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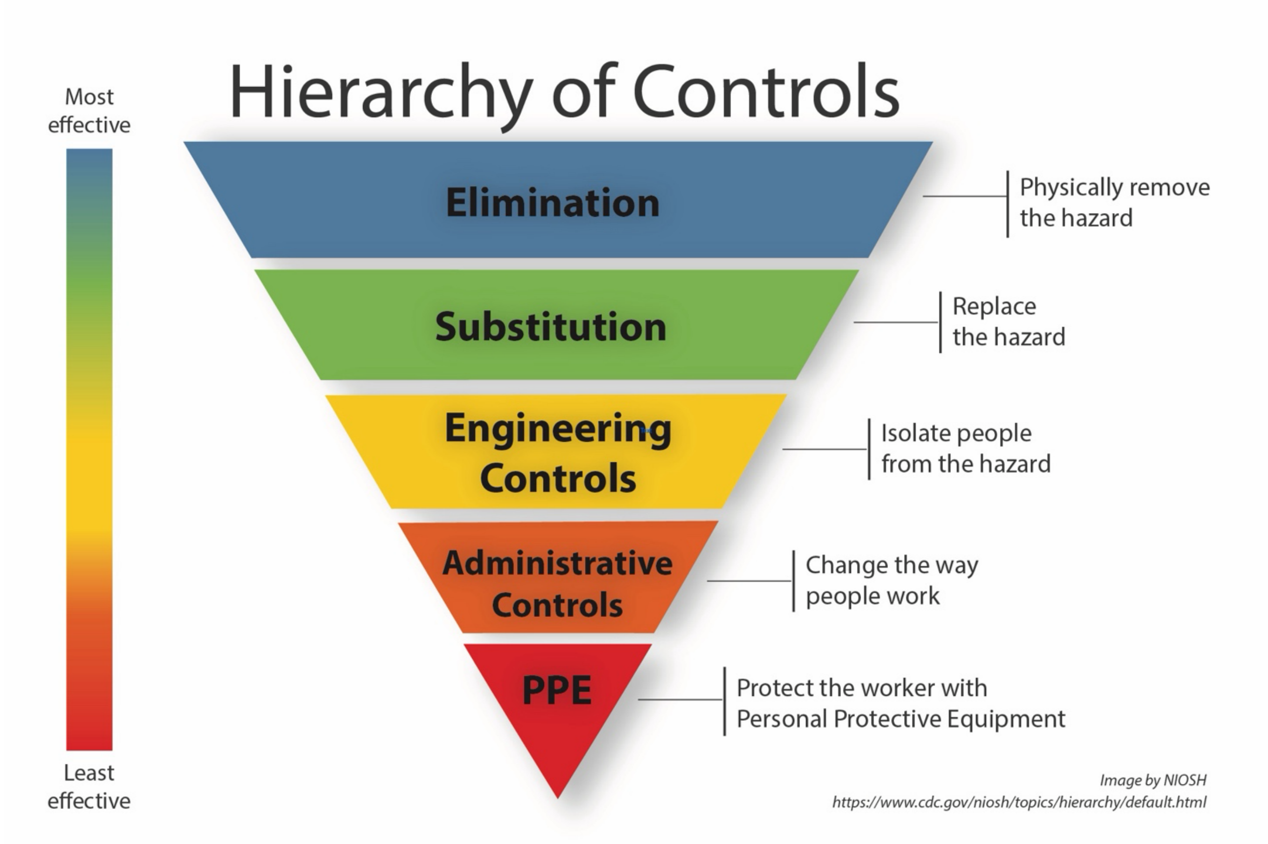
The "Hierarchy of Controls"

Origins and Applications to Process Safety and Risk Management



1. Origins

The hierarchy of controls formalises a principle long established in industrial hygiene: that exposure to a hazard is best managed by acting on the hazard itself before acting on the person exposed to it. The United States National Institute for Occupational Safety and Health (NIOSH), created under the Occupational Safety and Health Act of 1970, presents the hierarchy as the traditional method for selecting feasible and effective control measures, and situates it within its Prevention through Design programme, which gave the concept wider institutional traction from 2007 onward.

The hierarchy was subsequently codified in the American voluntary consensus standard ANSI/ASSP Z10, first issued in 2005 and revised in 2012 and 2017, which requires that organisations use the hierarchy of controls to achieve acceptable risk levels within an occupational health and safety management system. The same logic was carried into sector-specific standards, including the 2017 edition of NFPA 70E for electrical safety, where the pyramid diagram appears on the standard's cover. Parallel models developed in machinery safety (ANSI B11) and in prevention-through-design practice (ANSI/ASSP Z590.3) preserve the same ordering from elimination to personal protective equipment, while inserting intermediate categories such as minimisation, simplification and warning devices.

2. Structure and rationale

The canonical model ranks five tiers by decreasing reliability, lesser efficiency to reduce hazard. “Elimination” physically removes the hazard and is the most effective measure because it requires no ongoing human action. “Substitution” replaces the hazard with a less hazardous alternative. “Engineering controls” isolate people from the hazard through design, barriers or ventilation. “Administrative controls” change the way people work, through procedures, training, permits and scheduling. “Personal protective equipment” protects the individual worker but does not act on the hazard itself, and is classified as the least effective tier because its reliability depends entirely on correct and continuous human use, it is sometimes referred as the “sorry level” in the field.

The ordering reflects a single organising idea: controls positioned near the top of the pyramid do not depend on sustained correct behaviour, and therefore degrade less under fatigue, distraction, workload or organisational drift. Controls positioned near the base depend on it directly, and must be actively maintained to remain effective.

3. Application to Process Safety[i*]

In process safety, the hierarchy underlies the principles of inherently safer design, commonly summarised as minimise, substitute, moderate and simplify, which are applied upstream of layer-of-protection analysis and barrier-based risk models such as the bow-tie. Each protection layer or barrier in such a model can be classified against the same five tiers, which allows a facility to assess not only whether a hazard is controlled, but how structurally reliable that control is.

The hierarchy also frames incident investigation and corrective-action management. Recommendations arising from an investigation are conventionally ranked by where the proposed fix sits in the hierarchy, with elimination or engineering solutions preferred over retraining, signage or additional PPE, since NIOSH explicitly cautions against over-reliance on the lower, administrative tiers as a substitute for structural correction.

4. Application to general risk management

The same logic extends beyond occupational safety into general risk management, including project, technical and contractual risk. Risk is first avoided or eliminated at the design or scoping stage where possible; where it cannot be avoided, it is substituted for a lower-severity exposure, engineered out through technical or contractual controls, managed procedurally through governance and reporting, and, as a residual measure, transferred, insured or reserved against. This mapping is explicit in the ANSI/ASSP Z590.3 model, which extends the hierarchy to include a formal risk-avoidance step above elimination, and it is the same reasoning that underlies risk-allocation clauses in contract management, where the objective is to place each residual risk with the party best placed to control it, rather than to price it and accept it by default.

5. The residual base: accepting the least-effective tier and cultivating chronic unease

The base of the pyramid is explicitly the least effective tier, not because administrative controls and PPE are dispensable, but because they mark the floor of risk that remains after every higher-order control has already been applied as low as reasonably practicable (ALARP), or so far as is reasonably practicable (SFAIRP) — the point at which further reduction would be grossly disproportionate to the benefit gained. A team operating at this floor cannot remove the remaining exposure; it can only manage it, and accept it as the condition for continuing the work. When something nonetheless goes wrong at this level, the honest position is that reasonable measures were taken and the outcome is regretted, rather than that a control was missing — a distinction that matters for how an organisation learns from the event.

Sustaining safe performance at this floor is the specific purpose of what process-safety and high-reliability-organisation practice calls chronic unease, a term traced to Professor James Reason's 1997 description of a professional wariness toward risk, later adopted across high-reliability industries and developed as formal practice within drilling and process operations. Its working definition, drawing on the System 1/System 2 distinction in behavioural psychology, is the deliberate, effortful maintenance of doubt about whether current controls remain adequate, rather than the fast, intuitive assumption that an incident-free period means the risk has gone away.

Operationally, chronic unease is not a fixed attribute of a team but a state that must be renewed before each task and each shift, typically through toolbox talks, pre-job safety briefings and shift handovers, in which the team re-examines weak signals and residual hazards rather than treating the previous shift's risk assessment as still valid by default. This is what links the static pyramid diagram to day-to-day field behaviour: the lowest, least-effective tier is not a place to relax vigilance, but the one tier of the hierarchy that has to be actively re-earned at the start of every job.

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Definition of acronyms

ALARP — As Low As Reasonably Practicable — a risk-reduction target below which further mitigation would be grossly disproportionate to the benefit gained.

ANSI — American National Standards Institute.

ASSP — American Society of Safety Professionals.

HRO — High-Reliability Organisation(s).

LOPA — Layer of Protection Analysis.

NFPA — National Fire Protection Association.

NIOSH — National Institute for Occupational Safety and Health (United States).

OSHA — Occupational Safety and Health Administration (United States).

PPE — Personal Protective Equipment.

SFAIRP — So Far As Is Reasonably Practicable — the operative legal test underlying ALARP in several jurisdictions.

[i] *Process Safety:— a working definition*

Process safety is the discipline concerned with preventing loss of containment of hazardous materials or energy from a process — fires, explosions, toxic releases — as distinct from occupational (personal) safety, which addresses individual injuries such as falls or hand injuries. It is an interdisciplinary engineering discipline that applies systematic frameworks to manage the integrity of industrial processes handling hazardous substances, preventing major accidents such as uncontrolled releases, fires, explosions, and toxic exposures through hazard identification, risk evaluation, robust design, and operational safeguards, targeting low-frequency, high-consequence events arising from process deviations, equipment failures, or human errors. AIChE's Center for Chemical Process Safety puts it more simply: chemical process safety is just another name for process safety, distinct from chemical safety, which pertains specifically to protection against the toxic effects of chemicals arising in normal usage.

Two distinct threads of origin are usually cited:

1. The long thread.
AIChE traces the practice itself much further back: process safety was born on the banks of the Brandywine River in the early days of the 19th century at the E. I. du Pont black powder works — i.e. black-powder manufacturing risk control predates the modern chemical industry by more than a century. Institutionally, early initiatives included the annual symposia on Safety in Ammonia and Related Plants dating back to the early 1950s, and the Loss Prevention Symposium, first held in 1967, which led to the formation of AIChE's Safety and Health Division in 1979.

2. The formalising thread — the 1970s-80s major-accident sequence.
The discipline as a distinct management system took shape after a run of catastrophic industrial accidents: the 1974 Flixborough disaster in the UK, in which a temporary bypass pipe around a damaged cyclohexane-oxidation reactor ruptured and released roughly 50 tons of vapour that ignited in a vapour-cloud explosion, killing 28 workers, followed by Seveso (1976), and then the Bhopal disaster of 2–3 December 1984, in which contamination of a methyl isocyanate tank caused a catastrophic toxic release that killed more than 3,000 people and injured over 100,000. Bhopal was the decisive trigger for institutionalisation: industry leaders asked AIChE to lead a collaborative effort to eliminate catastrophic process incidents, and on 25 March 1985 AIChE formed the Center for Chemical Process Safety with seventeen charter member companies. In parallel, Bhopal was also the triggering event for the development of the US OSHA Process Safety Management standard, and for the establishment of the US Chemical Safety Board, with OSHA 29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals, formally adopted in 1992 following the Norco, Pasadena and Channelview incidents. In Europe, the same accident sequence produced the regulatory line running from the original Seveso Directive through to today's Seveso III.

So in short: the underlying practice is roughly two centuries old, but "process safety" as a named, codified discipline with its own management-system standards (CCPS guidelines, OSHA PSM, Seveso) is a product of the 1974–1992 window, forged directly by Flixborough and Bhopal.