weighted average exposure, apply the additive index for a mixture, convert between ppm and $mg \cdot m^{-3}$, and size an extraction flow rate from a capture velocity	Question 2
Analysis	Build a cause tree from the factual account of an accident and read from it the prevention measures it justifies	Question 3
Decision	Rank prevention measures according to the hierarchy of controls and justify the rank; distinguish intrinsic and residual risk	Question 3
Health	Explain the meaning and the limits of an occupational exposure limit; describe the logic of occupational disease tables and the consequence of latency	Questions 1 and 2
Environment	Describe the domains of environmental protection, the logic of the classified installations regime, and the difference between an impact study and a hazard study	Question 1 and case
Perspective	Situate sustainable development, the circular economy and life-cycle thinking with respect to an industrial process, with at least one quantified indicator	Case
Verification	Audit a barrier: existence, functioning, adequacy to the scenario, and record	Case

Semester plan — fifteen weeks

The canevas allocates seven weeks to Chapter 1 and eight weeks to Chapter 2. The plan below respects that split exactly. The right-hand column states the work expected *before* the session; the lecture assumes it has been done.

Week	Session content	Section	Preparation and deliverable
1	Framing of the course. Vocabulary: hazard, exposure, risk, damage, hazardous event. First reading of an installation from a photograph.	1.1	None
2	The actors of prevention inside and outside the establishment. Who may demand what, and on what legal basis.	1.2	Read §1.2
3	The nine general principles of prevention. The hierarchy of controls. Barriers and the bow-tie.	1.3	Bring one photograph of a real workplace situation
4	Indicators of occupational accidents: frequency rate, severity rate, frequency index, mean duration. Worked computations.	1.4	Calculator; read §1.4
5	Occupational diseases: definition, tables, presumption of origin, declaration chain, the latency problem. Leading indicators.	1.4	Exercise set 1 handed in
6	Observing and analysing a work situation: the five M, job safety analysis, the risk matrix, the risk register.	1.5	Read §1.5
7	The cause tree: method, logical links, construction workshop on a real accident account.	1.6–1.7	Read §1.6
8	Occupational hygiene: the anticipate–recognise–evaluate–control loop. The five families of harmful agents.	2.1	Exercise set 2 handed in
9	Exposure limits, time-weighted averages, short-term limits, mixtures, sampling strategy, biological monitoring.	2.1	Calculator
10	Control of exposure: substitution, enclosure, local exhaust ventilation, dilution, noise reduction. Numerical sizing.	2.1	Read §2.1.6 and §2.1.7
11	Hygiene of the built environment: drinking water, hot water and legionella, indoor air, lighting, sanitary facilities.	2.2	Read §2.2
12	Environmental protection: water, air, soil, waste, nuisances. Emission limit values, mass loads and self-monitoring.	2.3	Exercise set 3 handed in
13	The classified installations regime: nomenclature, authorisation, impact study, hazard study, emergency plans.	2.3	Read §2.3.4
14	Sustainable development, cleaner production, life-cycle thinking, circular economy, eco-efficiency indicators. Institutional map.	2.4–2.5	Read §2.4
15	Integrated case studies, synthesis, examination method, walkthrough of the specimen paper.	all	Revise the whole course

Complementary personal work (2 h 30 in the canevas) is used for the three exercise sets. Each set is short — four to six questions — and is corrected in class at the beginning of the following session. It is not marked, and it is the single best predictor of the examination result.

Chapter 1 — Introduction to risk assessment and control; analysis of accidents

Seven weeks. Programme content 1.1 to 1.4 of the canevas.

1.1 The four words that must never be confused

Everything in this discipline rests on a distinction that ordinary language ignores. In everyday French and English, *danger* and *risque*, *hazard* and *risk*, are used interchangeably. In this course they are not, and the confusion is not a matter of style: it changes which solutions become visible.

Term	Definition used in this course	Example in a water treatment plant	Can it be removed?
Hazard *danger*	Intrinsic property of a substance, an energy or a situation, able to cause harm. It exists whether or not anyone is present.	Chlorine gas is toxic by inhalation. That is a property of chlorine, valid in an empty room.	Only by removing the substance or the energy itself — by substitution or elimination
Exposure *exposition*	The encounter between the hazard and a target, described by its intensity, its duration and its frequency.	An operator spends forty minutes a day in the chlorination room, twice a week during cylinder changeover.	Yes — by distance, by time, by enclosure, by automation
Risk *risque*	The combination of the likelihood of a hazardous event and the severity of its consequences. A risk is always a quantity or a rank, never a thing.	The risk of acute intoxication during cylinder changeover, judged possible and severe.	It is reduced, rarely annulled; what remains is the residual risk
Damage *dommage*	The realised consequence: injury, illness, death, property loss, environmental impairment.	Chemical pneumonitis of the operator; fish kill in the receiving stream after an uncontrolled discharge.	It is repaired or compensated, never prevented after the fact

The sentence “chlorine is a risk” is therefore wrong, and the error is not verbal. If chlorine is a *risk*, then removing the operator solves nothing, since the cylinder is still there; if chlorine is a *hazard* and the risk lies in the exposure during changeover, then a great many solutions appear at once: automatic changeover, remote isolation valve, gas detection interlocked with the ventilation, or replacing gaseous chlorine by sodium hypochlorite — which substitutes an acute inhalation hazard by a corrosive contact hazard, and that trade must itself be assessed rather than assumed favourable.

A fifth term completes the chain and is often the missing link in student answers: the **hazardous event** (*événement redouté*), the moment at which control is lost — the rupture, the release, the contact, the start of the fire. Prevention acts before it; mitigation acts after it. Almost every practical disagreement about a safety measure comes down to a disagreement about which side of the event the measure sits on.

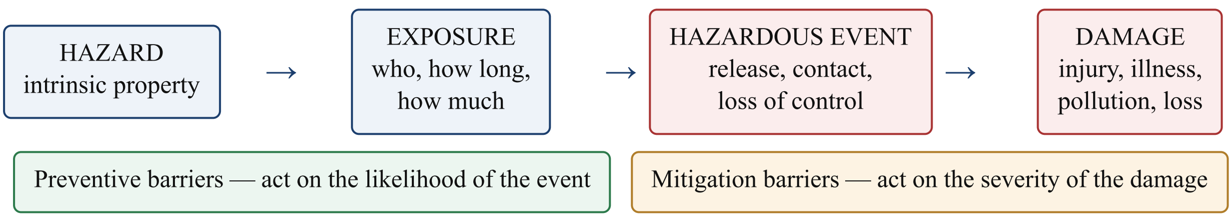

Figure 1.1 — The causal chain of an accident and the two places where a barrier can be inserted.

1.1.1 The risk expression

In its simplest teaching form, risk is written as a combination of two dimensions:

$$R = f(L, S) \quad \text{and, in ranking practice,} \quad R = L \times S$$

where L is the likelihood of the hazardous event over a stated period and S the severity of its consequences. Two warnings, both examinable.

1. The product form is a **convention of ranking**, not a physical law. It lets you sort situations against each other; it does not give you a probability of death per year, and it must never be presented as such to a management or to an inspector.
2. A third dimension is often added in industry: the **frequency of exposure**, or the possibility of avoiding the event once it has started. Whatever scale is adopted, it must be written down and used identically by everyone in the establishment. Two teams using different scales produce rankings that cannot be compared, which destroys the only virtue of a ranking.

Note also the asymmetry between the two factors. Likelihood can usually be reduced by a factor of ten with organisation and maintenance; severity is fixed by physics — by the quantity of substance present, by the pressure, by the height of a fall. This is why the measures that reduce *severity*, and above all those that reduce the **inventory** of dangerous substance held on site, are structurally stronger than those that reduce likelihood. Storing two tonnes of chlorine instead of twenty is worth more than any procedure written about the twenty.

1.1.2 The bow-tie

The bow-tie is the single most useful drawing in industrial safety, and it can be taught in five minutes. On the left, the causes; in the centre, the top event, which is the loss of control; on the right, the consequences. Between them, the barriers.

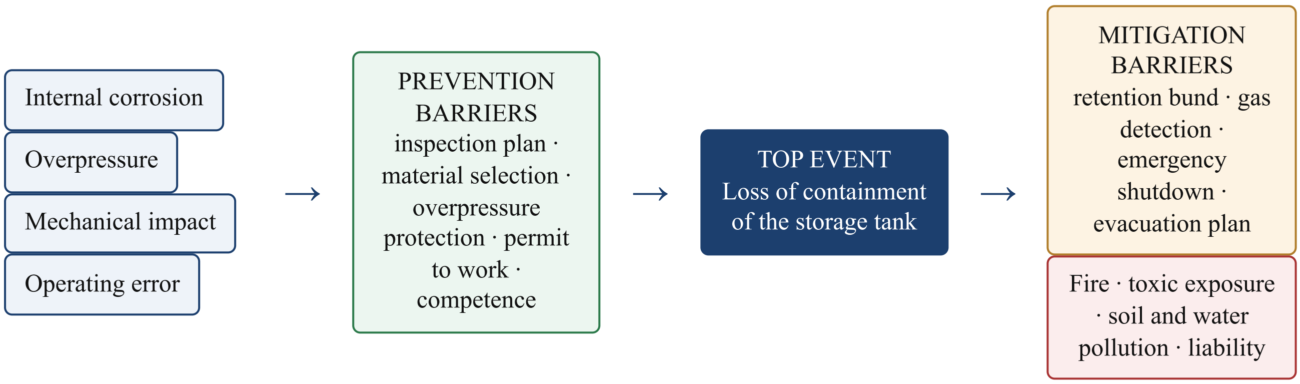

Figure 1.2 — Bow-tie of a loss of containment. Read left to right it is an accident scenario; read right to left it is a programme of work.

Read the drawing twice. Left to right, it is a scenario. Right to left, it is a programme: each barrier must have an **owner**, a **periodicity of verification** and a **record**. The third objective of this course — verifying the reality and the effectiveness of what is in place — is exactly the audit of these three attributes, and it is treated in §1.7.

Exercise 1.1 — vocabulary in a real situation

A workshop degreases metal parts in an open tank of solvent. Identify, in one sentence each: the hazard, the exposure, one plausible hazardous event, one possible damage, one preventive barrier and one mitigation barrier.

Solution. *Hazard*: the solvent is volatile, its vapour is toxic by inhalation and may be flammable — an intrinsic property. *Exposure*: the operator stands over the open bath for several hours a day and breathes the vapour that evaporates from a free surface. *Hazardous event*: saturation of the atmosphere above the bath after the extraction fails, or ignition of the vapour by a nearby hot point. *Damage*: acute narcosis or chronic neurotoxicity; burns and property loss in the fire scenario. *Preventive barrier*: closing the tank and fitting a lateral capture hood, plus substitution of the solvent by an aqueous degreasing process — the strongest of all. *Mitigation barrier*: fixed vapour detection with an alarm, emergency ventilation, eye-wash and first-aid arrangements. Note that the two strongest actions, closing the tank and changing the chemistry, are process decisions and not safety decisions.

1.2 The actors of prevention

Prevention is not the private business of a safety officer. It is a distribution of duties, and each duty comes with a power. An engineer who does not know who may demand what will either obstruct a legitimate request or fail to make one.

1.2.1 Inside the establishment

Actor	Duty	Power, and its limit
The employer, or the head of establishment	Bears the general obligation of safety: safe premises and equipment, information and training, medical surveillance, written risk assessment, provision of protective equipment free of charge	Organises the work and gives instructions; may sanction a worker who violates a safety rule — but may not delegate the obligation itself, only its execution
The workers	Apply the instructions, use the equipment provided, do not disable safety devices, report any situation of serious danger	May report and, in a situation of serious and imminent danger, withdraw; may not decide alone that a rule is unnecessary
The joint hygiene and safety committee, mandatory above a threshold of staff	Inspects the premises, investigates accidents, gives an opinion on new installations and on the annual prevention programme	Investigates and recommends with the authority of a joint body; does not manage, and cannot substitute itself for the employer
The designated safety officer, in smaller establishments	Carries out the same functions in a reduced form, with a defined time allowance	Advises and alerts; his written alerts are the first evidence produced after an accident
The occupational physician	Pre-employment and periodic examinations, fitness decisions, workplace visits, contribution to the risk assessment, health surveillance of the exposed	May demand a workplace study and propose a change of post; is bound by medical confidentiality and is not a disciplinary authority
The HSE department, where it exists	Risk assessment, procedures, permits to work, training, emergency planning, incident investigation, environmental monitoring, reporting	Has the authority its position on the organisation chart gives it — which is why the position of that box matters more than the size of the department
Line management and supervisors	Make prevention real at the level of the task: briefing, verification, tolerance or refusal of a deviation	The strongest lever in the whole system: what a supervisor tolerates becomes the actual standard of the plant

1.2.2 Outside the establishment

- **The labour inspectorate** — controls the application of labour legislation, may issue formal notices with a deadline, may report an offence.
- **The social security fund for salaried workers** — recognises and compensates occupational accidents and diseases, holds the national statistics used as sector denominators, and finances prevention actions. A high accident record has a direct financial cost through contribution rates.
- **The national institute for the prevention of occupational risks** — studies, documentation, training, technical assistance and measurement campaigns.
- **The sectoral prevention body for building and public works** — for that branch, where the accident burden is heaviest.
- **Civil protection** — emergency response, fire prevention, examination of intervention plans, exercises.
- **The environmental administration** at wilaya level and the national agencies — classified installations, permits, waste, monitoring data.
- **Accredited third parties** — inspection bodies for pressure equipment, lifting appliances and electrical installations; testing laboratories; certification bodies. Their independence is what gives their report its value, a point developed at length in the companion course.
- **The International Labour Organization**, at the level of conventions and codes of practice, and the **World Health Organization** for health guidance values.

> **National legal anchors, to be looked up and verified in the *Journal officiel*.** The law of 26 January 1988 on hygiene, safety and occupational medicine; the executive decree of 19 January 1991 on the general prescriptions of protection applicable in the workplace; the executive decree of 8 January 2005 on the joint hygiene and safety committees and the designated safety officers; the law of 2 July 1983 on occupational accidents and diseases; the law of 19 July 2003 on environmental protection within the framework of sustainable development; the law of 12 December 2001 on waste; the executive decree of 31 May 2006 on establishments classified for environmental protection and the decree of 19 May 2007 fixing their nomenclature. **You are required to bring the exact number, date and publication reference of any text you cite in an examination answer, or to cite none and describe the obligation in your own words.** The second option is always accepted; a wrong number never is.

Exercise 1.2 — who do you call?

For each situation, name the actor to address first and say why: (a) a relief valve on a steam receiver has no record of periodic inspection; (b) an operator complains of headaches at the end of each shift in the same room; (c) a contractor's team arrives without any of the training certificates required for confined-space entry; (d) a drum of unlabelled waste has been standing behind the workshop for a year; (e) a worker refuses to enter a pit, saying he considers the situation dangerous.

Solution. (a) The accredited inspection body, through the maintenance department: periodic inspection of pressure equipment is a regulated third-party act, and the missing record is itself the non-conformity. (b) The occupational physician, in parallel with an atmospheric measurement: a repeated symptom with a clear time pattern is an exposure signal, and the medical route protects the worker's confidentiality. (c) The head of establishment and the person responsible for the contract: the co-activity obligations and the prevention plan are contractual and legal duties of the ordering party, not of the contractor alone. (d) The environmental correspondent of the establishment, then the waste stream operator: an unidentified waste cannot be moved legally until it is characterised. (e) The line supervisor and the hygiene and safety committee immediately: the withdrawal from a situation of serious and imminent danger is a protected act, and the correct response is an investigation, never a sanction.

1.3 The general principles of prevention and the hierarchy of controls

Prevention has an order. It is not a matter of taste, and inverting it is the most common professional fault. The classical statement of the general principles, which you should be able to reproduce in substance, runs as follows.

1. Avoid risks.
2. Evaluate the risks that cannot be avoided.
3. Combat risks at source.
4. Adapt the work to the person — workstation design, choice of equipment, methods of work.
5. Take account of the state of technical progress.
6. Replace what is dangerous by what is not, or by what is less dangerous.
7. Plan prevention coherently, integrating technique, organisation of work, working conditions, social relations and the influence of ambient factors.
8. Give collective protection priority over individual protection.
9. Give appropriate instructions to the workers.

Principles 3, 6 and 8 are the operative ones for an engineer; the others describe the frame in which they are applied. Their technical translation is the hierarchy of controls.

1. ELIMINATE — remove the hazard: suppress the operation, change the design, avoid the substance. Most effective, and only possible early.

2. SUBSTITUTE — replace by something less dangerous: another reagent, a lower pressure, a smaller inventory, a mechanised operation.

3. ENGINEERING CONTROLS — enclosure, local exhaust ventilation, interlocks, guarding, automation, distance, retention.

4. ORGANISATIONAL CONTROLS — procedures, permits, training, rotation, signage, planned maintenance, supervision.

5. PERSONAL PROTECTIVE EQUIPMENT — last line; protects one person, while correctly worn, and fails silently.

Figure 1.3 — The hierarchy of controls. Effectiveness and permanence decrease from top to bottom; the number of people protected by a single decision decreases with them.

Why the order matters. A measure high in the list protects **everyone**, **permanently**, and **without requiring a decision** from the exposed person. A measure low in the list protects **one person**, **while worn correctly**, and **fails silently** — nobody is alerted when a respirator cartridge is saturated. Personal protective equipment is not forbidden and is often indispensable; it is the last resort, legitimate when the higher levels have been examined and documented as insufficient, and it must always be accompanied by selection, fit, training, maintenance and replacement rules.

Level	Acts on	Persistence over time	Typical failure mode
Elimination and substitution	The hazard itself	Permanent, survives changes of staff and of management	Was never considered, because the design was already frozen
Engineering controls	The exposure, physically	High, provided maintenance is funded	Bypassed because it slows the work; degraded silently when unmaintained
Organisational controls	The behaviour, through the organisation	Medium, decays with turnover and production pressure	Procedure impossible to apply as written, therefore not applied
Personal protective equipment	The consequence, at the last moment	Low, must be re-established at every shift	Not worn, wrong size, saturated, damaged, or protective against the wrong agent

> **Applied reading.** "Combat the risk at source" is the principle most often violated in practice, because the source is upstream, expensive, and belongs to another department. An extraction hood at the emission point costs more than a box of dust masks and protects a hundred times more people, for ten years, without asking anything of anyone. When you argue for it, argue with two numbers: the number of people protected, and the persistence of the protection over time. Those two numbers are the language management understands.

1.3.1 Two families of barrier, and what makes one strong

A barrier is **passive** when it works without detection, decision or action — a bund wall, a firewall, a double-walled tank, a physical separation of incompatible storages. It is **active** when it requires a chain of detection, decision and action — a gas detector that triggers an alarm that calls an operator who closes a valve. Passive barriers are stronger because their chain is shorter; active barriers are more flexible and can be added to an existing plant. A barrier is characterised by four properties, and an audit examines all four: *effectiveness* (does it stop the scenario), *response time* (does it act before the damage), *independence* (does it fail together with something else), and *auditability* (can it be tested, and is the test recorded).

Independence deserves an example, because it is where real accidents are born. A level control and a high-level alarm on the same tank, both fed by the same transmitter, are one barrier drawn twice. If the transmitter blocks, both disappear at the same instant, and the drawing that shows two protections is a false drawing.

1.3.2 Intrinsic risk, residual risk and the tolerability question

A risk assessment scores twice: the **intrinsic** risk, as it would be without the barriers, and the **residual** risk, with the barriers that genuinely exist and are verified. The gap between the two is the measured value of the prevention effort, and it is the only figure that lets a management compare a safety investment with another investment. A residual risk is then declared acceptable, tolerable subject to measures, or unacceptable, according to a rule written in advance — never after seeing the score.

> **The most frequent methodological error.** Students score the risk *as it should be with all the barriers working as designed*. The correct practice is to score the intrinsic risk first, then to grant credit only to barriers whose existence, functioning and record have been verified. A barrier that cannot be shown to work does not reduce the score. This single rule turns a risk assessment from a work of imagination into a work of evidence.

1.4 Indicators of occupational accidents and diseases

An indicator exists to make two situations comparable. Its definition therefore matters more than its value, and a value quoted without its definition is worthless.

1.4.1 Definitions

Frequency rate (*taux de fréquence*, TF) — number of lost-time accidents per million hours actually worked:

$$\mathrm{TF} = \frac{\text{number of lost-time accidents} \times 10^6}{\text{number of hours actually worked}}$$

Severity rate (*taux de gravité*, TG) — number of calendar days lost per thousand hours actually worked:

$$\mathrm{TG} = \frac{\text{number of days lost} \times 10^3}{\text{number of hours actually worked}}$$

Frequency index (*indice de fréquence*) — number of lost-time accidents per thousand workers:

$$I_\mathrm{f} = \frac{\text{number of lost-time accidents} \times 10^3}{\text{average headcount}}$$

Mean duration of absence — days lost divided by the number of lost-time accidents. It is the bridge between the two rates: a plant can hold a low frequency rate and a catastrophic severity rate if its rare accidents are grave.

Three definitional details decide whether two figures can be compared at all. *What counts as an accident with lost time* — any absence, or an absence beyond a threshold of days? *Which days are counted* — calendar days or working days, and are the days of permanent incapacity added as a lump sum? *Which hours are in the denominator* — hours actually worked, or hours paid including leave? Changing any of the three moves the result by tens of percent without a single injury being avoided.

1.4.2 Worked example 1 — the four indicators of a plant

A plant employs an average of **250 workers**, each working **1,800 hours** in the year. During the year, **9 accidents with lost time** are recorded, causing **180 calendar days** of absence in total.

Hours actually worked: 250 × 1,800 = **450,000 h**.

$$TF = (9 \times 10^6) / 450{,}000 = \mathbf{20} \qquad TG = (180 \times 10^3) / 450{,}000 = \mathbf{0.40}$$

$$I_f = (9 \times 10^3) / 250 = \mathbf{36} \qquad \text{mean duration} = 180 / 9 = \textbf{20 days per accident}$$

Interpretation, which is where the marks are. A frequency rate of 20 means that one lost-time accident occurs roughly every 50,000 hours worked, that is about every 28 worker-years. The severity rate of 0.40 says that four working days in every ten thousand hours are lost to accidents. The frequency index of 36 says that 36 workers in a thousand were injured with lost time during the year — the figure a workforce understands immediately, because it speaks of people and not of hours. None of these numbers is a judgement on its own: each must be compared with the same indicator, computed on the same definitions, for the same activity sector. A plant that counts only accidents with more than three days of absence will mechanically display a better frequency rate than a plant counting all of them.

1.4.3 Worked example 2 — a trend that is not a trend

The same plant records, over three consecutive years: year 1, TF = 20 and TG = 0.40; year 2, TF = 14 and TG = 1.85; year 3, TF = 12 and TG = 0.35. Management announces a 40 % improvement in safety over three years. Comment.

Analysis. The frequency rate does fall steadily, and that is a real signal if the reporting rules have not changed. But year 2 shows a severity rate 4.6 times higher than year 1 with fewer accidents: one grave accident — a fracture, an amputation, a serious burn — dominates the year. The three-year story is therefore "fewer small accidents, and one severe event that the frequency rate does not see". Two conclusions must appear in the answer. First, **frequency and severity must always be read together**; a single indicator can always be improved without improving safety. Second, with nine accidents a year, statistical fluctuation alone can move the frequency rate by several units, so a difference of two or three points between two consecutive years is not evidence of anything. Small populations require **leading indicators** rather than accident rates.

1.4.4 Lagging and leading indicators

Lagging indicators — count the damage	**Leading indicators — count the prevention**
Frequency rate; severity rate; frequency index; number of occupational diseases recognised; number of environmental incidents declared; cost of accidents	Percentage of planned inspections actually carried out; percentage of barrier tests done on time; number of near misses reported and processed; percentage of workers trained and re-trained on time; average delay to close a corrective action; percentage of permits audited in the field; number of safety visits by line management
Available late, in small numbers, and morally uncomfortable to "improve"	Available weekly, in large numbers, and directly actionable by a supervisor

A plant of two hundred people may go two years without a lost-time accident and still be dangerous; it cannot go two years with an inspection completion rate of 40 % and be safe. That asymmetry is the whole argument for leading indicators.

Exercise 1.3 — compute, compare and decide (solution inside)

Workshop A: 120 workers, 1,750 hours each, 6 lost-time accidents, 96 days lost. Workshop B: 60 workers, 1,900 hours each, 2 lost-time accidents, 210 days lost. Compute the frequency rate, the severity rate and the mean duration for each workshop, and state which one you would inspect first, with your reason.

Solution. A: hours = 120 × 1,750 = 210,000 h; TF = 6 × 10^6 / 210,000 = **28.6**; TG = 96 × 10^3 / 210,000 = **0.46**; mean duration = 16 days. B: hours = 60 × 1,900 = 114,000 h; TF = 2 × 10^6 / 114,000 = **17.5**; TG = 210 × 10^3 / 114,000 = **1.84**; mean duration = 105 days. Workshop A has the higher frequency; workshop B has a severity rate four times higher and a mean absence of 105 days, which signals grave injuries. You inspect **B** first: frequent minor accidents cost money, rare grave accidents cost limbs. Add the statistical caution: two events do not make a trend, so B must be judged on its barriers and its near misses rather than on its rates.

Exercise 1.4 — the denominator (solution inside)

A contractor reports a frequency rate of 8 for a site where 40 workers were present for 6 months at 45 hours a week, with 3 lost-time accidents. Verify the figure and explain the discrepancy if there is one.

Solution. Hours worked ≈ 40 × 45 × 26 weeks = 46,800 h. TF = 3 × 10^6 / 46,800 = **64**, not 8. A rate of 8 would require about 375,000 hours, that is eight times the hours actually worked on the site. The probable explanations, all of which must be checked before accusing anyone: the company reported hours for its whole workforce and accidents for this site only; or it counted only accidents with more than three days lost; or it reported an annualised figure over a period during which most of its staff were elsewhere. **Method to retain: always recompute the denominator before accepting an indicator.**

1.4.5 Occupational diseases

An occupational disease differs from an accident on three points, and the examination asks for them: it is **progressive** rather than sudden, it has a **latency** that may reach decades, and it is recognised through official **tables** that state the disease, the exposure that causes it, the minimum duration of exposure and the maximum delay of onset after the end of exposure. A disease listed in a table and contracted under the stated conditions is **presumed** occupational: the worker does not have to prove the causal link. That presumption is the entire point of the table system, and it is why a table is a legal instrument and not a medical one.

Disease family	Typical exposure in process industries	Latency	Prevention that actually works
Pneumoconioses (silicosis)	Crystalline silica dust: crushing, sandblasting, refractory work	10 to 30 years	Wet processes, enclosure, extraction at source, substitution of the abrasive
Asbestos-related diseases	Historic insulation, gaskets, brake linings, demolition	20 to 40 years	Inventory before any work on an old plant; removal by qualified firms
Noise-induced hearing loss	Compressors, blowers, grinding, pumps	5 to 20 years	Source treatment, enclosure, distance, limitation of exposure time
Occupational asthma and dermatitis	Isocyanates, amines, chromates, epoxy resins, latex	Months to years	Substitution, closed transfer, gloves selected by permeation data
Chemical intoxications	Lead, mercury, solvents, carbon monoxide	Weeks to years	Exposure measurement, biological monitoring, ventilation
Occupational cancers	Aromatic amines, benzene, hexavalent chromium, hardwood dust	15 to 40 years	Elimination; there is no safe exposure level to a genotoxic carcinogen
Musculoskeletal disorders	Manual handling of drums and sacks, repetitive gestures	Months to years	Mechanical handling, workstation design, rotation

The practical consequence for an engineer is severe: **today's exposure produces tomorrow's disease, and the plant that generated it may no longer exist when the disease appears.** This is why occupational hygiene relies on the measurement of exposure rather than on the observation of health effects. By the time the effect is visible, prevention has already failed, and it has failed for a whole cohort at once.

The declaration chain must also be known in outline: medical observation of the case, declaration by the worker or the physician to the social security fund within the regulatory delay, examination of the file against the table, recognition or refusal, compensation, and — the part that concerns the engineer — the obligation to re-examine the workplace that produced the case, because a recognised disease is the proof that a control has failed for others still exposed.

1.5 Observing and analysing a work situation

1.5.1 The five M

To observe a work situation without forgetting a whole family of causes, use five entry points — the five M — which map directly onto the branches of an Ishikawa diagram. The value of the model is not classification for its own sake: it is that it forces you to look at the four families that the eye does not spontaneously see, because the eye goes straight to the worker and to the machine.

Entry point	What you look at	Typical finding in a process plant
Manpower *main-d'œuvre*	Training, experience, fatigue, staffing level, night work, language of the instructions, subcontracting	The procedure is written in a language the contractor's team does not read
Material and equipment *matériel*	Machines, guarding, tools, state of maintenance, conformity of the equipment, spare parts	The relief valve carries no record of its last test
Matter *matière*	Substances handled, their form and quantity, safety data sheets, incompatibilities, packaging	Hypochlorite and acid stored in the same retention bund
Method *méthode*	Operating procedures, permits, sequencing, supervision, interfaces between companies	No lock-out procedure for maintenance on the mixer
Milieu *milieu*	Layout, lighting, noise, temperature, ventilation, access, weather, co-activity	Confined pit with no forced ventilation and no gas detector

1.5.2 Job safety analysis

The job safety analysis — *analyse de sécurité des tâches* — is the most useful tool of the whole course for a young engineer, because it can be done in an hour, with the people who do the work, on a single sheet. The task is cut into steps in their real order; for each step the hazards are named; for each hazard a control is proposed and an owner is written. Below, the analysis of a chlorine cylinder changeover, abridged.

Step of the task	Hazard at this step	Control, with its level in the hierarchy
1. Prepare and check equipment	Wrong or degraded gasket; respirator not checked	Kit prepared in advance with dated gaskets (organisational); escape respirator checked monthly and recorded (organisational)
2. Close the valve of the empty cylinder	Valve stiff, forcing, seat damage	Correct key held at the station; prohibition of extensions; valve maintenance plan (engineering and organisational)
3. Purge and disconnect the line	Residual chlorine released at face height	Purge to a neutralisation column (engineering); local extraction at the connection point (engineering)
4. Handle and position the new cylinder	Crushing of feet and hands; fall of the cylinder	Cylinder trolley and chaining to the wall (engineering); protective footwear (PPE, last)
5. Connect and leak-test	Leak at the connection; exposure while looking for it	Ammonia vapour test or portable detector (engineering); two persons, one at the door (organisational)
6. Put back in service and record	Undetected slow leak	Fixed detector interlocked with the extraction and with the alarm (engineering); written record of the operation (organisational)

Notice what the table reveals without anyone arguing: five of the eleven controls are engineering controls, and the whole task disappears if the plant substitutes sodium hypochlorite dosing for gaseous chlorine — an elimination decision that belongs to the process engineer and not to the safety officer.

1.5.3 The risk matrix

After identification comes estimation. The simplest defensible instrument is a matrix with an explicit scale on each axis. The scales below are an example; what matters is that the establishment writes down its own and applies them uniformly.

Likelihood ↓ Severity →	S1 Minor, first aid	S2 Serious, lost time	S3 Severe, permanent impairment	S4 Fatal, or several victims
L4 Almost certain — weekly	4 moderate	8 high	12 unacceptable	16 unacceptable
L3 Likely — monthly	3 low	6 moderate	9 high	12 unacceptable
L2 Possible — yearly	2 low	4 moderate	6 moderate	8 high
L1 Rare — once in the life of the plant	1 low	2 low	3 low	4 moderate

The decision rule attached to the matrix must be written down as well: *unacceptable* means the activity stops until a measure is in place; *high* means a measure is planned with a deadline and a named owner; *moderate* means the measure enters the annual programme; *low* means the situation is kept under surveillance and re-examined at the next review. **A matrix without a decision rule is decoration.**

1.5.4 The risk register

The output of the assessment is a document, not a feeling. Its minimum columns are fixed by practice and by the regulatory obligation to keep a written assessment: unit and situation of work; hazard; scenario; existing barriers; intrinsic score; residual score; measure decided; owner; deadline; date of verification; new score after verification. The register is a living document: it is revised at least annually, and immediately after any accident, any modification of the installation, and any new legal requirement.

Situation	Hazard / scenario	Existing barriers	Intrinsic	Residual	Measure decided	Owner / date
Chlorination room, cylinder changeover	Toxic release during connection	Local extraction; escape respirator; two operators	L3 × S4 = 12	L2 × S3 = 6	Fixed detector interlocked with the extraction; study of hypochlorite substitution	Head of production / 31 March
Dry well of the pumping station	Anoxia or intoxication on entry	None verified: ventilation out of service	L3 × S4 = 12	L3 × S4 = 12	Repair the ventilation; entry permit; second detector; quick-disconnect couplings	Maintenance / immediate

The second line illustrates the rule of §1.3.2: because no barrier could be verified, the residual score equals the intrinsic score. A register that never shows such a line is a register that has not been audited.

1.6 The cause tree

The cause tree — *arbre des causes* — is a **post-accident** method. It reconstructs, backwards from the injury, the network of facts which, combined, produced the event. Its power is that it forbids the two comfortable conclusions: “the worker was careless” and “it was bad luck”. Both close the file; neither prevents the next accident.

1.6.1 Method in four steps

1. **Collect the facts, immediately and on site.** A fact is objective, precise and verifiable. “The operator was imprudent” is a judgement; “the operator entered the pit without a gas measurement” is a fact. Collect from several sources — the injured person when possible, the witnesses, the equipment, the records — and separate what was seen from what is supposed.
2. **Order the facts backwards from the final injury.** For each fact ask two questions: *what was necessary for this to occur?* and *was that alone sufficient?* If it was not sufficient, another antecedent is missing and must be sought.

3. **Build the tree** with the three logical links below, and only those.
4. **Derive the prevention measures.** Every branch cut is a candidate measure; you then choose among the candidates by effectiveness, stability, cost and delay, and you rank them by the hierarchy of controls.

1.6.2 The three logical links

Link	Meaning	Consequence for prevention
Chain *enchaînement*	One antecedent, one consequence: X produced Y	Cutting anywhere along the chain stops the sequence
Conjunction *conjonction*	Two or more independent antecedents were all necessary: X and Y together produced Z	Suppressing *any one* of them breaks the accident — the cheapest branch may be the best target
Disjunction *disjonction*	One antecedent produced several consequences	One measure removes several effects at once — the highest-value target

1.6.3 Worked example — accident in a pumping station

Factual account. On a Thursday at 14 h 10, a maintenance worker went down into the dry well of a pumping station to change the mechanical seal of pump number 2. The station's forced ventilation had been out of service for eleven days; the fault had been reported in writing. No gas measurement was taken before entry, because the portable detector was at the central workshop for calibration. The worker was alone, the second team member having been reassigned that morning to another site. At 14 h 25 he lost consciousness. He was found at 15 h 05 by a driver making a delivery, and was hospitalised with hydrogen sulphide poisoning.

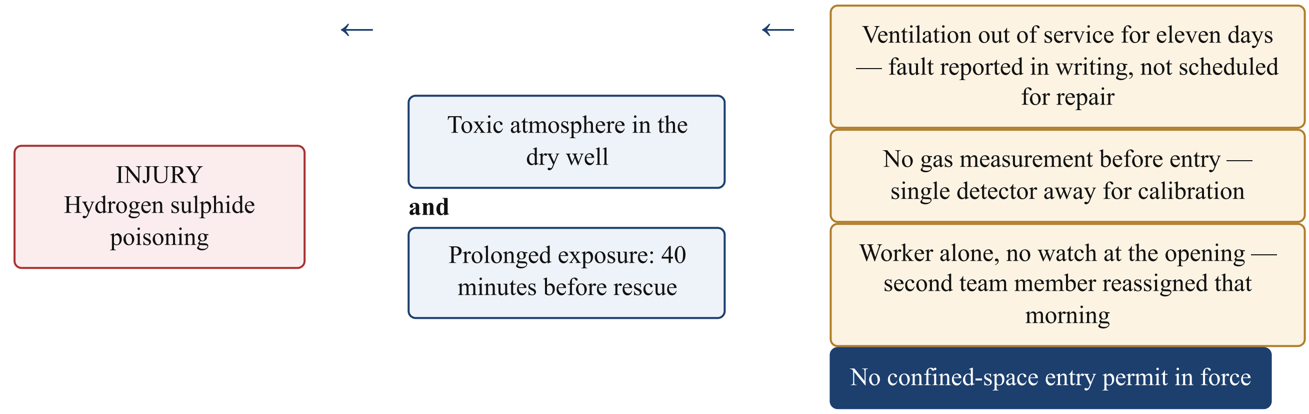

Figure 1.4 — Cause tree of the pumping-station accident, read from right to left. The two central facts are joined by a conjunction; the absence of an entry permit feeds two independent branches at once.

Reading the tree. The poisoning required a conjunction: a toxic atmosphere *and* a prolonged exposure. Each of these required in turn a conjunction of failures. Notice that no branch says "the worker was careless" — and that the account contains nothing that would justify such a branch. Notice also that two branches converge on the same root fact, the absence of a confined-space entry permit, which is exactly the kind of finding only a tree reveals: a single organisational measure cuts two independent branches at once.

Branch cut	Measure	Level in the hierarchy	Stability
Need to enter the well at all	Fit quick-disconnect couplings and a lifting davit so the pump is lifted out and repaired at the surface	Elimination of the exposure	Very high
Toxic atmosphere	Repair the forced ventilation and interlock it; install a fixed hydrogen sulphide detector with an alarm at the surface	Engineering	High
Absence of measurement	Second portable detector held at the station; calibration planned so that no station is ever without one	Engineering and organisational	Medium
Worker alone	Confined-space entry permit with a mandatory surface watch, harness and retrieval tripod	Organisational	Medium, depends on supervision
Reported fault left unrepaired	Rule that a safety-related fault report blocks the concerned work until repair, or until compensatory measures are formally recorded and time-limited	Organisational	Medium

1.6.4 Common errors, and how the method compares with others

- **Writing judgements instead of facts.** Every branch containing an adjective about a person is to be rewritten.
- **Stopping at the first cause found.** The first cause found is always the last event in time, and almost never the most useful to remove.
- **Confusing the cause tree with the fault tree.** The cause tree is built *after* an accident, from facts. The fault tree is built *before*, from hypotheses, with logical gates and, when data allow, probabilities.
- **Producing a tree and no measures.** The tree is an instrument, not a result. The result is the table of measures, with owners and dates.

Method	When	Input	Strength / limit
Cause tree	After an accident	Facts collected on site	Reveals conjunctions and organisational roots / requires facts, hence a rapid enquiry
Five whys	After a minor incident	A short discussion	Fast / follows a single line and misses conjunctions
Ishikawa diagram	Before or after	Group knowledge	Exhaustive by family / does not show necessity or sufficiency
Fault tree, HAZOP, FMECA	Before, at design	Drawings and process data	Systematic and predictive / heavy, and outside the scope of this course

Exercise 1.5 — build your own cause tree

On a Monday morning, an operator cleaning the discharge chute of a belt conveyor was injured at the hand. The machine had been stopped with the local stop button but not locked out. A colleague, seeing the machine stopped and the shift about to start, restarted it from the control room. The chute guard had been removed three weeks earlier for a repair and never refitted. The cleaning task appears in no written procedure.

Work required. (a) List the facts, separating them from the judgements. (b) Build the tree backwards from the injury, marking every conjunction. (c) Propose four measures ranked by the hierarchy of controls. (d) State which single measure cuts the largest number of branches. **Guidance for the correction.** The injury required a conjunction of three facts: the hand inside the chute, the absence of the guard, and the unexpected restart. The unexpected restart itself required the absence of lock-out and the absence of any signal that someone was working on the machine. The measure that cuts the largest number of branches is the *consignation* — lock-out and tag-out with a personal padlock — because it makes the restart physically impossible whatever the colleague believes; refitting the guard is the strongest engineering measure and removes the access to the moving part; writing the cleaning task into a procedure with a defined stopped state is the organisational complement. A fourth, higher measure exists and is expected from a process engineering student: design the chute so that it does not clog, or so that it can be cleaned from outside without removing a guard.

1.7 Verifying the reality and the effectiveness of what is in place

The third objective of the canevas deserves its own section, because it separates a real safety system from a paper one. Verification asks three questions of every barrier.

1. **Does it exist physically?** Go and look. A gas detector on a drawing is not a gas detector.
2. **Does it work?** Is there a test record — dated, signed, with a result, a threshold and the name of a competent person — produced at the stated periodicity?
3. **Would it work in the scenario for which it was chosen?** A retention bund sized for the smallest tank of the farm exists, works, and does not protect.

The instruments of verification are the periodic regulatory inspection by an accredited third party; the internal audit; the field visit with a checklist; the analysis of near misses; the test of the emergency arrangements by exercise; and — the most under-used of all — the interview of the operator who performs the task every day and who knows exactly which procedure is impossible to follow as written.

Barrier	What to verify	Typical periodicity	Evidence to file
Fixed gas detection	Response to test gas; alarm audible in the work area; interlock actually trips the ventilation	Quarterly, plus after any intervention	Test sheet with the gas concentration used and the measured response time
Relief valve	Set pressure and reseating on a test bench; state of the seat; absence of isolation upstream	Annual to multi-annual, by an accredited body	Third-party report with the identification of the valve
Retention bund	Volume against the largest tank plus the fire-water contribution; tightness; valve of the drain kept closed and sealed	Annual, and after every modification	Sizing note and inspection record with photographs
Emergency shower and eye-wash	Flow, temperature, absence of obstruction on the path, signage	Weekly flushing, recorded	Flushing register at the point of use
Permit to work	Field audit of live permits: does the situation on site match what the permit says?	Continuous sampling by supervision	Audited permits with observations and follow-up
Training and competence	Validity dates; the person actually doing the task is the person trained	Annual review	Training matrix by post, not by name only

The three questions you will be asked in the examination case. Which barriers exist for this scenario? Which of them can you prove? What do you decide about the risk while the proof is missing? The expected answer to the third is never "we continue and we will see": it is either a compensatory measure, time-limited and written, or a suspension of the activity.

Exercise 1.6 — audit of a barrier (solution inside)

An establishment shows you a fire-detection system covering a storage hall. Write the five questions you ask, in order, and say what conclusion you draw if question 3 has no answer.

Solution. (1) What scenario is the system supposed to detect, and how fast? (2) Is the coverage adapted to the height, the ventilation and the nature of the stored products — a smoke detector under a ten-metre roof with strong ventilation may never see a fire? (3) When was it last tested, by whom, with what result, and where is the record? (4) What happens when it triggers — an audible alarm only, a call to a permanently manned point, an automatic extinguishing action, and has that downstream chain been tested? (5) What happened to the faults recorded at the last test, and are they closed? If question 3 has no answer, the barrier is **not credited**: the residual risk is scored as if the detection did not exist, and a compensatory measure — rounds, a temporary detector, restriction of the stored quantity — is imposed until the test is performed. Note the reasoning: the absence of a record is not a documentary defect, it is the absence of proof that the barrier works.

Chapter 2 — Occupational hygiene, public health and the protection of the environment

Eight weeks. Programme content 2.1 to 2.5 of the canevas.

2.1 Occupational hygiene and public health

Occupational hygiene is the discipline that **anticipates, recognises, evaluates and controls** the physical, chemical and biological agents present in the workplace, so that health is preserved over a whole career. Its logic differs from that of safety on one decisive point: the damage it prevents is usually **deferred, cumulative and silent**. Nobody falls down beside a machine because of a solvent vapour at fifteen parts per million; the effect appears fifteen years later, in a person who has changed employer three times. This is why hygiene cannot be managed by counting accidents, and why it needs measurement.

ANTICIPATE at the design stage → RECOGNISE inventory of agents → EVALUATE measure and compare → CONTROL act at the source → VERIFY measure again

Figure 2.1 — The loop of occupational hygiene. It is a loop: the verification feeds the next anticipation, and a programme that never returns to the first box is an inspection, not a hygiene practice.

2.1.1 The five families of agents

Family	Examples in a process or water installation	Route and typical effect
Chemical	Chlorine, ammonia, solvents, acids and bases, dusts, welding fumes, disinfection by-products	Inhalation, skin, ingestion; irritation, intoxication, sensitisation, cancer
Physical	Noise, vibration, heat and cold, ionising and non-ionising radiation, pressure	Hearing loss, vascular disorders, heat stroke, radiation injury
Biological	*Legionella*, leptospires, enteric bacteria and viruses, moulds, endotoxins	Inhalation of aerosols, contact with waste water, wounds; infections
Ergonomic	Manual handling, repetitive gestures, awkward postures, work at height in confined access	Musculoskeletal disorders — the first cause of occupational disease almost everywhere
Psychosocial	Shift work, isolated work, workload, violence from the public	Sleep and cardiovascular disorders; also a factor of accidents through degraded vigilance

2.1.2 Occupational exposure limits

An **occupational exposure limit** is the concentration of an agent below which, in the state of knowledge, most workers may be exposed repeatedly without adverse effect. Three forms are used, and confusing them is a standard examination error.

- The **eight-hour limit** (VLEP-8h, TWA): averaged over a working day, it protects against chronic effects.
- The **short-term limit** (VLCT, STEL): averaged over fifteen minutes, it protects against peaks with acute effects, and must never be exceeded even if the daily average is compliant.
- The **ceiling value**: never to be exceeded at any instant, used for agents whose action is immediate.

> **Three warnings on limits.** They are **not** a boundary between safe and dangerous — they are an administrative compromise revised as knowledge advances. They assume a healthy adult working eight hours a day, which excludes the pregnant worker and the twelve-hour shift. And for carcinogens and sensitisers, **no threshold can be considered safe**: the obligation is to reduce as low as technically possible, not to reach the number.

Converting between units. Limits are published in parts per million for gases and in milligrams per cubic metre for dusts and mists; at 25 °C and 101.3 kPa the molar volume is 24.45 L·mol^{-1}, hence:

$$C\ (\text{mg·m}^{-3}) = C\ (\text{ppm}) \times \frac{M\ (\text{g·mol}^{-1})}{24.45}$$

For chlorine, M = 71 g·mol^{-1}, so a value of 5 ppm corresponds to 5 × 71 / 24.45 = **14.5 mg·m^{-3}**. The conversion must be done before comparing a measurement to a limit expressed in the other unit — comparing 5 ppm to a limit of 3 mg·m^{-3} as if the numbers were commensurable is a mistake that appears in real reports.

2.1.3 The time-weighted average, worked

Exposure varies during the day. The eight-hour exposure is therefore the average of the concentrations weighted by their durations:

$$\text{TWA} = \frac{\Sigma\, C_i \times t_i}{8}$$

Application. An operator is exposed 3 h at 40 ppm, 3 h at 20 ppm and 2 h at 5 ppm. The eight-hour limit is 25 ppm and the short-term limit is 50 ppm.

$$\text{TWA} = (3{\times}40 + 3{\times}20 + 2{\times}5) / 8 = (120 + 60 + 10) / 8 = 190 / 8 = \mathbf{23.75\ ppm}$$

Interpretation — the part that carries the marks. The result is below 25 ppm: the exposure is *formally compliant*. But it sits at 95 % of the limit, which means that any small change — an overtime hour, a ventilation fault, a warmer day — places the operator above it; and the three-hour phase at 40 ppm must still be checked against the short-term limit, because a daily average says nothing about a peak. The correct conclusion is therefore: compliant, insufficiently, and the phase at 40 ppm is where the action belongs.

2.1.4 Mixtures: the additive index

When several agents act on the **same organ or by the same mechanism**, their effects add, and each individual compliance proves nothing. The rule is:

$$I = \frac{C_1}{\text{VLE}_1} + \frac{C_2}{\text{VLE}_2} + \ldots \leq 1$$

Application. Two solvents attacking the same organ are measured at 30 ppm (limit 50) and 12 ppm (limit 25). Each is comfortably below its own limit. But I = 30/50 + 12/25 = 0.60 + 0.48 = **1.08** > 1: **the mixture is not compliant**. This single line of arithmetic is one of the most useful things this course teaches, because the situation it describes — several products, each individually acceptable — is the ordinary situation of a workshop.

2.1.5 Sampling strategy and biological monitoring

A measurement campaign is decided before it is performed, and five decisions define it.

Decision	Content, and the error to avoid
Who is measured	Homogeneous exposure groups, and within them the **most exposed** worker. Measuring the supervisor because the badge is easy to fit is the classic bias
Where	**Individual** sampling in the breathing zone for exposure; fixed-point sampling only to locate a source or to check a ventilation system
When and how long	Cover the full shift, including the short and dirty tasks; a measurement taken during the calm hour is a measurement of nothing
How many	One measurement is an anecdote. Several, over different days, are needed before a distribution can be discussed
By what method	A standardised method, with its edition, and a laboratory whose scope covers the analyte; direct-reading instruments for peaks and for immediate decisions

Biological monitoring measures the agent or its metabolite in blood or urine. It integrates all routes of entry, including the skin, and it accounts for the actual protection worn — which atmospheric measurement cannot do. Its limits are equally real: it comes after the exposure, it touches medical confidentiality, and it must remain under the responsibility of the occupational physician.

2.1.6 Controlling by ventilation

Local exhaust ventilation captures the pollutant at the point of emission, before it reaches the breathing zone. For an unflanged hood, the flow rate required to obtain a capture velocity v at a distance x from a hood of face area A is:

$$Q = v \times (10\,x^2 + A)$$

Application. A hood of face area $A = 0.12\ \text{m}^2$ must produce a capture velocity of $v = 0.5\ \text{m·s}^{-1}$ at $x = 0.25$ m: $Q = 0.5 \times (10 \times 0.0625 + 0.12) = 0.5 \times 0.7450 =$ **$0.37\ \text{m}^3\text{·s}^{-1}$**, that is about **$1{,}340\ \text{m}^3\text{·h}^{-1}$**. If the operator works at $x = 0.50$ m instead, $Q = 0.5 \times (10 \times 0.25 + 0.12) = 1.31\ \text{m}^3\text{·s}^{-1}$, nearly **four times more**. *The lesson*: doubling the distance quadruples the fan, so the cheapest improvement in ventilation is almost always to bring the hood closer, not to buy a bigger fan.

General dilution ventilation replaces contaminated air by clean air: $Q = G/C$, multiplied by a mixing factor of 2 to 10 to account for imperfect mixing. It is a weak control, acceptable only for low-toxicity agents emitted diffusely, and it is never a substitute for capture at the source. A ventilation installation must also be **verified periodically** — flow rates, velocities, pressure drops — because a system whose filter is clogged looks exactly like one that works.

2.1.7 Noise

Sound level is measured in decibels A, a logarithmic scale, which has an unintuitive consequence: **an increase of 3 dB(A) doubles the acoustic energy**, and therefore halves the permissible exposure time. Exposure is assessed over eight hours; typical action levels are set at 80 and 85 dB(A) and a limit not to be exceeded at the ear at 87 dB(A).

Application. Four hours at 92 dB(A) and four hours at 80 dB(A) give an eight-hour equivalent level of about **89 dB(A)** — much closer to the loud phase than an arithmetic average would suggest, because energy, not level, is averaged. Two consequences: a short, very noisy phase governs the whole day; and reducing the quiet phase changes almost nothing. Act on the loud phase, in this order: enclose or damp the source, separate the noisy machine from the occupied area, reduce the exposure time, and only then provide hearing protectors — whose real attenuation, when worn intermittently, collapses.

Exercise 2.1 — three calculations (solutions inside)

(a) Convert 2 ppm of chlorine (M = 71 g·mol^{-1}) into mg·m^{-3}. (b) An operator is exposed 2 h at 35 ppm, 4 h at 18 ppm and 2 h at 5 ppm to a solvent whose eight-hour limit is 20 ppm: compute and conclude. (c) A hood of face area 0.15 m^2 must give 0.4 m·s^{-1} at 0.30 m: compute the flow in m^3·h^{-1}.

Solutions. (a) 2 × 71 / 24.45 = **5.8 mg·m^{-3}**. (b) TWA = (2×35 + 4×18 + 2×5)/8 = (70 + 72 + 10)/8 = 152/8 = **19 ppm**, below the eight-hour limit of 20 ppm. The exposure is therefore **formally compliant, but at 95 % of the limit**: one hour of overtime, a ventilation fault or a warmer day places the operator above it, and the two-hour phase at 35 ppm must in addition be checked against the short-term limit. Conclusion: compliant, insufficiently, and the action belongs to the phase at 35 ppm. (c) Q = 0.4 × (10 × 0.09 + 0.15) = 0.4 × 1.05 = 0.42 m^3·s^{-1} = **1,512 m^3·h^{-1}**.

2.2 Hygiene of the built environment

The canevas places the hygiene of housing and of collective premises beside occupational hygiene, and rightly: the graduate of this Licence will be asked about the water of a canteen, the ventilation of a locker room and the sanitary facilities of a site as often as about a chemical exposure.

2.2.1 Drinking water: the multi-barrier principle

Water is made safe by a **succession of independent barriers**, never by a single one: protection of the resource; treatment; protection of the distribution network; and monitoring. If one barrier fails, the others must still hold, which is the same reasoning as the barriers of Chapter 1 applied to a public health problem.

- Protection of the resource: perimeters of protection around the catchment, control of activities upstream, tightness of the wellhead.
- Treatment: clarification, filtration and disinfection, each verified by its own parameter.
- Network: maintenance of a residual disinfectant, positive pressure at all times, prohibition of cross-connections, control of dead legs and of the materials in contact.
- Monitoring: a written programme of parameters, points and frequencies — and, above all, a written statement of the action to be taken at each result.

2.2.2 Legionella: a problem governed by temperature

Legionella lives in warm water, multiplies in biofilm and in the amoebae that inhabit it, and causes disease when **inhaled as an aerosol** — never by drinking. The at-risk installations are therefore those that heat water and disperse it: hot water networks, showers, cooling towers, humidifiers, high-pressure jets, spa pools, and thermal establishments.

Temperature	Behaviour of the bacterium	Consequence for the installation
Below 20 °C	Survives without multiplying	Cold water kept genuinely cold, protected from heating in the ducts
20 to 45 °C, optimum near 35 °C	**Active multiplication**	The range to be crossed quickly and never stored in
50 to 55 °C	Multiplication stops; slow inactivation	Loop return temperature to be maintained above 50 °C
60 °C and above	Rapid inactivation	Storage temperature; scalding protection required at the point of use

Four levers control the risk: **temperature**, **stagnation** (suppress dead legs, size the storage to the real consumption, flush unused outlets), **cleaning and disinfection** with a written record, and **control of the aerosol** at the point of use. Note the tension that must be managed explicitly: storing at 60 °C creates a scalding hazard, so mixing valves are installed as close as possible to the outlet — protecting against scalding without creating a tepid reservoir upstream.

> **The case that recurs in this region.** A thermal establishment supplied by a natural spring at **44 °C** cannot use the temperature lever at all: the water arrives inside the multiplication range and the therapeutic purpose forbids heating it. Safety must then come entirely from the other three levers, deliberately reinforced. This case is developed in full at the end of these notes.

2.2.3 Indoor air, lighting, sanitary facilities

Indoor air. Confinement is estimated by the carbon dioxide concentration, a proxy for the renewal of air per occupant; the pollutants of concern are those emitted by the building and its uses — formaldehyde and solvents from materials, combustion products from unvented appliances, moulds from damp, and radon in some geologies. The remedy is almost always the same: ventilate, and act on the source rather than on the symptom.

Lighting. Insufficient light is a factor of accidents and of visual fatigue. Orders of magnitude: 100 to 200 lux for circulation areas and stores, 300 to 500 lux for ordinary work, more for fine tasks and inspection. Uniformity, absence of glare and absence of flicker matter as much as the number of lux, and emergency lighting must be tested, not merely installed.

Sanitary facilities and premises for the staff. Sufficient and separate lavatories, washbasins with hot water and cleaning products, showers where the work is dirty or exposing, changing rooms with **separated compartments for work clothes and personal clothes** where contamination can be carried home, a place to eat away from the work area, and drinking water available. These are not comforts: separated changing rooms are a barrier against domestic contamination by lead, asbestos, pesticides or biological agents, and a canteen inside a workshop is an ingestion route.

Housekeeping and neighbourhood. Order and cleanliness are a genuine safety indicator: a site whose floors are clear and whose products are labelled is almost always a site whose barriers are maintained. Externally, the establishment owes its neighbourhood the control of its noise, its odours, its dusts and its traffic — and an explicit channel to receive complaints, which is the cheapest early-warning system an operator can have.

2.3 The domains of environmental protection

Environmental protection is not a single subject but a set of domains, each with its own physics, its own indicators, its own regulation and its own administration. An engineer must be able to place any problem in the right domain before looking for a rule.

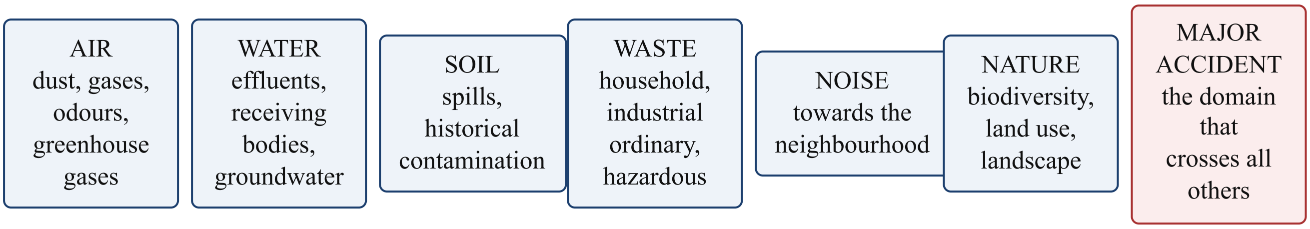

Figure 2.2 — The domains of environmental protection. A major accident is not a seventh domain beside the others: it is the event that damages several of them at once.

2.3.1 Emission limits, and the difference between a concentration and a load

Regulations fix **emission limit values** as concentrations — $mg{\cdot}L^{-1}$ in a discharge, $mg{\cdot}Nm^{-3}$ in a stack. A concentration alone does not measure the pressure exerted on the environment: what the receiving medium receives is a **mass flow**.

$$\text{Load (kg·day}^{-1}) = \text{concentration (mg·L}^{-1}) \times \text{flow rate (m}^3\text{·day}^{-1}) \times 10^{-3}$$

Application. A plant discharges 800 $m^3{\cdot}day^{-1}$ of effluent containing 110 $mg{\cdot}L^{-1}$ of suspended solids, against a limit of 35 $mg{\cdot}L^{-1}$. The load discharged is $110 \times 800 \times 10^{-3}$ = **88 kg·day^{-1}**; the load authorised is $35 \times 800 \times 10^{-3}$ = **28 kg·day^{-1}**. The exceedance is 60 kg per day, or about 22 tonnes a year of solids sent to the receiving stream.

> **The dilution trap.** The plant could reach 35 $mg{\cdot}L^{-1}$ by adding 1,700 $m^3{\cdot}day^{-1}$ of clean water. The concentration would then comply and the load discharged would be *unchanged at 88 kg per day*. Dilution is forbidden as a means of compliance for exactly this reason, and it is why modern permits fix both a concentration and a mass load, and why they require the effluent flow to be measured and recorded rather than estimated.

Two families of parameters must be distinguished in an effluent: those describing the **organic load** — chemical oxygen demand, biochemical oxygen demand over five days, and their ratio, which indicates biodegradability — and those describing **specific pollutants** — metals, hydrocarbons, phenols, cyanides — whose treatment is chemical and whose limits are far lower. Adding a biological stage to a plant that discharges chromium treats nothing.

2.3.2 Classified installations

The regulatory backbone of industrial environmental protection is the regime of **installations classified for environmental protection**. Its logic is identical in most countries and must be understood as a mechanism, independently of the numbers.

1. A **nomenclature** lists activities and substances, each with thresholds — quantity stored, power installed, capacity treated.
2. According to the threshold crossed, the installation falls under **declaration**, **authorisation**, or an intermediate regime. The heavier the potential impact, the heavier the procedure.

3. Authorisation requires a file containing, in particular, an **impact study** and, for the installations presenting major risks, a **hazard study**, together with a public enquiry.
4. The authorisation is granted with **prescriptions**: limit values, monitoring, records, reporting, financial guarantees, and rules for cessation of activity and site rehabilitation.
5. **Any substantial modification** — change of capacity, of process, of substances — requires the file to be re-examined. This is the article most often forgotten, and it is the first one an inspector checks after a plant has been extended.

Criterion	Impact study — *étude d'impact*	Hazard study — *étude de dangers*
Question asked	What are the effects of **normal operation** on the environment and on health?	What are the effects of an **accident**, and how is its likelihood reduced?
Time scale	Chronic, continuous, cumulative	Sudden, rare, potentially catastrophic
Typical content	Initial state of the environment, emissions, noise, water, waste, traffic, landscape, mitigation measures, monitoring programme	Inventory of hazardous substances, accident scenarios, effect distances for thermal flux, overpressure and toxic concentration, barriers, emergency plans
Principal output	Limit values and a monitoring programme	Safety distances, barriers with their performance, and the emergency arrangements

Emergency planning follows from the hazard study: an **internal plan** organising the response with the plant's own means, and, for the most dangerous establishments, an **external plan** prepared by the public authority for the protection of the surrounding population. Both are worth exactly what their **exercises** prove: an emergency plan never tested is a document, not a barrier — the same rule as in §1.7.

2.3.3 Waste

Waste is governed by three ideas that must be stated in this order. **Classification** first: household and assimilated, ordinary industrial, hazardous industrial, inert, and the special streams — healthcare, electrical and electronic equipment, used oils, batteries. **Responsibility** next: the producer of a waste remains responsible for it until its final elimination, so choosing the cheapest collector without verifying his authorisation is a liability that returns to the producer years later. **Traceability** last: characterisation of the waste, register of quantities produced and dispatched, movement documents signed by each holder, and verification of the final destination.

The **hierarchy of waste management** orders the options: prevent at source, reduce, reuse, recycle, recover energy, and only then dispose. It is the same shape as the hierarchy of controls in §1.3, for the same reason: acting on the origin is stronger, more permanent and cheaper than treating the consequence.

2.4 Sustainable development

2.4.1 Definition and the three pillars

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The definition, formulated by the world commission on environment and development in 1987, contains two ideas that are examinable separately: the notion of **needs**, in particular the essential needs of the poorest, to which priority should be given; and the notion of **limitations** imposed by the state of technology and social organisation on the capacity of the environment to meet present and future needs.

ENVIRONMENT
resources, emissions, ecosystems

ECONOMY
viability, employment, competitiveness

SOCIAL
health, safety, equity, working conditions

Environment × Economy = **viable** · Economy × Social = **equitable** · Social × Environment = **liveable** · the three together = **sustainable**

Figure 2.3 — The three pillars and their pairwise intersections. Occupational health and safety belongs to the social pillar; it is not an addition to sustainable development but one of its components.

Four principles complete the frame and should be quotable: **prevention** — act at source rather than repair; **precaution** — the absence of scientific certainty must not delay measures against a risk of serious or irreversible damage; **polluter pays** — the cost of pollution is borne by the one who produces it, not by the community; **participation and information** — the public has a right to environmental information and to be consulted.

2.4.2 From end-of-pipe treatment to cleaner production

Approach	Principle	Limit or benefit
End-of-pipe treatment	Treat the emission after it has been produced	Necessary and often unavoidable, but it displaces the pollution — a scrubber turns an air emission into a liquid effluent, a filter turns dust into a hazardous waste — and it is a permanent operating cost
Cleaner production	Modify the process so that the pollution is not created: substitution, closed loops, recovery, optimisation of yields	Reduces the emission and the raw material consumption at the same time; often profitable, and always more robust
Eco-design and life cycle thinking	Consider the whole life of the product: extraction, manufacture, transport, use, end of life	Avoids transferring an impact from one stage to another, or from one domain to another
Circular economy	Keep materials in use: reuse, remanufacture, recycle, industrial symbiosis between neighbouring plants	Requires quality of the secondary material and stable outlets; the waste of one plant becomes the feedstock of another
Best available techniques	Reference to the best techniques economically applicable in the sector	Gives the administration and the operator a common technical language instead of a negotiation

2.4.3 Measuring: eco-efficiency indicators

An absolute quantity of pollution says nothing about performance if production has changed. Indicators are therefore expressed **per unit of production**: cubic metres of water per tonne of product, kilowatt-hours per tonne, kilograms of waste per tonne, kilograms of chemical oxygen demand discharged per tonne.

Application. A plant consumes 42,000 m^3 of water for 12,000 t of product in year 1, and 39,000 m^3 for 13,500 t in year 2. The specific consumption falls from 3.50 to **2.89 $m^3 \cdot t^{-1}$**, an improvement of 17 %, while the absolute consumption falls by only 7 %. Both figures are true and they answer different questions: the specific figure measures the **efficiency of the process**, the absolute figure measures the **pressure on the resource**. A plant may improve its efficiency and still take more water from a river that has none. Report both, always — that is the honest practice, and the examination expects it.

2.4.4 Management systems, and their honest use

Voluntary management system standards — quality, environment, occupational health and safety — structure the effort around the same loop: plan, do, check, act. Their value is that they impose a documented cycle, a legal register kept up to date, defined responsibilities, competence requirements, control of documents and records, internal audits, management review and corrective actions. Their limit is that **a certificate attests conformity to the standard, not the absence of risk**: a certified plant can have an accident, and a well-run plant may never seek a certificate. The companion course develops this point at length; it is repeated here because students are tempted to treat certification as a conclusion rather than as a tool.

2.5 The institutions of health, safety and the environment

Level	Body	Role in the system
International	International Labour Organization	Conventions and recommendations on occupational safety and health; codes of practice; tripartite structure
International	World Health Organization	Health guidance values, in particular for drinking water and air quality; classification of health risks
International	United Nations Environment Programme; the international agency for the research on cancer	Environmental conventions and programmes; classification of carcinogens on which many national rules rest
National — labour	Ministry in charge of labour; labour inspectorate	Regulation of hygiene, safety and occupational medicine; control and sanction
National — health	Ministry in charge of health; public health institutes	Public hygiene, water quality, epidemiological surveillance, occupational health guidance
National — environment	Ministry in charge of the environment; the directorates at wilaya level; the national agencies for waste, for the observation of the environment and for river basins	Classified installations, permits, monitoring, waste policy, environmental information
National — prevention	The national institute for the prevention of occupational risks; the sectoral body for building and public works	Studies, training, technical assistance, measurement campaigns
National — insurance	The social security fund for salaried workers	Recognition and compensation of accidents and occupational diseases; national statistics; incentive financing of prevention
National — emergency	Civil protection	Response, fire prevention, examination of intervention plans, exercises
National — quality infrastructure	The standardisation institute, the accreditation body, the legal metrology office	Standards, accreditation, metrology — the subject of the companion course
Establishment	Employer, hygiene and safety committee, occupational physician, HSE department, workers	Where prevention is actually done or not done

PLAN
legal register, risk assessment, objectives, programme
→
DO
measures, competence, procedures, emergency preparedness
→
CHECK
measurement, indicators, inspections, audits, incident analysis
→
ACT
corrective actions, management review, revision of the programme

Figure 2.4 — The improvement loop, which structures both the internal organisation of an establishment and the way an inspection examines it.

Exercise 2.2 — place the problem (solution inside)

For each situation, name the domain, the type of study or document that governs it, and the administration to which the establishment reports: (a) a cooling tower emits a visible plume above a residential street; (b) the plant wishes to double its storage of ammonia; (c) sludge from the effluent treatment plant has accumulated for two years behind the workshop; (d) a discharge exceeds the limit for chemical oxygen demand every Monday morning.

Solution. (a) Domain *air and health*, with a legionella dimension because a cooling tower produces aerosols: the governing documents are the impact study, the maintenance and treatment programme of the tower and its analysis records; the administration is the environment directorate, and the health services if a case appears. (b) Domain *major accident*: doubling the ammonia inventory is a substantial modification, so the classification must be re-examined against the nomenclature thresholds, the hazard study updated, the effect distances recomputed and the authorisation revised before the work — not after. (c) Domain *waste and soil*: the sludge must be characterised to determine whether it is hazardous, entered in the waste register, and dispatched to an authorised facility with movement documents; the two-year accumulation is itself an unauthorised storage. (d) Domain *water*: the Monday pattern points to a start-up practice — tanks purged at restart — rather than to a treatment failure; the answer is to spread or to buffer the discharge, and the self-monitoring records will show it. Note that in three of the four cases the correct first act is to **look at the records**, not to take a sample.

Integrated case studies

The two cases below cross the whole programme. They are the model of what is asked in the final examination case, and they are worked in the last session of the semester.

Case A — A thermal establishment supplied at 44 °C

The situation. A thermal establishment is supplied by a natural spring delivering water at **44 °C**. The water is stored in an intermediate tank, distributed to individual bath cabins and to a treatment room fitted with high-pressure jets and an aerosol-producing shower. Two operators maintain the installation; three attendants work in the cabins. The forced ventilation of the technical basement has been out of service for an unknown period. There is no written analysis programme; two analyses of the year are available, one of which is dated after the summer peak. The waste water is discharged to a small stream sixty metres away. During the summer, the establishment receives up to two hundred people a day.

Questions

1. Identify the hazards, distinguishing them from the risks, for the users, for the staff, and for the environment.
2. Explain why the temperature of 44 °C is the central technical fact of the file.
3. Draw up a risk register with at least five lines, scored intrinsic and residual, with the barriers that exist and those that can be verified.
4. Propose a set of measures ranked by the hierarchy of controls, with owners and deadlines.
5. Define the monitoring programme: parameters, points, frequencies, methods, and what triggers an action.
6. State the environmental obligations attached to the discharge and to the waste.

Expected answer, in outline

1. Hazards. *Biological*: *Legionella* and other water-borne organisms, the exposure route being the inhalation of aerosols in the treatment room and the showers; amoebae and other opportunists in warm water. *Chemical*: disinfectant products handled by the staff, and the gases naturally dissolved in some thermal waters. *Physical*: scalding at 44 °C for a fragile or elderly user, slipping on wet floors, confined atmosphere in the unventilated technical basement, noise of the pumps. *Environmental*: thermal and chemical load of the discharge on a small receiving stream. The risks are the combinations of these hazards with the exposures: for example, the risk of legionellosis in a user inhaling the aerosol of the treatment room, judged possible and severe.

2. Why 44 °C governs the file. The resource arrives inside the multiplication range of *Legionella*, near the upper part of it, and it cools further in the tank, in the pipes and at the point of use, passing through the optimum near 35 °C. The classical control lever — storing above 60 °C and distributing above 50 °C — is therefore **unavailable** without heating a natural water, which the therapeutic purpose forbids. The safety of the establishment cannot come from temperature. It must come from the three remaining levers: eliminating stagnation, treating and cleaning, and controlling the aerosol. This is exactly the reasoning expected: *identify which barrier is unavailable, and reinforce the others deliberately rather than by default.*

3. Extract of the risk register.

Situation	Scenario	Existing barriers	Intr.	Resid.	Measure
Treatment room, high-pressure jets	Inhalation of contaminated aerosol by a user	None verified; two analyses without a programme	L3 × S4 = 12	12	Analysis programme; disinfection; enclosure and extraction of the aerosol; medical screening of contraindications
Intermediate storage tank	Stagnation and biofilm feeding the whole network	Unknown cleaning history	L4 × S3 = 12	12	Reduce the volume to the daily need; scheduled cleaning and disinfection with a record; suppress the dead legs
Technical basement	Anoxia or gas accumulation during maintenance	Ventilation out of service	L2 × S4 = 8	8	Repair the ventilation; gas measurement before entry; entry permit; prohibition of working alone
Cabins, wet floors	Fall of an elderly user	Non-slip flooring in part of the area	L4 × S2 = 8	L3 × S2 = 6	Complete the non-slip flooring; grab bars; drainage; call button in each cabin
Discharge to the stream	Thermal and chemical impact on a small receiving body	Direct discharge, not characterised	L4 × S2 = 8	8	Characterise the effluent; buffer and cool; declare and regularise the discharge

4. Measures ranked. *Elimination and substitution*: suppress the high-pressure jets producing the finest aerosols where the therapeutic benefit does not require them; remove the intermediate tank if direct distribution is feasible. *Engineering*: suppression of dead legs, sizing of the storage to the daily consumption, treatment adapted to a natural water, enclosure and extraction of the treatment room, repair of the basement ventilation, non-slip flooring and grab bars. *Organisational*: written cleaning and disinfection plan with records, analysis programme, entry permit for the basement, training of the attendants, information of users on contraindications, register of incidents. *Personal protection*: respiratory and skin protection for the staff during cleaning and disinfection operations only.

5. Monitoring programme. Temperature at defined points, continuously or at each opening; disinfectant residual where a treatment is applied; microbiological analyses including legionella at the most representative points — tank outlet, the furthest cabin, the aerosol-producing device — at a frequency higher in summer; each result recorded with the sampling point, the date, the method and its edition, and the identity of the laboratory. **The programme states in advance what is done at each threshold**: continue, re-sample, disinfect, or close the concerned point. Deciding after the result arrives is the failure mode this clause exists to prevent.

6. Environment. Characterisation of the effluent, comparison with the applicable limit values, examination of the classification of the establishment against the nomenclature, declaration or authorisation of the discharge, management of the sludge and of the used chemical containers as waste with a register and authorised collectors.

Grading grid used for a case of this type	Marks
Hazards correctly distinguished from risks, and the four terms used rigorously	3
Identification of the temperature as the governing fact, with the consequence on the available barriers	3
Risk register: relevant lines, explicit scales, residual score not credited to unverified barriers	5
Measures ranked by the hierarchy, with owners and deadlines, and no jump to protective equipment	4
Monitoring programme with thresholds and pre-defined actions	3
Environmental dimension not forgotten	2

Case B — The chlorination room

The situation. A drinking water plant disinfects with gaseous chlorine, stored in 50 kg cylinders — four in service, six in reserve — in a room adjoining the pump hall and opening directly onto the yard. The extraction fan is switched on manually by a switch *inside* the room. A gas detector is fixed on the wall; its last test is not recorded. Two escape respirators hang beside the door; their cartridges are undated. Cylinder changeover is performed by one operator, on average once a week. The neutralisation column has never been used and its reagent has not been renewed since installation.

Questions and expected answer

1. **Bow-tie of the scenario "loss of containment of a chlorine cylinder".** Causes: corrosion of the valve, mechanical impact during handling, connection error, failure of the flexible connector, fire in the adjoining hall. Top event: release of gaseous chlorine. Consequences: intoxication of the operator, intoxication of the pump hall staff, toxic cloud reaching the yard and beyond, interruption of the water supply.
2. **Barriers and their audit.** Detection: exists, *not credited* — no test record. Extraction: exists, but its **command is inside the room**, which requires entering a contaminated atmosphere to start it — a design error that turns a barrier into a trap. Respirators: exist, *not credited* — undated cartridges. Neutralisation column: exists, *not credited* — reagent not renewed and never tested. Two operators: does not exist. Result: **the residual risk equals the intrinsic risk**, and this conclusion is the heart of the expected answer.
3. **Immediate measures**, before any study: move the extraction command outside the room and add an automatic start on detection; test the detector and establish a quarterly test sheet; date and replace the respirator cartridges and inspect them monthly; verify or renew the neutralisation reagent; forbid changeover by a single operator and institute a written procedure with a watch at the door.
4. **Structural measures**: reduce the inventory held on site; separate the chlorination room from the pump hall by a tight partition with its own ventilation; and study the **substitution** of gaseous chlorine by on-site electrochlorination or by sodium hypochlorite dosing — stating honestly that the substitution replaces an acute inhalation hazard by a corrosive contact hazard and a storage stability problem, and that the trade must be assessed, not assumed.
5. **Emergency arrangements**: alarm audible in the yard and in the control room, evacuation direction depending on the wind, a wind sock visible from the room, informing the neighbours and the civil protection, and an exercise at least annually with a written debriefing.

Examination method

The assessment is a **final examination counting for the whole mark**, over 100 %, in accordance with the canevas. It lasts one hour thirty minutes and is composed of three parts. The paper is written in English; answers in English are expected, and a technical term given in French in brackets is never penalised.

Part	Marks	What is assessed, and the commonest way of losing the marks
I. Definitions and short questions	6	Precision of vocabulary. Marks are lost by confusing hazard and risk, by defining an indicator without saying what is in the denominator, and by describing prevention where mitigation was asked
II. Calculation and interpretation	6	Frequency rate, severity rate, time-weighted average, additive index, ventilation flow, pollutant load. **A result without a unit and without a sentence of interpretation is worth half.** Show the intermediate line
III. Case study	8	Identification, assessment, measures ranked by the hierarchy, and verification. Marks are lost by jumping straight to protective equipment and by proposing measures with no owner and no deadline

Five habits that raise a mark by several points. Write the formula before the numbers. Carry the units through the calculation. Give one sentence of interpretation after every result. Rank every list of measures from elimination downwards. And when you cite a legal text, give its number and its date, or describe the obligation without naming a text — both are accepted, an invented reference is not.

Specimen examination paper

Licence HSI / GP — Semester 3 — UED 2.1 — HSE for Industrial Installations

Duration: 1 h 30. Documents not permitted. Non-programmable calculator authorised. The three parts are independent.

Part I — Definitions and short questions (6 marks)

1. Define *hazard*, *exposure*, *risk* and *damage*, and illustrate the four with a single example taken from a water treatment plant. (2)
2. State the hierarchy of controls in order and explain, in two sentences, why the order is not a matter of preference. (1.5)
3. What is the difference between a preventive barrier and a mitigation barrier? Give one example of each on a storage tank. (1)
4. Distinguish an occupational accident from an occupational disease on three criteria. (1)
5. What is a leading indicator? Give two examples and say why they matter in a small establishment. (0.5)

Part II — Calculation and interpretation (6 marks)

6. A workshop employs 180 workers, each working 1,760 hours in the year. Seven accidents with lost time are recorded, totalling 154 calendar days of absence. Compute the frequency rate, the severity rate, the frequency index and the mean duration of absence, and comment on the profile of the workshop in three sentences. (3)
7. An operator is exposed 2 h at 45 ppm, 4 h at 18 ppm and 2 h at 6 ppm to a solvent whose eight-hour limit is 20 ppm and whose fifteen-minute limit is 40 ppm. Compute the eight-hour time-weighted average, conclude on compliance, and state the two actions you take. (2)
8. A plant discharges 1,200 m^3 per day of effluent at 90 $mg \cdot L^{-1}$ of suspended solids, the limit being 35 $mg \cdot L^{-1}$. Compute the daily load discharged and the daily load authorised. The plant proposes to dilute with clean water to reach the limit: comment in two sentences. (1)

Part III — Case study (8 marks)

A pumping station comprises a dry well four metres deep, accessible by a fixed ladder, housing two pumps. The forced ventilation has been out of service for three weeks; the fault is recorded in the maintenance log. The single portable gas detector of the sector is away for calibration. Maintenance is carried out by a two-person team, but the second member is frequently reassigned. No confined-space entry permit exists. (a) List the hazards present and name the scenario you consider the most serious. (2) (b) Draw the cause tree of an accident in which a worker loses consciousness in the well, marking the conjunctions. (2) (c) Propose five measures ranked by the hierarchy of controls, with an owner and a deadline for each. (3) (d) Which single measure cuts the largest number of branches of your tree, and why? (1)

Answer key and marking notes

Question 6. Hours worked = 180 × 1,760 = **316,800 h**. TF = 7 × 10^6 / 316,800 = **22.1**. TG = 154 × 10^3 / 316,800 = **0.49**. I_f = 7 × 10^3 / 180 = **38.9**. Mean duration = 154 / 7 = **22 days**. *Comment expected*: a frequency comparable to that of a plant with a significant manual activity; a mean absence of 22 days indicating accidents that are more than benign; and the caution that with seven events the year-to-year variation is dominated by chance, so the workshop must be judged on its barriers and its near misses rather than on the movement of its rates.

Question 7. TWA = (2×45 + 4×18 + 2×6)/8 = (90 + 72 + 12)/8 = 174/8 = **21.75 ppm**, above the limit of 20 ppm: **not compliant**. Actions: treat the two-hour phase at 45 ppm at source — capture, enclosure, substitution — and verify by direct-reading instrument that the fifteen-minute limit of 40 ppm is not exceeded during that phase, since 45 ppm sustained over two hours makes an exceedance likely. Reducing only the duration would be an accounting solution. *Marking note*: full marks require the conclusion and the two actions, not the number alone.

Question 8. Load discharged = 90 × 1,200 × 10^{-3} = **108 kg·day^{-1}**. Load authorised = 35 × 1,200 × 10^{-3} = **42 kg·day^{-1}**. Dilution would lower the concentration while leaving the load discharged unchanged at 108 kg per day; it is not a treatment, it is forbidden as a means of compliance, and modern permits fix a mass load precisely to close this route.

Part III. (a) Hazards: anoxia and toxic gases — hydrogen sulphide in particular — in a confined space; fall from the ladder; drowning; electrical hazard; biological hazard of waste water. Most serious scenario: loss of consciousness in the well followed by a prolonged exposure with no rescue. (b) The tree must show a conjunction between the toxic or anoxic atmosphere — itself produced by the conjunction of the biological production of gas and the ventilation failure — and the prolonged exposure, itself produced by the absence of a surface watch and of retrieval means. Full marks require the conjunctions to be marked and require no branch to contain a judgement on the worker. (c) Measures: suppress the entry by quick-disconnect couplings and a lifting davit (elimination); repair the ventilation and fit a fixed detector with a surface alarm (engineering); provide a second portable detector and plan calibrations so no station is left without one (engineering and organisational); institute a confined-space entry permit with a mandatory watch, harness and tripod (organisational); train the teams and audit live permits in the field (organisational). Each with a named owner and a dated deadline. (d) The entry permit, because it conditions the measurement, the watch and the retrieval means at once, and therefore cuts several branches; but the answer must add that the permit is an organisational barrier and that the **elimination of the entry** is stronger and should be studied in parallel.

Appendix A — Formula sheet

Quantity	Formula	Notes
Frequency rate	TF = accidents with lost time × 10^6 / hours worked	Hours actually worked, not hours paid
Severity rate	TG = days lost × 10^3 / hours worked	State whether the days are calendar or working days
Frequency index	I_f = accidents × 10^3 / average headcount	The indicator a workforce understands
Mean duration	days lost / number of accidents	Bridges frequency and severity
Risk score	$R = L \times S$	A ranking convention, not a probability
Time-weighted average	$\mathrm{TWA} = \Sigma\,(C_i\,t_i) / 8$	Times in hours over the eight-hour reference
Additive index of a mixture	$I = \Sigma\, C_i / \mathrm{VLE}_i \leq 1$	Only for agents acting on the same organ
ppm to $\mathrm{mg{\cdot}m^{-3}}$	$\mathrm{C(mg{\cdot}m^{-3}) = C(ppm)} \times M / 24.45$	At 25 °C and 101.3 kPa
Capture flow rate of a hood	$Q = v\,(10\,x^2 + A)$	Unflanged hood; Q in $\mathrm{m^3{\cdot}s^{-1}}$
Dilution flow rate	$Q = G / C$ × mixing factor	Mixing factor 2 to 10; weak control
Pollutant load	load = concentration × flow rate	Watch the units; dilution does not change it
Eco-efficiency indicator	consumption or emission / tonne produced	Report the absolute value beside it

Appendix B — Bilingual glossary

English	Français	Note
Hazard	Danger, phénomène dangereux	Intrinsic property
Risk	Risque	Combination of likelihood and severity
Exposure	Exposition	Intensity, duration, frequency
Harm, damage	Dommage	The realised consequence
Hazardous event	Événement redouté	The moment control is lost
Barrier, control	Barrière, mesure de maîtrise	Preventive or mitigating
Lost-time accident	Accident avec arrêt	The definition must be stated
Frequency rate / severity rate	Taux de fréquence / taux de gravité	Per million / per thousand hours
Near miss	Presqu'accident	A free lesson
Cause tree	Arbre des causes	Built after the accident, from facts
Occupational exposure limit	Valeur limite d'exposition professionnelle	Eight-hour, short-term, ceiling
Local exhaust ventilation	Ventilation par aspiration à la source	Capture at the emission point
Personal protective equipment	Équipement de protection individuelle	Level 5, last resort
Lock-out / tag-out	Consignation	Physical impossibility of restart
Permit to work	Permis de travail, autorisation de travail	Audited in the field, not only signed
Confined space	Espace confiné	Measurement, watch, retrieval means
Emission limit value	Valeur limite d'émission	Concentration; add the mass load
Classified installation	Installation classée	Declaration or authorisation regime
Impact study / hazard study	Étude d'impact / étude de dangers	Normal operation / accident
Retention bund	Cuvette de rétention	Sized on the largest tank
Waste hierarchy	Hiérarchie des déchets	Prevent, reuse, recycle, recover, dispose
Sustainable development	Développement durable	Three pillars, four principles

Appendix C — Self-assessment checklist

Tick each item only if you can do it without notes. An unticked item names your revision.

I can…	Section	Checked
define the four terms of the causal chain and place a hazardous event between them	1.1	☐
draw a bow-tie for a scenario of my choice and place four barriers on it	1.1.2	☐
name the actors of prevention and say what each may demand	1.2	☐
state the hierarchy of controls and justify the order with two arguments	1.3	☐
distinguish intrinsic and residual risk, and refuse credit to an unverified barrier	1.3.2	☐
compute and interpret the four accident indicators	1.4	☐
explain why an occupational disease is invisible in an accident rate	1.4.5	☐
carry out a job safety analysis on a task in six steps	1.5.2	☐
build a risk matrix with its decision rule and fill a risk register	1.5.3	☐
build a cause tree from facts and mark the conjunctions	1.6	☐
audit a barrier with the three questions of existence, function and adequacy	1.7	☐
compute a time-weighted average and an additive index, and interpret both	2.1.3	☐
size the extraction of a hood and explain the effect of distance	2.1.6	☐
explain the legionella temperature ranges and the levers available at 44 °C	2.2.2	☐
convert a concentration into a load and refute a dilution argument	2.3.1	☐
distinguish an impact study from a hazard study	2.3.2	☐
state the waste hierarchy and the producer's responsibility	2.3.3	☐
define sustainable development and compute an eco-efficiency indicator	2.4	☐
name the institutions and say what each does	2.5	☐

Bibliography and working sources

The references below are the families of sources on which the course rests. Students are required to verify the exact number, date and publication reference of any national text before citing it, and to state the edition of any standard they invoke. The rule announced at the beginning of these notes applies to the notes themselves.

- **National legislation and regulation** — the law on hygiene, safety and occupational medicine of 26 January 1988; the executive decree of 19 January 1991 on the general prescriptions of protection applicable in the workplace; the executive decree of 8 January 2005 on the joint hygiene and safety committees and the designated safety officers; the law of 2 July 1983 on occupational accidents and diseases; the law of 19 July 2003 on environmental protection within the framework of sustainable development; the law of 12 December 2001 on waste; the executive decree of 31 May 2006 on installations classified for environmental protection and the decree of 19 May 2007 fixing their nomenclature. All to be consulted in the *Journal officiel de la République algérienne*.
- **International standards** — occupational health and safety management systems; environmental management systems; risk management guidelines and vocabulary; standards on the enumeration of legionella in water; sampling and analysis standards for workplace atmospheres. The edition in force must be verified in the catalogue of the national standardisation body.
- **International organisations** — conventions, recommendations and codes of practice of the International Labour Organization; the guidelines of the World Health Organization on drinking water quality and on air quality; the technical documents of the international agency for the research on cancer on the classification of carcinogens.
- **Reference documentation** — the technical notes and brochures of the national institutes of prevention on ventilation, on chemical risk, on noise and on confined spaces; sectoral guides for the water industry and for the chemical industry.
- **Classical textbooks** — general treatises on occupational hygiene, on industrial safety and on the analysis of accidents by the cause-tree method; textbooks on industrial pollution control and on cleaner production.

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