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UNIVERSITE YAHIA FARES DE MEDEA

Faculté de Technologie
Département de Génie des Procédés et Environnement

Polycopié de cours

Filière : Hygiène et Sécurité Industrielle / Génie des Procédés
Spécialité : Licence — 2e année, Semestre 3

HSE OF INDUSTRIAL INSTALLATIONS

HSE des installations industrielles

Unité d'enseignement UED 2.1 — VHS 22 h 30 — 1 crédit — coefficient 1

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Course description

Degree	Licence — Industrial Hygiene and Safety (HSI) / Process Engineering (GP), second year
Semester	Semester 3
Teaching unit	UED 2.1 — Discovery unit
Subject	HSE of industrial installations
Hours	22 h 30 total — lecture 1 h 30 per week, 15 weeks
Credits / coefficient	1 / 1
Assessment	Final written examination — 100 %
Language	English, with the French and Arabic technical terms given in the glossary
Lecturer	Dr. Ahmed Cherif Rahmani, Maître de conférences B

Aims of the course

At the end of this course the student should be able to:

1. **identify and assess a risk** in an industrial installation, distinguishing rigorously between the hazard, the exposure and the risk;
2. **select and implement the appropriate prevention measures**, in the order of effectiveness fixed by the hierarchy of controls;
3. **verify the existence and the effectiveness** of the measures actually put in place, using indicators that can be recomputed by a third party.

A fourth aim runs through the whole course and is not written in the official syllabus: to acquire the habit of **stating what one measures, how one measures it, and what one has not measured**. An assessment that does not declare its limits is not an assessment, it is an opinion.

Prerequisites

General chemistry and physics of the first year; basic descriptive statistics; elementary knowledge of unit operations in process engineering. No prior knowledge of law is required — the legal framework is introduced as it is needed.

Structure and weekly plan

Weeks	Content	Figure	Key skill
1–2	Chapter 1.1 — Hazard, exposure, risk, damage. The vocabulary and why it matters	Fig. 1.1	Distinguish hazard from risk
3	Chapter 1.2 — The actors of prevention, inside and outside the undertaking	Fig. 1.7	Name who does what
4–5	Chapter 1.3 — Indicators of occupational accidents and diseases	Fig. 1.4	Compute FR and SR
6	Chapter 1.4 — Observing and analysing a work situation. Risk matrix. Hierarchy of controls	Fig. 1.2, 1.3	Rank and treat a risk
7	Chapter 1.5 to 1.8 — Tree of causes. Bow-tie. HAZOP. Major accidents	Fig. 1.5, 1.6, 1.14	Build a tree of causes
8–10	Chapter 2.1 and 2.2 — Occupational health, public hygiene, hygiene of premises	—	Recognise a health hazard

Weeks	Content	Figure	Key skill
11–13	Chapter 2.3 — The domains of environmental protection in a plant	Fig. 1.8	Map the plant’s impacts
14	Chapter 2.4 — Sustainable development and the industrial installation	—	Situate HSE in it
15	Chapter 2.5 to 2.7 — Bodies responsible. Fire. Emergency plan. Management system	Fig. 1.10, 1.11, 1.13	Know where to refer

Chapter 1 — Risk assessment and control, and the analysis of accidents

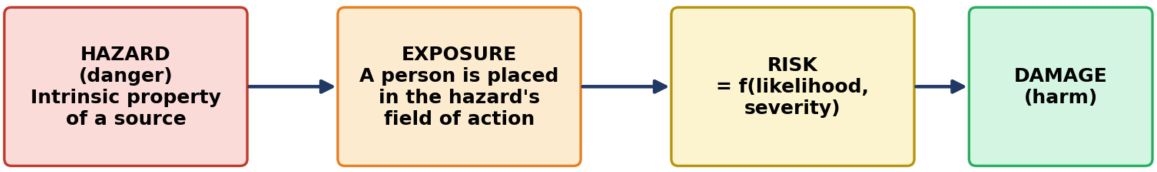
Seven weeks. This chapter builds the vocabulary and the three basic instruments of the safety engineer: the risk matrix, the hierarchy of controls, and the tree of causes.

1.1 The four terms: hazard, exposure, risk, damage

Everyday language uses *danger* and *risk* as synonyms. Safety engineering cannot, because the two words designate things on which one acts differently. The distinction is not a refinement of vocabulary: it decides where money is spent.

> **Hazard** — the intrinsic property of a substance, an item of equipment, a method or a situation, capable of causing harm. Sulphuric acid is corrosive whether or not anyone is near it. A hazard exists independently of any person. **Exposure** — the fact that a person is placed in the field of action of the hazard, with a frequency and a duration. **Risk** — the combination of the likelihood that harm occurs and of the severity of that harm. Risk exists only where hazard and exposure meet. **Damage** (harm) — the realised injury, illness, or loss.

Figure 1.1 — From hazard to damage: the four terms of risk



No exposure → no risk, however great the hazard.
Prevention acts on the hazard or on the exposure — never on the damage.

Two consequences follow immediately, and they organise the whole of prevention.

First: without exposure there is no risk, however great the hazard. A drum of concentrated acid stored in a locked, ventilated, bunded room presents a very high hazard and a very low risk. This is why the first prevention measures act on the hazard itself or on the exposure, and never on the damage — acting on damage is no longer prevention, it is first aid.

Second: risk has two dimensions and they must never be collapsed into one. A frequent minor cut and a rare fatal fall may receive the same score in a crude ranking, yet they call for entirely different treatment. Any method that reduces risk to a single number must state how it combined the two dimensions.

Worked distinction

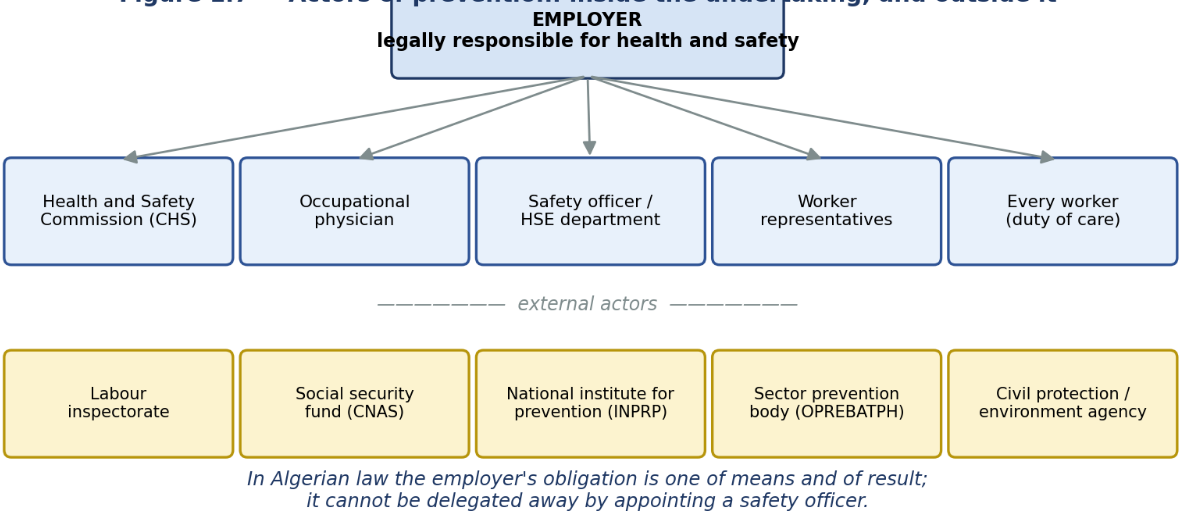
Situation	Hazard	Risk
Nitrogen cylinder in a closed room	Asphyxiant gas — high hazard	High if the room is unventilated and entered; near zero if ventilated and monitored
Pump running with its coupling guard removed	Rotating machinery — entanglement	High: the exposure is permanent for anyone passing

Situation	Hazard	Risk
Noise at 92 dB(A) in a compressor room	Hearing damage — chronic	Depends on daily duration of exposure, not on the peak level alone
Reactor operating at 12 bar	Stored energy — burst, projection	Low if the relief device is sized, tested and not isolated; high if any of the three fails

1.2 The actors of prevention

Prevention is not the business of one person. It is distributed between actors whose duties are defined by law, and a student who cannot name them cannot organise anything.

Figure 1.7 — Actors of prevention: inside the undertaking, and outside it



Inside the undertaking

- **The employer** bears the legal responsibility for the health and safety of the workers. In Algerian law this obligation derives from Law no. 88-07 of 26 January 1988 on occupational hygiene, safety and medicine, and from executive decree no. 91-05 of 19 January 1991 on the general prescriptions of protection. It cannot be transferred by appointing a safety officer: delegating a task does not delegate the responsibility.
- **The health and safety commission (CHS)** is the joint body where employer and worker representatives examine accidents, inspect the premises and propose measures. Its existence is a legal obligation above a threshold of employees, and its minutes are a source of evidence.
- **The occupational physician** carries out the medical surveillance of exposed workers, keeps the exposure records, and is the only actor entitled to declare a worker fit or unfit for a given post. The physician advises; the physician does not manage production.
- **The HSE department or safety officer** prepares the risk assessment, organises training, keeps the register of accidents and near misses, and monitors the effectiveness of measures.
- **Every worker** has a duty of care: to use the equipment as instructed, to wear the protective equipment provided, and to report any situation presenting a serious and immediate danger. This duty does not diminish the employer's.

Outside the undertaking

- **The labour inspectorate** verifies the application of the law, may serve formal notice and may order work to stop.
- **The social security fund (CNAS)** compensates occupational accidents and diseases, and holds the statistics from which national indicators are computed.
- **The National Institute for the Prevention of Occupational Risks (INPRP)** conducts studies, measurements and training in prevention.
- **The sector prevention body for construction, public works and hydraulics (OPREBATPH)** performs the same role for a sector where the accident rate is structurally the highest.
- **Civil protection and the environmental authorities** intervene on major accident hazards and on the environmental consequences of an installation.

> *Note for the student.* Legal references are given so that you know where to look, not to be learned by heart. Always verify the version in force: texts are amended, and citing a repealed article is a serious error in a professional report.

1.3 Indicators of occupational accidents and diseases

Measurement precedes management. An installation that does not count its accidents cannot say whether it is improving, and cannot compare itself with anything. But an indicator badly defined is worse than no indicator, because it produces confident false conclusions.

The two definitions that must be fixed first

Occupational accident — a sudden event, occurring by reason of or in the course of work, producing a bodily injury. Three elements: suddenness, a work connection, and an injury. A gradual hearing loss is not an accident, because it is not sudden.

Occupational disease — a pathology resulting from habitual exposure to a risk factor in the performance of work, and listed in an official schedule of occupational diseases. The schedule fixes the exposure conditions, the delay of onset and the work operations concerned. A disease not listed may still be recognised, but the burden of proof changes.

The four classical rates

Indicator	Formula	What it says
Frequency rate FR	FR = (number of lost-time accidents × 1 000 000) / number of hours worked	How often accidents happen. Independent of plant size
Severity rate SR	SR = (number of days lost × 1 000) / number of hours worked	How heavy their consequences are
Incidence rate IR	IR = (number of accidents × 1 000) / average number of workers	Used where hours worked are not recorded
Mean duration MD	MD = days lost / number of lost-time accidents	Average gravity of a single accident

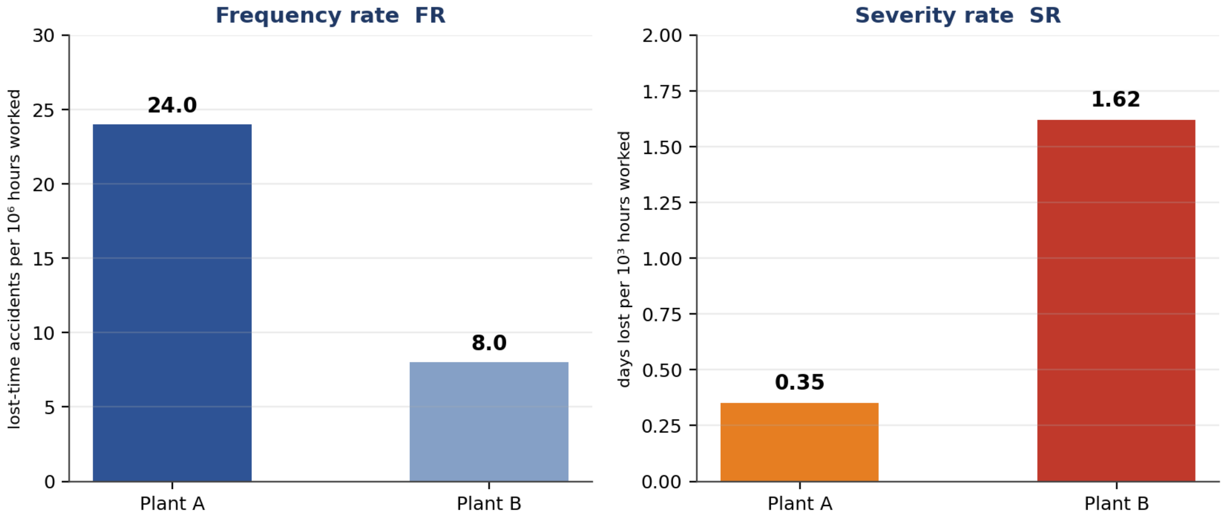
The two first are the ones to know. Note the multipliers: a million hours for the frequency rate, a thousand for the severity rate. They exist only to give numbers of convenient size, and **an indicator quoted without its multiplier is meaningless**.

Worked example

> Two plants of the same group, over one year. **Plant A** — 250 workers, 1 600 hours each, so 400 000 hours worked. Ten lost-time accidents, totalling 140 days lost. **Plant B** — 500 workers, 1 600 hours

each, so 800 000 hours worked. Six lost-time accidents, totalling 1 300 days lost, of which one accident alone accounts for 1 100 days. **Plant A** — FR = (10 × 1 000 000) / 400 000 = **25.0**; SR = (140 × 1 000) / 400 000 = **0.35**; MD = 140/10 = **14 days**. **Plant B** — FR = (6 × 1 000 000) / 800 000 = **7.5**; SR = (1 300 × 1 000) / 800 000 = **1.63**; MD = 1 300/6 = **217 days**.

Figure 1.4 — The two rates say different things, and both are needed
Plant A: many small accidents. Plant B: few accidents but severe ones.



Read the two rates together, never one alone. Plant B looks three times better on frequency and five times worse on severity. Its safety record is not better: it has fewer events but one of them was very nearly fatal. A management judged on the frequency rate alone would congratulate plant B and would miss precisely the accident that matters.

Two further cautions, which are the origin of most disputes over these figures. **Hours worked must be actual hours**, not contractual hours, otherwise plants with much overtime appear artificially safe. And **the counting rule for lost-time accidents must be identical** across the plants compared: if one counts accidents with at least one day lost and the other counts those with at least three, the comparison is void. This is a data quality problem before being a safety problem.

Near misses and the accident pyramid

The four rates all count events that have already produced an injury. They therefore measure the past, and they measure it with a very small sample: a plant may work several years without a serious accident and conclude, wrongly, that it is safe.

Figure 1.9 — The accident pyramid

The base is free information: near misses have the same causes as the accidents above them, but cost nothing. A plant that reports no near miss is not safe — it is not reporting.

The pyramid, established by Heinrich in the 1930s and refined by Bird in the 1960s, expresses a statistical regularity: **for one serious injury there are of the order of ten minor injuries, thirty events causing damage only, and several hundred events causing nothing at all**. The exact ratios vary with the industry and are not a law of nature. What matters is the shape, and its consequence for management.

The base of the pyramid is **free information**. A near miss has the same causes as the accident above it — the same missing guard, the same absent procedure — but it has cost nothing. A plant that collects, analyses and treats its near misses is analysing accidents that have not yet happened. A plant that reports none is not safe: it is not reporting, usually because reporting is punished.

> **The indicator that goes with this idea.** The number of near misses reported per hundred workers per year is a *leading indicator*: it announces the future. The frequency rate is a *lagging indicator*: it records the past. A management that watches only lagging indicators always reacts too late, and — worse — is rewarded for a low reporting rate, which is precisely the wrong incentive.

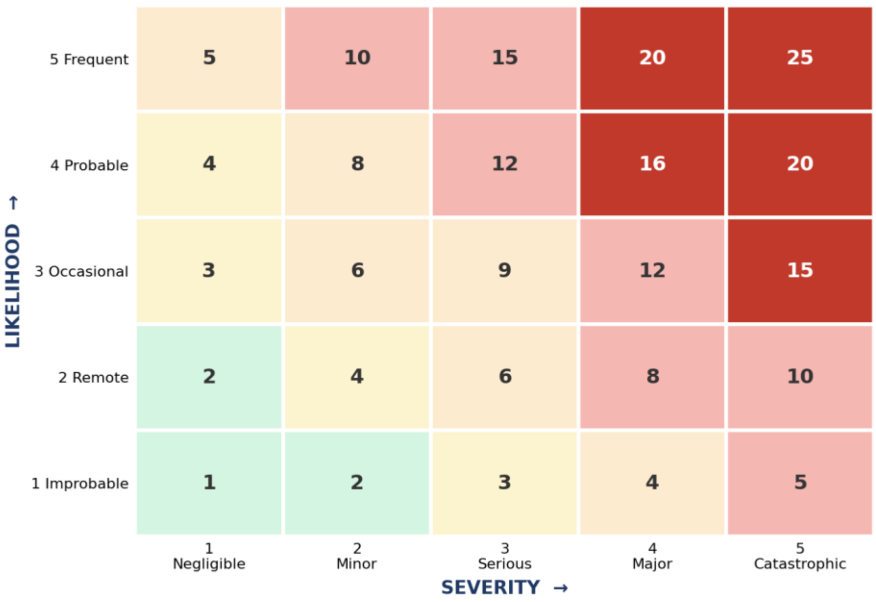
1.4 Observing and analysing the risks of a work situation

Risk assessment is a documented procedure, not an impression. It proceeds in five steps, and each produces a written trace.

4. **Break the plant into work units.** A unit is a group of posts exposed to the same risks — a workshop, a line, a maintenance team. Too coarse a division hides risks; too fine a division produces an unusable document.
5. **Identify the hazards present** in each unit: mechanical, electrical, chemical, thermal, noise and vibration, radiation, biological, ergonomic, psychosocial, and hazards of the working environment such as falls from height, circulation, or confined spaces.
6. **Characterise the exposure**: who is exposed, how often, for how long, and under which operating mode. Most severe accidents occur in **non-routine modes** — start-up, shutdown, cleaning, maintenance, breakdown — and an assessment that only considers normal operation misses them.
7. **Estimate and rank the risks**, by combining likelihood and severity in a matrix.
8. **Decide the measures**, following the hierarchy of controls, then plan them with a person responsible and a date, and verify their effectiveness afterwards.

The risk matrix

Figure 1.2 — Risk matrix: criticality = likelihood × severity
Green: acceptable · Yellow/orange: to reduce · Red: intolerable, work must stop

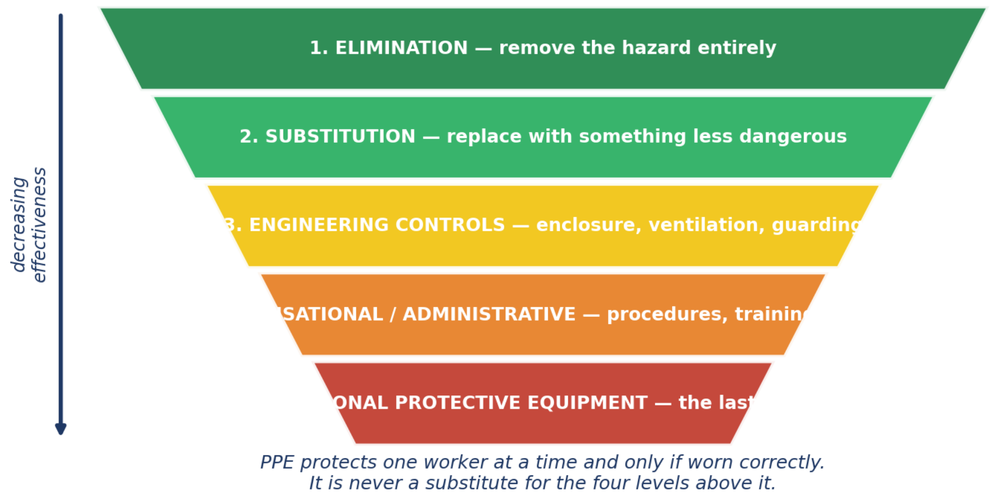


The matrix is a tool for **ranking**, not for measuring. Its scores have no physical meaning: a criticality of 12 is not twice a criticality of 6. Its whole value lies in producing a defensible order of priority and in forcing an explicit decision about what is acceptable. Three rules make it usable.

- **Define the scales in writing before scoring**, with examples: what counts as *serious*, what counts as *probable*. Otherwise two assessors score the same situation differently and the ranking is arbitrary.
- **Fix the acceptability boundary in advance**, not after seeing the results.
- **Never let a catastrophic severity be diluted by a low likelihood** without a specific examination. A rare event that kills is not managed like a frequent event that scratches, even at equal score.

The hierarchy of controls

Figure 1.3 — Hierarchy of prevention measures



The order is not a preference, it is a hierarchy of effectiveness, and it must be applied from the top downwards. Its logic is simple: the higher one acts, the less the measure depends on human behaviour.

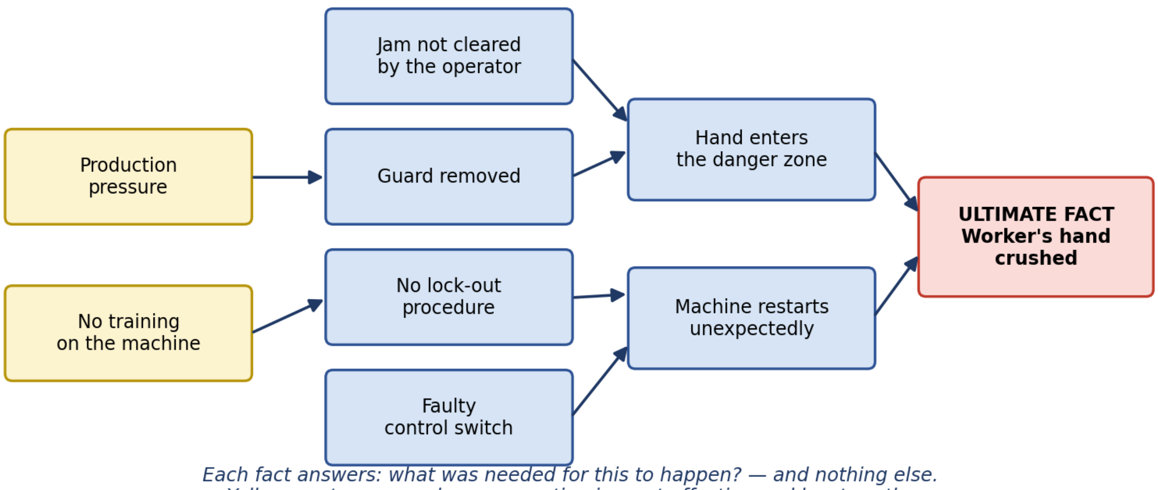
Level	Principle	Industrial example
Elimination	Suppress the hazard itself	Delete a solvent degreasing step by changing the process route
Substitution	Replace by something less hazardous	Replace benzene by toluene, or a powder by a granulate that does not form dust
Engineering	Interpose a physical barrier between hazard and person	Total enclosure with local exhaust ventilation; fixed guarding with interlock; closed transfer of liquids
Organisational	Reduce exposure by the way work is arranged	Permit-to-work, lock-out/tag-out, limiting the number of persons exposed, rotation, training
PPE	Protect the individual at the point of contact	Respirator, hearing protection, harness, gloves selected for the specific chemical

Why PPE comes last. It protects one person at a time; it works only if worn, correctly, throughout the exposure; it often adds discomfort and other risks; and it fails silently. It is the last barrier, never the first answer. A risk assessment whose only measure is *wear gloves* has not been done.

1.5 The tree of causes

The risk matrix looks forward. The tree of causes looks backward, from an accident that has occurred, to find the facts that made it possible. It was developed for occupational accident investigation and it has one great virtue: it forbids stopping at the first culprit.

Figure 1.5 — Tree of causes: read from right to left



Each fact answers: what was needed for this to happen? — and nothing else.
Yellow: root causes, where prevention is most effective and least costly.

Method

9. **Collect the facts**, as soon as possible after the event, on site, from those who were present. A fact is precise, observable and undisputed: *the guard was on the floor beside the machine*. It is not an opinion (*the operator was careless*), not a judgement, and not a hypothesis.
10. **Start from the ultimate fact** — the injury — and ask, for each fact: *what was necessary for this to happen?* Each answer is written to its left.

11. **Connect the facts** by the three possible links: a **chain**, where one fact leads to one fact; a **conjunction**, where two or more facts were all necessary together; a **disjunction**, where one fact produced several consequences.
12. **Stop** when a fact belongs to the permanent state of the workplace and no longer results from another fact of the event.
13. **Derive the measures.** Each fact of the tree is a possible point of action; the measures that act on the left of the tree — the root causes — are the most effective and usually the least expensive.

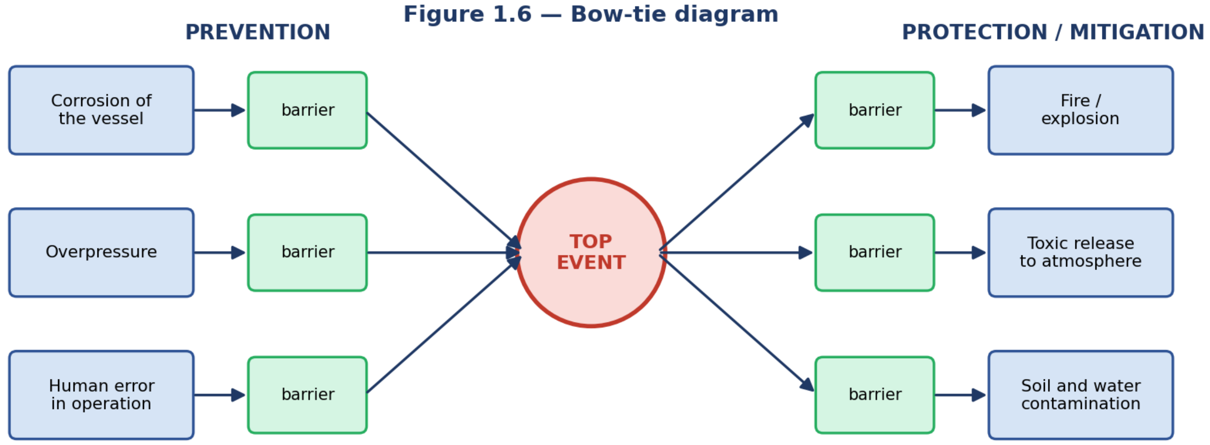
> **The rule that makes the method work.** Never write on the tree what did not happen. *The operator did not follow the procedure* is not a fact, it is an absence and a judgement. The fact is: *the procedure required lock-out; the machine was not locked out*. Turning judgements into facts is what allows an investigation to produce prevention instead of blame.

Applied to the example of Figure 1.5, a blame-based investigation stops at *the operator put his hand in the machine* and produces one measure: remind the operator. The tree reaches *no lock-out procedure*, *guard removed*, *production pressure* and *no training*, and produces four measures, three of which protect every future operator and not only this one.

1.6 Two complementary representations

The bow-tie

Figure 1.6 — Bow-tie diagram



Left of the knot: barriers that stop the event happening. Right: barriers that limit its consequences.
A barrier that appears on both sides is counted once, and its failure opens both paths.

The bow-tie places the feared event — loss of containment, fire, fall — at the knot. To its left, the threats that can cause it and the **prevention barriers** that stop them. To its right, the consequences and the **mitigation barriers** that limit them. It is the standard representation for major accident hazards in the process industries because it shows at a glance where barriers are missing, and because it makes explicit that a single barrier failure may open several paths.

The Swiss cheese model

Reason's model represents each barrier as a slice of cheese whose holes are its weaknesses. An accident occurs when the holes of every slice align. The teaching of the model is that **accidents are not caused by a single failure but by the coincidence of several latent weaknesses**, most of them created long before, by decisions of design, staffing or maintenance. It explains why searching for *the* cause of an accident is usually a mistake.

1.7 A priori risk analysis in an industrial installation

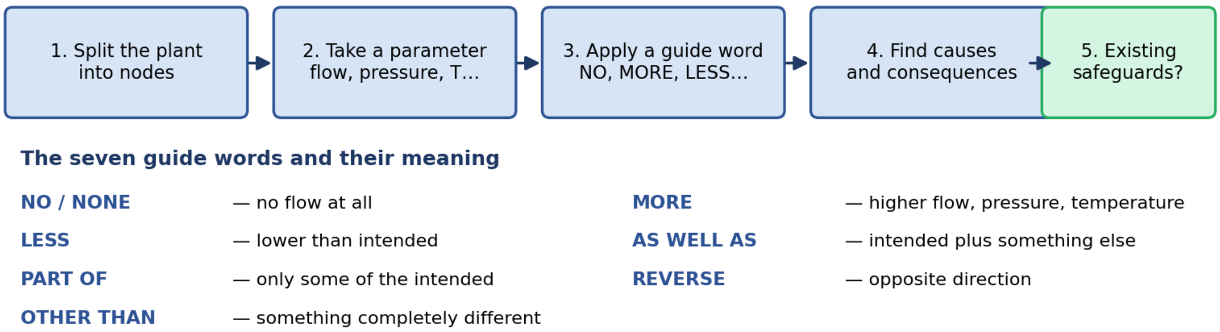
The methods of §1.4 suit the ordinary risks of a workplace. An industrial installation handling pressure, temperature, flammable or toxic substances requires something more systematic, because the dangerous scenarios are not visible by observation: they arise from **deviations of the process** that no one has imagined.

The three classical methods

Method	Principle	When it is used
Preliminary hazard analysis PHA	List the dangerous substances and energies present, and for each the possible undesirable events	Early, at the concept stage, when little is fixed. Cheap and coarse
HAZOP hazard and operability study	Divide the plant into nodes; for each node apply guide words to each process parameter and look for deviations	On a completed process flow diagram, before construction, and after any significant modification
FMEA failure modes and effects analysis	For each component, list its failure modes, their effects and their detection	On equipment and control systems, where the failure of a component is the starting point

HAZOP, the method to know

Figure 1.14 — The HAZOP method: a systematic search for deviations



HAZOP is conducted by a **team**, not by an individual: process, operations, maintenance, instrumentation and safety must all be present, because a deviation is dangerous for reasons that no single discipline sees. The team works through the plant node by node, and for each parameter — flow, pressure, temperature, level, composition — it applies each guide word and asks three questions: **what causes this deviation? what are its consequences? what already protects us?**

Worked extract of a HAZOP table

Node: feed line to a reactor. Parameter: flow.

Guide word	Cause	Consequence	Existing safeguard, and what is missing
NO flow	Pump stopped; valve closed in error; line blocked	Reaction stops; on restart, accumulation of unreacted feed then runaway	Low-flow alarm exists. **No interlock stopping the heating** — to be added
MORE flow	Control valve fails open; wrong set point	Excess reagent, exotherm exceeds cooling capacity, overpressure	Relief valve sized for fire case only. **Sizing for the runaway case not verified**

Guide word	Cause	Consequence	Existing safeguard, and what is missing
LESS flow	Partial blockage; strainer fouled	Off-specification product; local overheating in the exchanger	Differential pressure gauge, read manually. **No alarm**
REVERSE flow	Pump stops while the downstream is at higher pressure	Contamination of the feed tank by reaction mixture	**No non-return valve on the line** — to be installed

> **Read the last column.** The value of a HAZOP is not the list of deviations, which is predictable: it is the systematic confrontation of each deviation with the barriers that actually exist. Every line where that column is empty is a decision to be taken, with a person responsible and a date.

From analysis to barriers

A barrier is any element that interrupts a scenario. Barriers are classified by what they depend on, and this classification decides how much one may rely on them.

- **Passive barriers** — a bund, a wall, a flame arrester, a correctly sized relief device. They work without energy, without detection and without human action. They are the most reliable.
- **Active automatic barriers** — a safety instrumented function: a sensor, a logic solver, a final element. They require energy, calibration and periodic proof testing. Reliable if maintained, useless if inhibited.
- **Human barriers** — an operator responding to an alarm, a procedure, a permit. They are indispensable but the least reliable, because their performance falls exactly when the situation degrades, that is when they are most needed.

Two properties must be verified for every barrier and are the object of most audit findings: **independence** — a barrier that shares its sensor with the control system is not a second barrier, it is the same one counted twice — and **effectiveness**, which must be demonstrated by test and not assumed.

1.8 Major accidents and the domino effect

A major accident is an event — a major emission, a fire, an explosion — resulting from uncontrolled developments in an industrial activity, entailing a serious danger to people or to the environment, inside or outside the establishment. What distinguishes it from an occupational accident is not its violence but its **reach**: it can affect people who have no relation with the plant.

The four dangerous phenomena of the process industries

Phenomenon	Mechanism	Effect that reaches beyond the fence
Pool fire / jet fire	Ignition of a liquid pool or of a pressurised release	Thermal radiation; propagation to neighbouring equipment
Vapour cloud explosion	Delayed ignition of a flammable cloud in a congested area	Overpressure; window breakage and structural damage at distance
BLEVE	Rupture of a vessel containing a liquid above its atmospheric boiling point, engulfed in fire	Fireball, projectiles thrown several hundred metres
Toxic dispersion	Release of a toxic gas or vapour carried by the wind	Exposure of the surrounding population; effects depend on weather

The domino effect

The domino effect is the aggravation of an initial accident by the failure of neighbouring equipment that it damages. A pool fire heats an adjacent sphere, which bursts, whose fragments strike a third unit. Three consequences for design and for regulation follow, and they are examinable.

14. **Separation distances** between units are not an aesthetic choice: they are calculated from thermal radiation and overpressure thresholds.
15. **The initiating event must be studied together with its neighbours**, which is why the safety report of a classified installation examines the site and not each item of equipment in isolation.
16. **Emergency planning must consider the escalation**, because the resources adequate for the initial event are not adequate for the third one.

> **Why this concerns the process engineer specifically.** The distance between two units, the position of a control room, the choice between a pressurised sphere and refrigerated atmospheric storage, the decision to bund or not to bund — all are taken at the design stage, all fix the magnitude of the possible major accident, and none can be corrected afterwards without rebuilding.

1.9 A complete worked risk assessment

The methods of the preceding sections are worth nothing separately. This section applies them together to one work unit, in the form that a risk assessment document actually takes.

> **The unit.** A solvent storage and drumming area of a process plant: reception of road tankers, transfer to two 30 m^3 tanks, drumming into 200-litre drums, storage of full drums under a canopy. Four operators, one shift, one supervisor. Products: toluene and acetone, both flammable, both with occupational exposure limits.

Hazard	Situation of exposure	Possible damage	Initial rating	Measures, by decreasing level
Flammable atmosphere	Drumming in the open; vapours released at each filling	Flash fire, burns, possible vapour cloud explosion	L 3 × S 5 = **15**	Closed drumming with vapour return (engineering); electrical zoning and equipment suitable for the zone; bonding and earthing of the drum; no ignition source, permit for hot work
Inhalation of solvent vapour	Operator at the filling head, four hours a day	Narcosis, chronic effects on the nervous system	L 4 × S 3 = **12**	Closed transfer (engineering); local exhaust at the filling head; measurement of the exposure and comparison with the eight-hour and short-term limits; respirator only for non-routine tasks
Spillage and spreading	Hose disconnection, drum overfill	Environmental contamination; fire spread	L 3 × S 4 = **12**	Bunding sized for the largest tank plus rain (passive); level alarm and automatic cut-off at high level; absorbent at the point of risk; drainage to an interceptor, not to the storm system
Overfilling of the tank	Tanker discharge without independent level control	Tank rupture, major spill	L 2 × S 5 = **10**	Independent high-level trip, separate from the level indication used for operation (independence of barriers); written discharge procedure with the driver

Hazard	Situation of exposure	Possible damage	Initial rating	Measures, by decreasing level
Manual handling of drums	Moving and stacking full 200-litre drums	Back injury, crushing of feet	L 4 × S 2 = **8**	Drum handler or pallet truck (engineering); limitation of stacking height; training in handling; safety footwear
Slipping	Floor wetted by product or by rain under the canopy	Fall, fracture	L 3 × S 2 = **6**	Non-slip surface; immediate mopping; drainage of the canopy; lighting

What this table teaches, and what the examination expects you to notice

- **The ranking is not the ranking of intuition.** Manual handling scores 8 and flammable atmosphere 15, yet the second is invisible while the first is obvious. Intuition ranks by visibility; the matrix ranks by criticality.
- **Every line begins with a measure above the level of protective equipment.** Where the first proposal is a respirator or a glove, the assessment has not been done.
- **The independence of barriers appears explicitly** on the overfilling line. A high-level trip that shares its sensor with the level indication is not a second barrier.
- *The rating is initial.* After the measures, the residual risk must be re-rated, and the difference is what justifies the expenditure. An assessment with a single column of ratings does not show that anything was gained.

> **And the column that this table does not have.** A real document adds, for each measure, the **person responsible** and the **deadline**, and afterwards the **verification of effectiveness**. Without those three, a risk assessment is a description of the plant and not a management instrument.

1.10 Case study: reading an accident with the instruments of the chapter

> **The narrative.** During a night shift, an operator is asked to clear a blockage in the outlet of a mixer. The interlocked guard has been bypassed for three weeks, since a faulty switch prevented the machine from starting; a work order was raised and the spare is on order. The lock-out procedure exists but applies to electrical maintenance and not to production interventions, which are described in no document. The operator, alone, opens the outlet and introduces a bar; the mixer, whose control switch is intermittent, restarts. The operator's hand is crushed. Sixty-two days of work are lost.

First reading: the indicators

The plant works 480 000 hours a year and records this accident plus four others, totalling 96 days lost including this one at 62. FR = (5 × 1 000 000) / 480 000 = **10.4**; SR = (96 × 1 000) / 480 000 = **0.20**; mean duration = **19 days**. Both rates are unremarkable. **The indicators do not see this accident**, because one severe event is diluted among four minor ones — which is exactly the limitation established in §1.3.

Second reading: the tree of causes

Ultimate fact: the hand is crushed. In conjunction to its left: *the hand was in the danger zone* and *the machine restarted*. To the left of the first: *the outlet was blocked* and *the intervention was made through the outlet*. To the left of the second: *the guard was bypassed* and *the control switch was intermittent*. Further left: *the spare switch was not in stock*, *no procedure covered production interventions*, *the bypass had been tolerated for three weeks*, and *the operator was alone at night*.

Note what the tree does not contain. It does not contain *the operator was imprudent*. That is a judgement, not a fact, and writing it would have stopped the analysis at the last link — producing one measure, a reminder to the operator, instead of the six that the root causes suggest.

Third reading: the barriers

Three barriers existed on paper and all three had failed, each in a different way. The **interlocked guard** was a physical barrier neutralised by a bypass — the strongest barrier, defeated because the plant preferred production to a stoppage. The **lock-out procedure** was a human barrier whose scope did not cover the situation — a barrier that exists but does not apply is not a barrier. The **maintenance system** should have replaced the switch within three weeks and did not, for a reason of spare parts management that has nothing to do with safety and everything to do with it.

This is the Swiss cheese of §1.6 in its exact form: three slices, three holes, and the holes aligned on a night when one operator was alone.

Fourth reading: what should have been done, and when

Moment	Instrument that would have caught it	Why it did not
At design	HAZOP or FMEA on the mixer: *blockage of the outlet* is a foreseeable deviation	The deviation was foreseen but the intervention method was not specified
At the first bypass	A register of bypasses with a deadline and an authorisation	No such register existed; a bypass was a workshop arrangement
During the three weeks	The near-miss pyramid of §1.3: working on a bypassed guard is a near miss reported every day	Nobody reports what everybody does
On the night itself	A rule forbidding lone working on an intervention inside a machine	The rule did not exist

> **The sentence to retain from this case.** The accident was not caused by the last gesture of the operator. It was caused three weeks earlier, by a decision to continue producing with a bypassed guard, and that decision was taken by people who were not present on the night and who were not injured.

1.11 Exercises — chapter 1

Exercise 1.1. A workshop of 120 workers records, over a year, 192 000 hours worked, 8 accidents with lost time and 96 days lost. Compute FR, SR and the mean duration. The group target is FR below 15. Is it met?

Exercise 1.2. Classify the following as hazard or risk, and justify in one sentence: (a) chlorine; (b) working alone at night on a chlorination unit; (c) a 400 V cabinet; (d) a 400 V cabinet whose door lock is broken and which stands in a passageway.

Exercise 1.3. A worker slips on an oil patch while carrying a drum, and fractures a wrist. The patch came from a leaking flange reported two weeks earlier; the repair was postponed for want of a spare gasket; the corridor lighting had been out for a month; no absorbent was available. Build the tree of causes and propose one measure per root cause.

Exercise 1.4. For a solvent degreasing bath, propose one measure at each of the five levels of the hierarchy of controls, and state for each what it depends on to remain effective.

Exercise 1.5. For the storage and drumming unit of §1.9, take the line *inhalation of solvent vapour* and propose a residual rating after the measures, justifying the change of likelihood, of severity, or of both.

Exercise 1.6. Apply four HAZOP guide words to the parameter *level* of the 30 m^3 tank of §1.9, and for each give a cause, a consequence, and the barrier that should exist.

Exercise 1.7. In the case study of §1.10, identify which of the three failed barriers was passive, which was active and which was human, and rank them by the reliance one may place on them.

Exercise 1.8. A plant reports 0 near misses and an FR of 6. A second reports 240 near misses and an FR of 18. Which of the two would you rather work in, and why? Use §1.3.

Chapter 2 — Occupational health and environmental protection

Eight weeks. Chapter 1 dealt with the sudden event. This chapter deals with what acts slowly: the health of the worker, the hygiene of the premises, and the effects of the installation beyond its fence.

2.1 Occupational health and public hygiene

Occupational health is not the medicine of accidents. Its object is the chronic effect of work on the body, which appears after months or years, and which no accident indicator will ever detect. Three notions structure it.

Dose and exposure. For a chemical or physical agent, the effect depends on the intensity of exposure and on its duration. This is why occupational limits are expressed as time-weighted averages over eight hours, complemented by short-term limits for agents whose peaks matter. A worker exposed to half the limit for sixteen hours is not in the same situation as one exposed to the limit for eight.

Route of entry. Inhalation, skin absorption, ingestion. The dominant route decides the protection: a substance absorbed through the skin makes a respirator useless on its own, and many solvents are in this case.

Medical surveillance. Pre-assignment and periodic examinations, targeted according to the exposures actually present. Their purpose is not to select healthy workers but to detect the earliest reversible effect and to remove the person from exposure before the damage becomes permanent.

The main families of health hazards in an industrial installation

Family	Examples	Principal effect
Chemical	Solvents, acids, dusts, welding fumes, isocyanates	Irritation, sensitisation, organ toxicity, cancer
Physical	Noise, vibration, heat, cold, ionising and non-ionising radiation	Hearing loss, vascular disorders, heat strain
Biological	Legionella in cooling towers, moulds, contact with effluent	Infection, allergy
Ergonomic	Manual handling, repetitive movements, awkward postures, screen work	Musculoskeletal disorders — the first cause of occupational disease almost everywhere
Psychosocial	Excessive workload, shift work, isolation, lack of control	Sleep disorders, cardiovascular effects, error rate

> **A point worth remembering for the examination.** Musculoskeletal disorders and hearing loss dominate the statistics of occupational disease in almost every industrialised country, while public attention concentrates on chemical risk. The two are not proportionate, and this discrepancy is itself a fact of the discipline.

Occupational exposure limits and how they are used

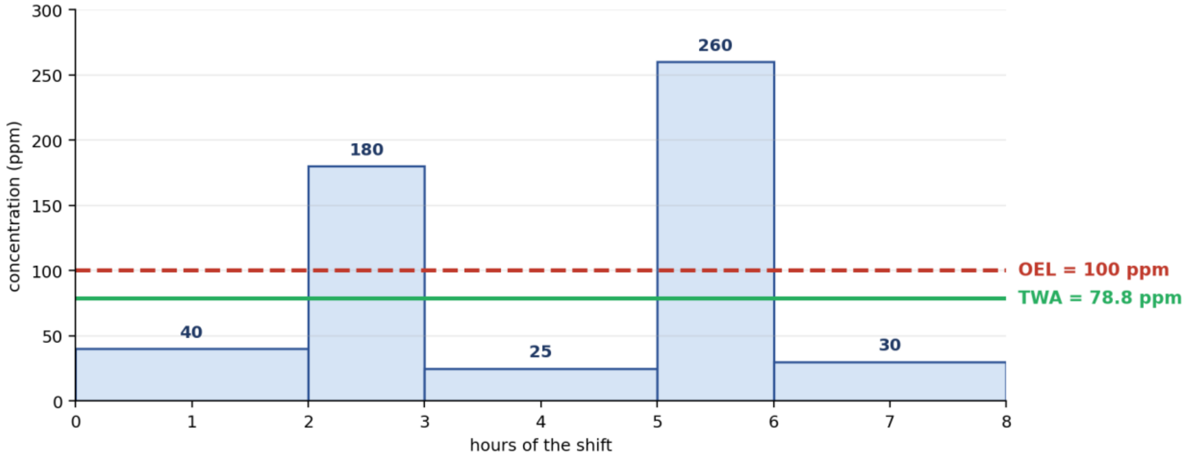
An occupational exposure limit is the concentration of an airborne agent to which a worker may be exposed, under defined conditions, without damage to health. Two limits coexist and both must be respected.

- **The eight-hour time-weighted average (TWA)**, which addresses chronic effects. It is a weighted mean over the shift, so that a period above the limit may be compensated by a period below it.

- **The short-term exposure limit (STEL)**, usually over fifteen minutes, which addresses acute effects — irritation, narcosis, immediate toxicity. It is never compensated: a peak above it is a breach whatever the average.

Worked example: computing a TWA

Figure 1.12 — Time-weighted average: the shift complies, two peaks do not
TWA below the limit does not exempt from the short-term limit on the peaks



> An operator is exposed to a solvent during an eight-hour shift, measured in five periods: 2 h at 40 ppm · 1 h at 180 ppm · 2 h at 25 ppm · 1 h at 260 ppm · 2 h at 30 ppm. TWA = (2×40 + 1×180 + 2×25 + 1×260 + 2×30) / 8 = (80 + 180 + 50 + 260 + 60) / 8 = 630 / 8 = **78.8 ppm**. Against an eight-hour limit of 100 ppm, **the shift complies**. But the periods at 180 and 260 ppm must be compared with the short-term limit, and if that limit is 150 ppm, **two breaches have occurred** even though the average is satisfactory.

The lesson is general and worth stating in an examination. An average conceals its own distribution. Two exposures with the same mean may be safe or dangerous depending on how the exposure is spread, which is why any exposure assessment reports the profile and not only the mean.

Noise, a case where the arithmetic is different

Noise is measured on a logarithmic scale, so levels are not added arithmetically. Two machines each producing 85 dB(A) together produce 88 dB(A), not 170. The rule to remember: **doubling the acoustic energy adds 3 dB**. Consequently, for the same daily dose, an increase of 3 dB(A) halves the permissible exposure time — 8 hours at 85 dB(A), 4 hours at 88, 2 hours at 91, 1 hour at 94.

Two thresholds structure the regulation of noise almost everywhere: a **lower action value**, at which hearing protection must be made available and information given, and an **upper action value**, at which its use becomes obligatory, the areas are signposted and a programme of technical reduction becomes mandatory. Note the order: the obligation to reduce at source is never replaced by the obligation to wear protection.

2.2 Hygiene of premises and of the working environment

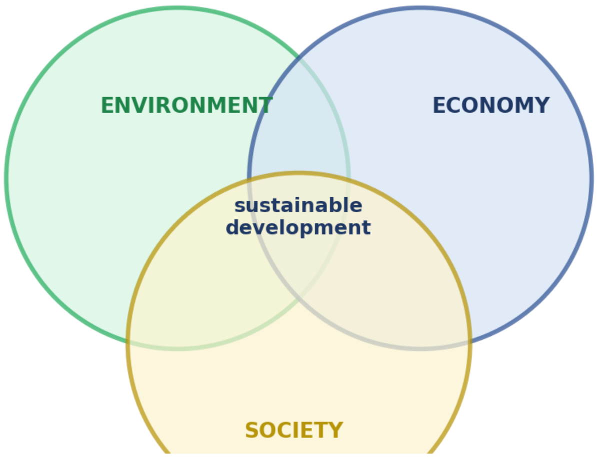
The syllabus calls this *hygiène de l'habitat*: the conditions that must be met by the place where people work or live, independently of any particular process. They are the oldest part of occupational regulation, and the most often neglected because they are unspectacular.

Element	What is required, and why
Air and ventilation	A minimum rate of fresh air per occupant; general ventilation to dilute, local exhaust to capture at source. Capturing at source is always superior: it removes the contaminant before it reaches the breathing zone
Lighting	Levels adapted to the task, absence of glare and of stroboscopic effect on rotating machinery, and emergency lighting on escape routes
Thermal environment	Temperature, humidity and air velocity within the comfort range; heat stress management where the process imposes high temperatures
Water and sanitation	Drinking water, washing facilities proportionate to the workforce and to the soiling of the work, separate facilities where a chemical risk exists
Premises and circulation	Floors even and non-slip, gangways free, separation of pedestrian and vehicle traffic, protected changes of level
Cleaning and waste	Cleaning regime adapted to the process; segregation of hazardous waste at the point of production, not at the gate
Rest and meals	Areas separate from the work areas — eating in a workshop is a classical route of ingestion of contaminants

2.3 The domains of environmental protection

An industrial installation exchanges matter and energy with its surroundings. Environmental protection consists in knowing these exchanges, measuring them, and keeping them within limits fixed by the authority. The main instrument in Algerian law is Law no. 03-10 of 19 July 2003 on environmental protection within the framework of sustainable development, together with the regime of **classified installations**, which subjects an activity to authorisation or declaration according to the hazard and nuisance it presents.

Figure 1.8 — Environmental protection and the three pillars



Domains of environmental protection in an industrial plant

- Air quality and emissions
- Water: abstraction, discharge, quality
- Soil and contaminated land
- Waste: hazardous and non-hazardous
- Noise and vibration
- Biodiversity and land use
- Energy and greenhouse gases

The seven domains, and what is measured in each

Domain	Sources in a plant	Typical measurement
Air	Stacks, vents, fugitive emissions from flanges and seals, combustion	Concentration and mass flow at the stack; ambient monitoring at the boundary
Water	Process effluent, cooling water, run-off from paved areas	Flow, pH, COD, BOD, suspended solids, specific pollutants
Soil and groundwater	Leaks from tanks and pipes, historical contamination, spills	Soil sampling, monitoring boreholes downstream of the site

Domain	Sources in a plant	Typical measurement
Waste	Process residues, sludge, used oils, packaging, laboratory waste	Quantities by category, traceability from production to final disposal
Noise	Compressors, fans, flares, road traffic generated	Equivalent level at the boundary, day and night
Biodiversity and land	Land take, discharge to a receiving water body, fragmentation	Impact assessment before construction
Energy and greenhouse gases	Combustion, electricity, process emissions, flaring	Consumption, emission inventory

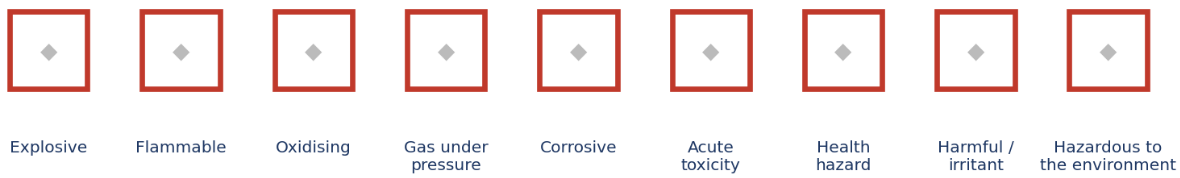
The instrument that ties them together is the environmental impact assessment, required before authorisation of a new installation or a substantial modification. Its logic is the same as that of risk assessment: describe the initial state, identify the effects, evaluate them, propose measures to avoid, reduce and — only as a last resort — compensate them, and set out how the result will be monitored.

> **Why the process engineer, and not only the environmental officer, must know this.** Almost every environmental improvement is decided at the design stage: a closed transfer instead of an open one, a condenser on a vent, a heat recovery loop, a segregated drain. Once the plant is built, the only remaining options are end-of-pipe treatments, which are the most expensive and the least reliable.

Hazard communication: labelling and the safety data sheet

An installation may hold hundreds of chemical products. None of the preceding methods works if the operator cannot know, in a few seconds, what is in the drum in front of him. This is the purpose of the globally harmonised system of classification and labelling, adopted in most countries and transposed into national regulation.

Figure 2.13 — The nine hazard pictograms of the GHS (shape and frame only)



A label carries: the pictogram, a signal word (DANGER or WARNING), hazard statements (H) and precautionary statements (P), the product identifier and the supplier. The safety data sheet develops all of it in sixteen sections.

A compliant label carries six elements: the **product identifier**, the **pictograms**, a **signal word** — DANGER for the more severe category, WARNING for the less severe — the **hazard statements** coded H, the **precautionary statements** coded P, and the **supplier's details**. Each is prescribed by the classification and none is left to the supplier's choice.

The **safety data sheet** develops the same information in sixteen sections, in a fixed order, so that a given information is always found in the same place: identification, hazards, composition, first aid, firefighting, accidental release, handling and storage, exposure controls and personal protection, physical and chemical properties, stability and reactivity, toxicological information, ecological information, disposal, transport, regulatory information, other information. **Sections 8 and 9 are the ones the process engineer uses most**: they give the exposure limits and the properties — flash point, vapour pressure, explosive limits — from which the design of ventilation, of electrical zoning and of storage is derived.

> **A rule of professional practice.** A product entering a site without its safety data sheet cannot be assessed, therefore cannot be safely used. Making the receipt of the sheet a condition of acceptance of the delivery is one of the least expensive and most effective measures available to an HSE department.

2.4 Sustainable development and the industrial installation

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own. Applied to an installation, the definition becomes operational through three commitments that can be verified.

- **Do not transfer the problem.** A measure that reduces an atmospheric emission by producing a hazardous sludge has displaced the impact, not reduced it. This is why impacts are examined together and not one at a time.
- **Act at the source rather than at the end of the pipe.** Prevention of pollution — better yields, closed loops, substitution of solvents, recovery of heat — costs less and is more robust than treating a waste stream once created. This is the same reasoning as the hierarchy of controls in safety, and it is not a coincidence: both rank measures by their independence from human vigilance.
- **Measure and declare.** An objective without an indicator, a method and a baseline is a statement of intent. The indicator must be defined precisely enough for a third party to recompute it.

The link with HSE is direct. Safety protects the worker inside the fence, environmental protection protects the population and the ecosystems outside it, and health protects both over the long term. They use the same instruments — identification, assessment, hierarchy of measures, verification — which is why they are managed together, and why the three management standards ISO 9001, ISO 14001 and ISO 45001 share the same high-level structure.

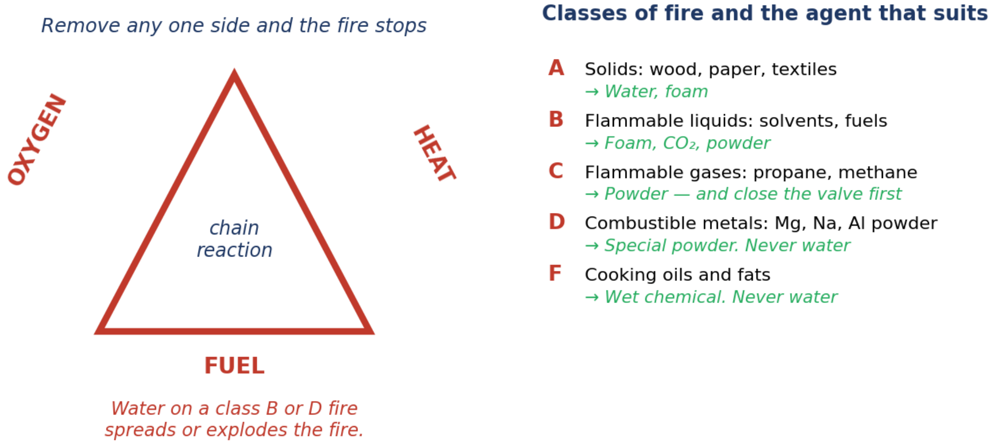
2.5 The bodies responsible, and their missions

Body	Mission
Labour inspectorate	Verify the application of labour and safety law; serve notice; order stoppage in case of serious and imminent danger
CNAS	Compensate occupational accidents and diseases; hold the national statistics; incentivise prevention through contribution rates
INPRP	Study, measure, train and advise on occupational risk prevention
OPREBATPH	Same mission for construction, public works and hydraulics
Occupational health services	Medical surveillance, exposure records, fitness opinions, advice on workplace design
Civil protection	Emergency response; approval of emergency plans for hazardous installations
Environmental administration and its agencies	Authorisation of classified installations, inspection, examination of impact assessments
Public health services	Water quality, food hygiene, communicable disease, including the health of populations around installations

2.6 Fire and emergency preparedness

Fire is the most frequent major event in industry and the one whose physics is simplest to teach, which is why it belongs in a first course.

Figure 1.10 — The fire triangle and the classes of fire



Combustion requires three elements simultaneously — a **fuel**, an **oxidiser**, and an **ignition source** providing the activation energy — sustained by a chain reaction of free radicals. Removing any one of them extinguishes the fire, and every extinguishing technique corresponds to one of the four removals: **cooling** removes the heat, **smothering** removes the oxygen, **starving** removes the fuel, and certain powders and gases **break the chain reaction** chemically.

Three quantities that decide everything, and that come from the safety data sheet

- **Flash point** — the lowest temperature at which a liquid gives off enough vapour to form an ignitable mixture. Below it, no flame can be sustained above the liquid. It is the criterion by which liquids are classified as flammable and by which storage rules are fixed.
- **Explosive limits** — the lower and upper concentrations of vapour in air between which the mixture ignites. Below the lower limit the mixture is too lean, above the upper limit too rich. **Ventilation aims to keep the atmosphere below the lower limit**, usually below a fraction of it.
- **Auto-ignition temperature** — the temperature at which the mixture ignites without any external source. It fixes the maximum surface temperature permitted for equipment in the zone.

Emergency preparedness

Figure 1.13 — Chain of an internal emergency plan

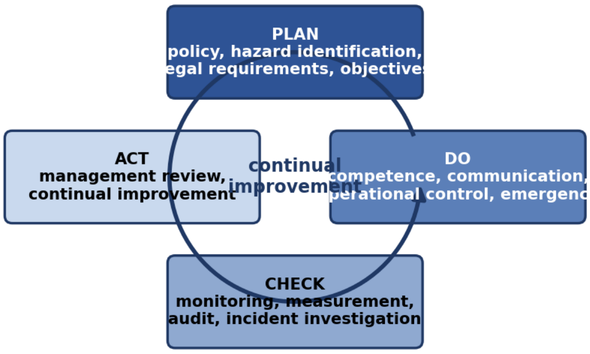
Every link must be tested by exercise at least once a year, and the head count is the link that fails most often.
A plan never exercised is a document, not a plan.

An internal emergency plan organises the response to an event that exceeds ordinary means. Its content is less important than two properties that are systematically checked in an audit: **it must be exercised**, at least annually and with the external services, and **it must be updated** after every exercise and every modification of the installation. The link that fails most often is not the fire fighting: it is the **head count at the assembly point**, because it depends on a list of persons present that nobody maintains in real time.

2.7 Managing HSE: the system and its cycle

Everything in this course — assessment, measures, indicators, investigation, emergency planning — is a fragment. A management system is what makes the fragments into a whole that survives the departure of the person who created it.

Figure 1.11 — The PDCA cycle of a management system (ISO 45001)



The PDCA cycle is the skeleton of ISO 45001 for occupational health and safety, and of ISO 14001 for the environment. Its four phases are not a slogan.

PLAN	Determine the context and the interested parties; identify the hazards and assess the risks; identify the legal requirements applicable; set objectives that are measurable and dated
DO	Provide the resources and the competence; communicate; control the operations, including those of contractors and of purchasing; prepare the emergency response
CHECK	Monitor and measure; evaluate compliance with the legal requirements; investigate incidents; audit internally
ACT	Review the system at management level; correct the nonconformities; improve continually

> **The clause students underestimate and auditors do not.** *Evaluation of compliance* requires the organisation to establish which legal requirements apply to it, and to verify periodically that it meets them, with evidence. It is the point where this course and the companion course on regulation and standards meet: you cannot evaluate compliance with a text you have not identified, and you cannot identify it without knowing the hierarchy of norms.

Waste and effluent: two worked applications

Waste. The first operation is not treatment, it is **classification**, because the rules that follow depend on it. A waste is hazardous if it presents one of the properties listed by the regulation — flammable, corrosive, toxic, ecotoxic, infectious — and the classification decides the packaging, the labelling, the authorised carrier, the authorised destination and the documents that must accompany it.

Three rules govern practice, and they are examinable. **Segregate at the point of production**: once a hazardous waste has been mixed with a non-hazardous one, the whole becomes hazardous, and the cost multiplies. **Never dilute to comply**: dilution changes the concentration without changing the quantity of pollutant, and it is prohibited. **Keep the traceability**: a tracking document follows the waste from producer to final destination, and the producer's responsibility does not end at the gate.

Effluent. An authorisation fixes limit values for a discharge, typically pH, temperature, suspended solids, chemical and biochemical oxygen demand, hydrocarbons, and the specific pollutants of the activity. Two of these deserve explanation because students confuse them.

Parameter	What it measures	What its value tells the engineer
COD chemical oxygen demand	The oxygen consumed to oxidise chemically all the oxidisable matter	The total organic load, biodegradable or not
BOD_5 biochemical oxygen demand	The oxygen consumed by micro-organisms in five days	Only the biodegradable fraction

> **The ratio COD/BOD_5 is the diagnostic.** Near 2, the effluent is largely biodegradable and a biological treatment will work. Above about 4, a large fraction is not biodegradable and biological treatment alone will fail, whatever its size. **A design decision therefore rests on two analyses that cost very little** — which is a good illustration of why measurement precedes engineering.

2.8 Exercises — chapter 2

Exercise 2.1. For a solvent recovery unit, list the emissions and discharges by domain, using the seven domains of §2.3, and propose for each one indicator that could be measured monthly.

Exercise 2.2. A cooling tower serves a plant of 300 people. Which family of health hazard does it introduce, by which route of entry, and what two measures address it? Which of the two acts higher in the hierarchy of controls?

Exercise 2.3. An improvement project reduces atmospheric emissions by 40 % by scrubbing, and generates 12 tonnes per year of hazardous sludge. Comment on this result in the light of §2.4, and propose an alternative acting at source.

Exercise 2.4. Compare, in a table of your own construction, the risk assessment of chapter 1 and the environmental impact assessment of §2.3: object, moment, method, output document, and who verifies.

Exercise 2.5. An effluent has COD = 1 800 mg/L and BOD_5 = 300 mg/L. Compute the ratio, say whether a biological treatment alone is appropriate, and propose an alternative.

Exercise 2.6. A liquid has a flash point of −18 °C and lower and upper explosive limits of 1.2 % and 7.1 % by volume. What does the flash point imply for its storage in a workshop at 25 °C, and what is the objective of ventilation expressed in terms of the explosive limits?

Exercise 2.7. Two machines each produce 88 dB(A) at the operator's position. What is the resulting level? For a daily limit of 85 dB(A) over eight hours, what exposure time would be permissible at the resulting level?

Exercise 2.8. Take the PDCA cycle of §2.7 and place in each of the four phases three activities described elsewhere in this course.

Solutions to selected exercises

Only the reasoning is given. A complete answer states the formula, then the numerical application with its units, then the interpretation.

Exercise 1.1

FR = (8 × 1 000 000) / 192 000 = **41.7**. SR = (96 × 1 000) / 192 000 = **0.50**. MD = 96 / 8 = **12 days**.

The target of 15 is **not met**, and by a wide margin: the workshop has almost three times the accepted frequency. The mean duration of twelve days indicates accidents of moderate severity, so the problem is the number of events and not their gravity. Prevention should therefore concentrate on the recurrent minor events, and the near-miss reporting of §1.3 is the natural starting point.

Exercise 1.2

(a) Chlorine is a **hazard**: toxicity is an intrinsic property of the substance. (b) Working alone at night on a chlorination unit is a **risk**: the hazard is unchanged but the exposure has increased and the possibility of rescue has decreased. (c) A 400 V cabinet is a **hazard**. (d) The same cabinet with a broken lock in a passageway is a **risk**, and a high one, because exposure has become permanent and involuntary.

Exercise 1.3

Ultimate fact: fractured wrist. To its left, in conjunction: *the worker slipped* and *the worker was carrying a drum*, which removed the possibility of catching himself. To the left of the slip: *oil on the floor* and *the patch was not visible*. To the left of the oil: *the flange leaked* and *the leak was not repaired*, itself explained by *no spare gasket in stock* and *no absorbent available*. To the left of the invisibility: *corridor lighting out for a month*.

Root causes and measures: spare parts management — hold a minimum stock of gaskets; maintenance of the premises — treat lighting failure as a safety fault with a fixed deadline; spill response — absorbent available at the point of risk; and manual handling — a truck rather than carrying, which acts higher in the hierarchy than any of the others.

Exercise 1.4

Elimination: suppress the degreasing step by changing the upstream operation so that the part is not soiled. Substitution: replace the solvent by an aqueous detergent, or by a solvent of much lower volatility and toxicity. Engineering: enclose the bath, fit a lid and local exhaust ventilation with a measured capture velocity. Organisational: written procedure, restricted access, limited duration, training, and a permit for cleaning operations. PPE: gloves selected for that specific solvent by their breakthrough time, and eye protection.

What each depends on: elimination and substitution depend on a technical decision taken once; engineering depends on the ventilation being maintained and measured; the organisational measures depend on supervision; the gloves depend on the right glove being chosen, worn, and replaced before breakthrough — three conditions that fail silently.

Exercise 2.2

A cooling tower introduces a **biological** hazard, *Legionella*, whose route of entry is **inhalation of aerosols**, and whose reach extends beyond the plant because the plume disperses. Two measures: a treatment and monitoring programme of the water — temperature control, biocide, periodic counts — and a design or modification limiting the emission of aerosol, by drift eliminators or, more radically, by replacing the wet tower with a dry cooler. **The second acts higher in the hierarchy**: the first is an operational control that fails if the programme lapses, the second removes the mechanism of exposure.

Exercise 2.3

The result is a **transfer of impact**, not a reduction: an atmospheric emission has become a hazardous waste, which will be transported, treated or landfilled, with its own impacts and its own cost. It may still be the right decision, but it must be presented as an arbitration and not as an improvement. An alternative acting at source would be to modify the process so that the pollutant is not formed — a change of solvent, a closed loop with recovery and reuse, a better yield — which suppresses both the emission and the sludge.

Exercise 1.8

The second. A frequency rate of 6 with no near miss reported means that the reporting system does not work: the events exist — the pyramid guarantees it — but they are not declared, usually because declaring is punished or useless. That plant is blind, and its low rate is a measurement artefact. The first plant sees its weak signals, therefore can act on them before they become injuries, and its higher rate reflects a more complete count. **A rising near-miss rate is usually good news and a falling one is usually bad**, which is counter-intuitive and is the point of the question.

Exercise 2.5

$COD/BOD_5 = 1\,800 / 300 = \mathbf{6}$. Well above 4: the effluent is largely non-biodegradable, and a biological treatment alone will remove only the fraction corresponding to about 300 mg/L, leaving 1 500 mg/L of chemical oxygen demand. A physico-chemical stage — coagulation, adsorption, chemical oxidation — is needed before or instead of the biological one. **Better still, look upstream**: a ratio of 6 usually signals a specific stream of recalcitrant matter that could be segregated at source rather than treated once diluted in the whole effluent.

Exercise 2.7

Two equal sources double the acoustic energy, which adds 3 dB: the level is **91 dB(A)**. Since 3 dB above the limit halves the permissible time, 8 hours at 85 give 4 hours at 88 and **2 hours at 91**. The correct answer to the situation is nonetheless not to limit the time but to reduce at source — enclosure, silencer, anti-vibration mounting — because time limitation is an organisational measure and reduction at source is an engineering one.

Glossary — English, French, Arabic

English	Français	العربية
Hazard	Danger	خطر
Risk	Risque	مخاطرة
Exposure	Exposition	تعرّض
Harm, damage	Dommage	ضرر
Occupational accident	Accident du travail	عمل حادث
Occupational disease	Maladie professionnelle	مهني مرض
Frequency rate	Taux de fréquence	التكرار معدل
Severity rate	Taux de gravité	الخطورة معدل
Tree of causes	Arbre des causes	الأسباب شجرة
Near miss	Presqu’accident	وشيك حادث
Hierarchy of controls	Hiérarchie des mesures de prévention	الوقاية تدابير تدرّج
Personal protective equipment	Équipement de protection individuelle	الفردية الحماية معدات
Lock-out / tag-out	Consignation	والوسم العزل
Permit to work	Permis de travail	العمل رخصة
Local exhaust ventilation	Captage à la source	الموضعي الشفط
Classified installation	Installation classée	مصنّفة منشأة
Environmental impact assessment	Étude d’impact sur l’environnement	البيئة على التأثير دراسة
Sustainable development	Développement durable	المستدامة التنمية

Assessment and study advice

Assessment: final written examination, 100 % of the mark. The paper is built on the five verbs of the aims: distinguish, identify, compute, rank, propose. Expect one computation of indicators with a comment, one tree of causes to build from a narrative, one situation to be treated by the hierarchy of controls, and short questions on the actors and on the environmental domains.

Three pieces of advice. First, learn the four terms of §1.1 well enough to use them without hesitation: half the marks lost in this subject come from confusing hazard and risk. Second, always write the formula before the numbers, and always state the unit and the multiplier. Third, in any question asking for measures, follow the hierarchy of controls in order and justify why the higher levels were or were not applicable — an answer that begins with protective equipment loses most of its value whatever follows.

Appendix — Four one-page tools for practice

These four instruments are given in a form directly usable in a workshop. They are not examinable as such, but the reasoning behind each one is.

A.1 Checklist before any intervention inside a machine

17. Is the intervention covered by a written procedure? If not, it must not proceed on the basis of habit.
18. Have all energies been isolated — electrical, mechanical, hydraulic, pneumatic, thermal, chemical, and stored energy such as springs and gravity?
19. Is the isolation locked, tagged, and is the key held by the person inside the machine?
20. Has the absence of energy been **verified**, and not assumed?
21. Is there a second person, and does that person know what to do?
22. If a guard has been bypassed, is the bypass registered, authorised and dated?

A.2 Reading a safety data sheet in five minutes

Section	What to read	What it decides
2	Hazard classification, pictograms, H statements	Whether the product may be used here at all
8	Exposure limits, engineering controls, PPE	The ventilation and the protective equipment
9	Flash point, explosive limits, vapour pressure, density	Electrical zoning, storage, ventilation rate
10	Incompatibilities, conditions to avoid	Segregation in the store
4 and 6	First aid, accidental release	The emergency instruction at the workstation

A.3 Ten questions that reveal a risk assessment made on paper only

- Does it cover start-up, shutdown, cleaning and breakdown, or only normal operation?
- Does it name a person responsible and a date for each measure?
- Is there a residual rating after the measures?
- Does any line begin with personal protective equipment?
- Are contractors and their work covered?
- When was it last revised, and after which event?
- Are the operators of the unit named among those consulted?
- Are the barriers claimed actually tested, and how often?
- Are two barriers claimed as independent really independent?
- Can the person who wrote it explain one line without reading it?

A.4 What to record about an accident, on the day itself

Position of the persons and of the equipment; state of the guards, of the switches, of the lighting; what was being done and why; who was present; the last modification of the installation and its date; the last maintenance intervention; the photographs, taken before anything is moved. **Everything not recorded**

on the first day is lost, because the site is cleared, the machine is repaired and the memories converge on a single agreed story.

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Legal references are given for orientation. Always consult the version in force before using them in a professional document.

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