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Encouraging inherently safer production in European firms: a report from the field

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Abstract

It is now generally recognized that in order to make significant advances in accident prevention, the focus of industrial firms must shift from assessing the *risks* of existing production and manufacturing systems to discovering *technological alternatives*, i.e. from the identification of problems to the identification of solutions. Encouraging the industrial firm to perform (1) an *inherent safety opportunity audit* (ISOA) to identify *where* inherently safer technology (IST) is needed, and (2) a *technology options analysis* (TOA) and to identify *specific inherently safer options* that will advance the adoption of primary prevention strategies that will alter production systems so that there are less inherent safety risks. Experience gained from a methodology to encourage inherently safer production (ISP) in industrial firms in the Netherlands and Greece is discussed. Successful approaches require both technological and managerial changes. Firms must have *the willingness*, *opportunity*, and the *capability* to change. Implications for the EU Seveso, IPPC, and EMAS Directives are also discussed. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Accident prevention; Environmental management systems; Inherent safety; Pollution prevention; Prevention; Safety management systems; Seveso directive; Technology assessment

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1. Introduction: the concept of inherent safety

An important consideration, which has received relatively little attention among firms and government, is the *sudden and accidental releases of chemicals* that affect both workers and communities. This contrasts with the greater willingness to address the problems from “gradual pollution” of the environment stemming from *expected* byproducts and waste of industrial, agricultural, transportation and extraction activities. Inherent safety is an approach to chemical accident prevention that differs fundamentally from secondary accident prevention and accident mitigation [1–9]. Sometimes also referred to as “primary prevention” [1,2], inherent safety relies on the development and deployment of technologies that prevent the *possibility* of a chemical accident.[2] By comparison, “secondary prevention” reduces the *probability* of a chemical accident[3], and “mitigation” and emergency responses seek to reduce the *seriousness* of injuries, property damage, and environmental damage resulting from chemical accidents.

Secondary prevention and mitigation, by themselves, are unable to eliminate the risk of serious or catastrophic chemical accidents, although improved process safety management can reduce their probability and severity. Most chemical production involves “transformation” processes, which are inherently complex and tightly coupled. “Normal accidents” are an unavoidable risk of systems with these characteristics [11]. However, the risk of serious, or catastrophic, consequences need not be. Specific industries use many different processes. In many cases, alternative chemical processes exist, which completely or almost completely eliminate the use of highly toxic, volatile, or flammable chemicals [12].

Inherent safety is similar in concept to pollution prevention or cleaner production. Both attempt to prevent the possibility of harm — from accidents or pollution — by

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[2] The authors are cognizant of the conventional wisdom that no technology is entirely safe, and that it might be more accurate to describe various technologies as safer. However, some technologies are in fact absolutely safe along certain dimensions. For example, some chemicals are not flammable, or explosive, or toxic. Some reactions carried out under atmospheric pressure simply will not release their byproducts in a violent way. Thus, inherent safety is, in some sense, an ideal analogous to pollution prevention. Just as some might argue that pollution prevention could never be 100% achieved, purists may argue that technologies can only be made inherently safer, not safe. Articulating the ideal, however, makes an important point: dramatic, not marginal, changes are required to achieve both. Like pollution prevention, the term “inherently safe” focuses attention on the proper target.

[3] In the accident prevention literature in the traditional chemical engineering journals, there is much attention given to the concept of the “root cause” of accidents. Enquiry into root causes has stimulated mostly secondary prevention by attempting to make production technology more “fail-safe,” that is, stronger vessels and piping able to sustain higher pressures, neutralizing baths, and automatic shut-off devices. A different tradition of analyzing accidents comes from tort and compensation law, where the “but-for” test is used to apportion responsibility between faulty technology and alleged careless workers. If the technology is not “fool-proof”, that is, it is not impossible for a human to initiate an event leading to an accident, then the firm is held at least partially liable — because, “but-for faulty design, the accident would not have occurred.” Primary prevention promotes “fool-proof”, rather than “fail-safe” technology. Another formulation is “error tolerant” [10].

eliminating the problem at its source. Both typically involve fundamental changes in production technology: substitution of inputs, process redesign and re-engineering, and/or final product reformulation.[4] Secondary prevention and mitigation are similar in concept to pollution control and remediation measures, respectively, in that each involves only minimal change to the core production system. In particular, secondary accident prevention focuses on improving the structural integrity of production vessels and piping, neutralising escaped gases and liquids, and shut-off devices rather than changing the basic production methods. When plants expand beyond the capacity they were initially designed for, secondary prevention capacities may be exceeded. Sometimes, overconfidence in these added-on safety measures may invite an expansion of production capacity. Accidents, of course, may also disable secondary safety technology, leading to runaway chemical reactions.

The superiority of pollution prevention and cleaner production as a tool of environmental policy has been recognised for more than a decade in both Europe and North America [13,14]. International meetings of the Cleaner Production Roundtables and the Pollution Prevention Roundtables are held annually in Europe and North America, respectively. The United Nations Environment Programme has spearheaded an aggressive cleaner production program [13]. The US EPA has established a hierarchy of policy choices, with pollution prevention given the highest priority over reuse or recycling, treatment, or disposal [15]. In 1990, the US Congress codified, as national environmental policy, a preference for pollution prevention over pollution control, when it passed the Pollution Prevention Act. The EU supports its Directive on Integrated Pollution Prevention and Control (IPPC) by funding research in Seville, Spain for the identification of Best Available Techniques (BAT).

In 1982, the European Union adopted the famous EU Directive (82/501/EC) on the Major Accident Hazards of Certain Industrial Activities, the so-called “Seveso Directive.” It requires member states to ensure that all manufacturers prove to a “competent authority” that major hazards have been identified in their industrial activities, that appropriate safety measures — including emergency plans — have been adopted, and that information, training and safety equipment have been provided to on-site employees [16]. A second Seveso Directive (96/82/EC) came into effect in February 1997. Seveso II strengthens the original provisions and coverage of accident-prevention activities, as well as broadens the types of installations, which must comply. Particularly worthy of note is the mention of inherent safety as a preferred approach to preventing chemical accidents in the accompanying guidance document for the preparation of the safety report required by the revised directive [17][5].

Finally, a discussion of inherent safety (or cleaner production) would be incomplete without noting the importance of the stage of the production process where inherent

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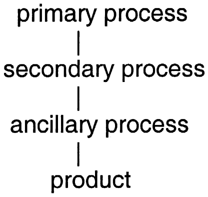
[4] Although inherent safety and pollution prevention are similar in concept, there are practical differences between the two that have, so far, made adoption of inherent safety measures less attractive to industry than pollution prevention/cleaner production.

[5] For other aspects of guidance, see Mitchison, N. (1999) The Seveso II directive: guidance and fine-tuning. Journal of Hazardous Materials 65(1/2): 23–36.

safety is implemented. Production systems can be thought of being comprised of at least four stages, which are found in each product line or productive segment in complex, multi-productline operations:



The distinction between primary, secondary, and ancillary manufacturing and production processes — and final products as well — is an important one for the identification of inherent safety opportunities. It also helps to explain why the receptivity to the adoption of inherent safety technology might be different for firms that (1) are already in existence and do not contemplate change, (2) firms that are contemplating changes or contraction/expansion of capacity (what we call operations in transition), and (3) new facilities or operations.

An illustrative example is offered in the context of casting and electro-plating metal screws. The primary process is the casting of the screw (both toxic fumes and dangers from workers coming in contact with molten metals are recognised hazards). The secondary process is electroplating (this too presents both toxic and corrosive hazards). The ancillary process is cleaning or degreasing the screw using organic solvents (which can be both toxic and flammable). The screw itself may have sharp edges and present an occupational hazard. If the firm focuses on the ancillary process, it might be relatively easy for it to search for and find an alternative, non-polluting, non-flammable cleaning process. Technological innovation would not likely be required. If electroplating is the process that needs to be modified, at least a new process might have to be brought into the firm — usually by the diffusion of alternative plating technology — but the firm would be expected to be uncomfortable about changing a proven method and taking a chance on altering the appearance of its product, even if it is a separate operation. The most resistance could be expected by demands on the primary process. Here, innovation might be necessary and the firm is not likely to invest in developing an entirely new casting process. Even if an alternative casting technology were available, the firm is unlikely to be enthusiastic about changing its core technology.

On the other hand, firms that have already been searching to change even their core technologies because of high energy, water and material costs, or for safety and environmental reasons, may be willing to plan for change. However, some firms in transition to new or expanded operation may delay implementing approaches to safety that require new investments if the remaining life of the existing facility, or portions of the facility, is limited. New operations are expected to be the most receptive to examining technology options that affect core, secondary and ancillary processes — and even final products.

2. Incentives, barriers, and opportunities for the adoption of inherently safer technology (IST)

The reasons that firms are embracing pollution prevention and cleaner production today are because of (1) the increased costs of continuing the current practices of waste transport/treatment and pollution control, (2) liability for environmental damage due to industrial releases of toxic substances, (3) increasingly available information about pollution and toxic releases to the public, and (4) the EU IPPC Directive [18] (and possibly the EMAS [19] and ISO 14000 [20] requirements), and to a lessor extent the Pollution Prevention Act of 1996 in the United States [21], force increased attention to changing production technology, rather than relying solely on end-of-pipe, add-on technologies. Thus, both economic and informational mechanisms are causing a gradual cultural shift away from pollution control and waste treatment and towards pollution prevention and cleaner production.

With regard to primary accident prevention, the same economic signals are not really there [2]. Firms do not pay the full social costs of injuries to workers (or to the public) and firms are under-insured. Unlike pollution, which has to be reckoned with as part of production planning, accidents are rare events and their consequences are not factored into the planning process.

Furthermore, an organisation's gradual emissions or wastes can be observed and calculated for any given time period, and this information can be used to measure the effectiveness of the organisation's pollution prevention efforts. Because acute chemical accidents are relatively rare events, an organisation implementing an effective chemical safety program may therefore receive no form of positive feedback whatsoever. Because the safety system is working, accidents do not occur. Of course, a hazardous chemical plant may eventually receive negative feedback, but only when it is too late to take preventive measures.

In earlier work, one of the authors [2] summarised the barriers to primary prevention.

> These include: (1) *inadequate information* about the potential for catastrophic accidents, the significant costs of secondary prevention and mitigation and the costs of chemical accidents, and the existence of inherently safe[r] alternatives; (2) *insufficient economic incentives* — in the form of workers' compensation, the tort system, regulatory fines, and insurance; (3) *organisational and managerial barriers* — linked to corporate attitudes, objectives, structure, and internal incentives, and the lack of a labour-management dialogue on safety; (4) *a lack of managerial awareness and expertise* about inherently safe[r] technologies; (5) *inadequate worker knowledge* about primary accident prevention; (6) *technological barriers* limiting primary accident prevention; and (7) *regulatory problems*. Primary prevention shares some of these barriers with secondary prevention and mitigation, but these barriers are of different importance.

Although firms sometimes do anticipate accidents and try to avoid them, the expenditures for adequate prevention have not been, and are not likely to be, invested without the right incentives. To the extent that the firm *knows* that the costs of maintenance and the inflexibility of traditional safety approaches are greater than using more reliable inherently safer approaches, the firm may respond by changing its technology.

One way of providing firms with *more visible* economic incentives would be to encourage them to exploit the opportunity to prevent accidents and accidental releases (1) by identifying *where* in the production process changes do inherently safer inputs, processes, and final products could be made and (2) by identifying the *specific IST that could be substituted*. The former we call Inherent Safety Opportunity Audits (ISOA). The latter we call Technology Options Analysis (TOA). Unlike a hazard, risk, or technology assessment, these techniques seek to identify *where and what superior technologies could be adopted* to eliminate the possibility, or to dramatically reduce the probability, of accidents and accidental releases.[6]

This paper reports on a research project undertaken for the EU Commission and designed to gain practical, firm-based experience regarding the feasibility of conducting both ISOAs and TOAs in firms partnering with technically informed consultants, in hopes that this would lead to the adoption of IST by those firms. In our fieldwork, these two activities were performed separately in some cases, and together in others. Both are necessary to implement the best changes possible.

From a general safety perspective, it is widely recognised that safety performance is determined by three elements:

- management and organisational factors,
- technological factors, and
- behavioural factors (also referred to as the human dimension, i.e. people).

These three factors interact and influence the safety of industrial manufacturing and production processes through their effects on the *willingness, opportunity, and capability* of organisations and people to change.

In some approaches that promote the adoption of inherent safety, the emphasis is mainly on technological factors, i.e. on identifying and disseminating information on

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[6] A hazard assessment, in practice, is generally limited to an evaluation of the risks associated with the firm's established production technology and does not include the identification or consideration of alternative production technologies that may be inherently safer than the ones currently being employed. Consequently, hazard assessments tend to emphasize secondary accident prevention and mitigation strategies, which impose engineering and administrative controls on an existing production technology, rather than primary accident prevention strategies, which utilize input substitution and process redesign to modify a production technology. In contrast to a hazard assessment, a technology options analysis would expand the evaluation to include alternative production technologies and would facilitate the development of primary accident prevention strategies.

superior technologies. In the current approaches to safety management — especially those falling under the rubric of Safety Management Systems — the emphasis is on management and organisational factors, and also on the human dimension, addressing the management of safety; these approaches assume minimal technological change, implicitly leaving the core and secondary production technologies essentially unchanged. Both of these distinct approaches are by themselves insufficient to maximise the adoption of desirable IST and frustrate further progress in safety performance and continual progress in safety management. There is therefore a clear need, both from a technical point of view and from an industrial practice perspective, for a generally accepted approach that bridges traditional safety management with inherent safer technology.

In this paper, we report on first attempts to develop and implement a methodology for the encouraging complementary managerial and technological changes aiming at making companies more willing *and* able to identify and use (or develop) IST for achieving *Inherently Safer Production* (ISP).

With regard to environmental protection from gradual pollution and waste, similar developments have taken place. Environmental improvements are often realised through the development, adoption, and implementation of Cleaner Technologies, as distinct from end-of-pipe treatment. However, methodologies to promote Cleaner Technologies always go beyond identifying or developing technology per se. This is most often expressed in the terms “Cleaner Production” and “Pollution Prevention.” Cleaner Production/Pollution Prevention, as distinct from Cleaner Technology, also addresses organisational and human factors [13,22]. In a similar fashion, we adopt the analogous term *ISP*.

3. Elements of an ISP approach

3.1. Timing and anticipation of decisions to adopt (or develop) inherent safety

It is generally acknowledged that taking action “as early as possible” in the design, planning, and construction of industrial plant is vital for the realisation of the most promising options for ISTs. This means that IST principles should be taken into account early in the design process of chemical producing and using plants, or even in the Research & Development process aiming at developing new technologies for production. This raises questions about how and when organisational and human factors should come into play with technological factors. Technological design and engineering usually precede organisational design and selection of personnel. Thus, the early-as-possible principle has a different meaning with respect to managerial and organisational factors. It implies that *organisational procedures must aim at the recognition and early adoption of relevant IST options* in the R&D and in the Design stage, before the plant is operational. These may be complemented by other (later) procedures that facilitate the implementation of promising IST options once the scope of production and general plant design are finalised. Both are important organisational elements for the concept of ISP.

The creation of appropriate internal incentives is also important. With respect to the human dimension, we argue that the *awareness of the key actors* (managers, engineers, researchers, safety experts, operators, and maintenance workers) *should, from the very beginning, be focused on opportunities for IST*. In this way, *willingness* (on the part of key actors in the firm), as an attitude, can precede the actual knowing of specific options for IST. Achieving this organisational awareness and willingness may require *leadership* of "enlightened" (top) managers. In the management of technology literature, there is the concept of the "technology gatekeeper" whose technical expertise is crucial for determining what technologies a firm adopts. We similarly use in this report the term "managerial gatekeeper" to denote the importance and need for organisational leadership.

It should be emphasised, however, that awareness in industry is not only an issue for individuals. Awareness of individuals is heavily influenced by social factors like communication and cooperation with other key-actors and by (formal or informal) corporate incentives. Ultimately, awareness in industry is mainly a collective awareness. The collective awareness in a company is greatly dependent on (but also reflected by) the existing *corporate culture*. The corporate culture is known to reflect the real core values of a company (which is not by definition the same as the official core values such a presented in 'senior management statements') on what is being rewarded or not in everyday practice, on subjects and issues that can be addressed or instead are off limits, and on missing elements in the awareness of managers and employees.

Therefore, awareness that influences willingness, and leadership, but also new forms of communication and cooperation and a possible shift in corporate (safety) culture, are all crucial elements for ISP. Good and successful examples set by companies seen as peers may also strongly stimulate industry.

3.2. Life cycle aspects

Another aspect of the time dimension of inherent safety concerns where in the life cycle of the plant the decision to consider inherent safety arises [23]. It is generally acknowledged that the benefits of IST may persist throughout the life cycle of a chemical process, or plant. This is actually one of the reasons why anticipation of the need for inherent safety is so important; being early can generate more benefits.

However, this all too often leads to the conclusion that IST is not relevant for existing plants, explaining why managers of existing facilities are often not much interested in IST. Their plants seem already technologically determined, and IST seems interesting only as a research or engineering curiosity.

Today's plants are, however, not as technologically rigid as they may seem. Customers ask for tailor-made products, often in small quantities, and delivered as soon as possible. This increases the need for flexibility in plants and processes. Added-on safety usually decreases flexibility, while IST can increase flexibility.

Furthermore, changes in existing plants take place, and change management is a well-known element of safety management. The methodologies for ISP should therefore be potentially attractive in every stage of the plant/process's life cycle, and could

Table 1
The inherently safer production approach

Phase one: preparatory work, firm commitment, and focus of the project

1. Start-up and obtaining commitment from the firm
   This first step entails obtaining general commitment and cooperation from management, selecting possible (parts of the) plant/unit/process/division, obtaining the specific commitment of the management of that (part of the) plant/unit/process/division, and formulating and formalising the project goals and project plan.
2. Initial design and preparation
   This step involves the establishment of an internal *project team* within the selected plant/division, assisted by the external consultants, to construct the project plan.
3. Conduct a traditional safety audit
   This safety audit is used for identifying inputs and material flows, processes and intermediates, and final products — *but* with special attention paid to human-material/process/equipment interactions that could result in (a) sudden and accidental releases/spills, (b) mechanical failure-based injuries, and (c) physical injuries — cuts, abrasions, etc. as well as ergonomic hazards.
   Additional sources of adverse effects/safety problem areas are records/knowledge of in-plant accidents/near misses, equipment failures, customer complaints, inadequate secondary prevention/safety procedures and equipment (including components that can be rendered non-operable upon unanticipated events), inadequacies in suppliers of material and equipment or maintenance services.
4. Selection of candidate processes or operations within the firm
   This step entails the selection of candidate processes or operations within the firm that warrant special attention. The discovery of *where* the process could benefit from the adoption of IST is the outcome of an Inherent Safety Opportunity Audit done within this and the next tasks. The criteria for identifying these include three categories: (a) general safety information, (b) symptoms of inherent unsafety, and (c) inefficiency of safety management.

Phase two: identifying inherently safer options for implementation

5. Functional review
   This step reviews the *functional purposes* of materials, equipment, processes and operations-noting obvious inefficiencies in material/water/energy use and gradual pollution, and obvious hazards due to spatial combinations of functions.
6. Specific set of search questions
   This step constructs *a specific set of search questions* to guide identification of opportunities for material substitution, equipment modification/substitution, changes in work practices and organisation, modifications in plant layout, and changes in final product.
7. Brainstorming to generate inherently safer options
   This step involves the planning of creative brainstorming sessions by the project team to generate as many initial options as possible.
8. Construction of *Search Process* for information on inherently safer options/alternatives
   This step involves planning the process of using external potentially useful information sources, including so-called “solution databases” (such as compiled by Lyngby, D.K. the Danish EPA and TNO), safety performance/benchmarking data, literature on process safety and reliability, literature on cleaner production/pollution prevention, academic experts/researchers — including the TNO Work and Employment/Ergonomia project staff, in-plant expertise including plant workers/union, suppliers, equipment manufactures, other domestic firms, foreign firms and technology, and national/international unions.
9. Identification of promising inherently safer options
   Identification of promising alternatives/options for materials, equipment, processes, operations, work practices and organisation.
10. Design of a consistent set of system changes
    With the involvement of both production and safety/environmental personnel, design internally

(continued on next page)

Table 1 (*continued*)

consistent sets of 2–3 alternative overall system changes
encompassing multiple component changes related to 9 above.

11. Feasibility study
Conduct feasibility studies utilising rough relative economic (cost) and safety assessment for these 2–3 system changes. Also included are environmental impacts and organisational impacts and requirements.

12. Commitment of the project team
Present results of the feasibility studies to the project team and obtain their commitment an endorsement.

13. Recommendations to management
Recommended system changes to the firm management.

Phase three: implementation of inherently safer options

14. Facilitate decision-making
Mobilise the decision-making processes within the plant/unit to implement the selected system, recognising overall firm imperatives and constraints.

15. Preparation of implementation
Work with in-plant personnel (both production and safety/environmental people, and the safety and health committee) to design general approach to changes in the plant/unit.

Phase four: monitoring and evaluating implementation

16. Monitor actual design changes
The step involves the in-plant project team in the monitoring and evaluation of the progress and success of the implemented options/system on the bases of safety, quality, technology, costs, and environmental impact.

Phase five: final project evaluation

17. Evaluation of overall project
This final step involves the project team in evaluating the outcome of the inherent safety project in the firm and formulating additional recommendations. This includes the results of plant management evaluation.

support the development of a new form of change management that is directed towards inherently safer alternatives.

4. A methodology for ISP

As is the case with the concept of cleaner production, it is essential that organisational, human and economic aspects are, together with technological aspects, integrated into the concept of ISP. We developed a methodology for involving the several organisational components of the industrial firm in ISP. The methodology envisions five phases:

- preparatory work, obtaining firm commitment, & designing the focus of the project;
- identifying inherently safer options for implementation;
- implementation of inherently safer options;
- monitoring and evaluating implementation; and
- evaluation of the final project.

Each phase consists of several sub-phases, and the use of some specific tools (see Table 1). Partner firms were engaged in the study to explore the usefulness of the methodology. Considerable effort was required to convince companies to cooperate in what we regarded as innovative research. Two partnerships were created in the Netherlands, one with Hoogovens Steel Strip mill Products (HSSP) for a pilot in their Hydrochloric Acid Regeneration plant and the other with Dutch State Mines (DSM), the Logistics Department of the HydroCarbon Unit. In Greece, one partnership was created with Editable Fats and Oils (ELAIS, part of the Unilever group) for two pilots, one focusing on its present installations in Athens and the other involving the design of a new plant for refining editable oils. The pilots in the Netherlands were carried out by researchers from NIA-TNO (now TNO Work and Employment), while the pilots in Greece were carried out by researchers from Ergonomia.

The results of the experience in the case studies were analysed in terms of *willingness*, *opportunity*, and *capability* of the partner firms to adopt and implement ISTs[7]. *Willingness* is seen as comprising initial commitment, awareness and the will to make a move towards IST, and therefore concerns mainly organisational and human aspects. *Opportunity* is seen as a combination of technological and economic aspects: technological options for ISTs, and the economic attractiveness/feasibility thereof. *Capability* is seen as the organisation's capability to *identify* inherently safer options, and to *implement* inherently safer options.

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[7] The importance of these three factors was first developed in the context of necessary and sufficient conditions for stimulating pollution prevention or cleaner production technologies [24,25]. The three affect each other, of course, but each is determined by more fundamental factors.

Willingness is determined by both (1) *attitudes towards changes in production in general* and by (2) *knowledge about what changes are possible*. Improving the latter involves aspects of capacity building, while changing the former may be more idiosyncratic to a particular manager or alternatively a function of organisational structures and reward systems. The syndrome "not in my term of office" describes the lack of enthusiasm of a particular manager to make changes whose benefit may accrue long after he has retired or moved on, and which may require expenditures in the short or near term.

Opportunity involves both supply-side and demand-side factors. On the supply side, technological gaps can exist (1) between the technology used in a particular firm and the already-available technology that could be *adopted or adapted* (known as diffusion or incremental innovation, respectively), and (2) the technology used in a particular firm and technology that could be *developed* (i.e. major or radical innovation). On the demand side, four factors could push firms towards technological change — whether diffusion, incremental innovation, or major innovation — (1) regulatory requirements, (2) possible cost savings or additions to profits, (3) public demand for safer industry, and (4) worker demands and pressures arising from industrial relations concerns.

Capacity or capability can be enhanced by both (1) increases in knowledge or information about inherent safety opportunities, partly through formal Technology Options Analyses or Inherent Safety Opportunity Audits, and partly through serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers, and other firms, as well as reading about safety issues, and (2) improving the skill base of the firm through educating and training its operators, workers, and managers, on both a formal and informal basis. Capacity to change may also be influenced by the inherent innovativeness (or lack thereof) of the firm as determined by the maturity and technological rigidity of particular product or production lines [24,25]. The heavy, basic industries, which are also sometimes the most unsafe industries, change with great difficulty, especially when it comes to core processes.

Finally, it deserves re-emphasising that it is not only technologies that are rigid and resistant to change. Personal and organisational flexibility is also important.

5. Results

5.1. Summary of main findings

The willingness of the companies to adopt and implement inherently safer options was found to be different for new installations, existing installations that will remain in production for several years (retrofit cases), and for installations that are more or less at the end of their life cycle (transitional stage).

In existing installations, the experience of the plant managers and on-site personnel is vital for willingness and may be triggered by frequent plant or installation troubles and associated safety problems. For a new plant/one contemplating expanding capacity, if there is no experience with prior safety problems, the firm's motivation for ISP may come from a more general pursuit of excellence, e.g. as part of an encompassing total quality management (TQM) policy.

Inherently safer technological options were identified in all four cases. The expert role of technologically oriented consultants, and an extensive external data search were important for the identification of (especially the more fundamental) options. Three factors seem to have a positive influence on the adoption of options (1) being "early in the life cycle" (e.g. at the design stage), (2) an in-company cross-functional workshop on the principles of inherent safety that includes a brainstorming session for the generation of inherently safer technological options, and (3) a facilitating role of the consultants in the adoption process.

The results with regard to the economic factors are very striking in all four cases: inherently safer options were identified that were not only economically feasible, but the overwhelming majority had pay-back times of less than 1 or 2 years, even in the existing plants. Thus, while at the beginning the economic imperative is not visible for the adoption of IST, once identified, they do represent economically attractive options.

The *capability* for generating, adopting and implementing inherently safer options varied considerably in the four cases. The advances in this capability varied even more. In the two Dutch cases, the capability was increased by the intensive cooperation between the company's personnel and the consultants/researchers in the pilot processes, especially during the workshops held to learn more about Inherent Safety and to generate IST Options. In these two Dutch cases, several initiatives in the respective action plans were specifically aimed at increasing the plant's capability to identify, adopt, and implement (future) inherently safer options, although the options generated in workshops with the firm's personnel were not dramatic examples of IST. In fact, many useful options of secondary prevention were also identified.

In the case of the design of a new plant (in Greece), there was no relevant experience within the plant from running and maintaining such a plant. In the two Greek cases, the consultants played an important expert role, which had a positive influence on the generation of fundamental and important inherently safer options, but the consultants were not able to exert a sufficiently positive influence on the firm's capability to adopt and implement these options. The consultants undertook extensive literature and other searches in order to identify inherently safer technological options, but — unlike the Dutch researchers — they did not involve the firm's personnel in the generation of options. This may partly explain the slowness in the adoption of these improvements by the firm.

The experiences in the four case studies show the importance of (1) factors influencing the willingness of the firm to search for technological alternatives, (2) using inherent safety concepts to develop a common language in the firm, (3) strategic integration of the ISP approach with Cleaner Production or Pollution Prevention approaches [26,27], and (4) the contribution of ISP to flexible strategic management and continuous improvement. Safety, Health, and Environmental (SHE) Management must address not only technological aspects of safety and environment, but managerial, organisational, economic, and human aspects as well. More detailed discussion of these issues is found below.

5.2. Influences on the willingness of the firm to search for technological alternatives

In the Greek cases, the managerial leadership of the company ELAIS was motivated to have an outside evaluation of both their present and future technologies. This was the partly the consequence of its fairly well-developed TQM, the integration of TQM principles in Leadership (the activities undertaken by the highest management) and the deployment of TQM principles throughout the company. The company has a genuine desire for production proficiency. ELAIS want the best technologies. However, the aim of ELAIS was to have an *external expert* evaluate their technologies, not to build internal expertise in safety.

ELAIS people were not interested, and did not participate actively, in the search for technological alternatives. As a result of using an external expert approach, a number of very interesting — even significant — ISTs were identified in both Greek cases (existing plant and the design of a new facility). Although the options identified were highly regarded by ELAIS, at the time of evaluation of the cases it was not yet clear to what extent ELAIS is going to implement the options.

Thus, throughout the Greek pilot projects, there was practically no development of the *willingness* to search for technological alternatives, and there was no improvement of the *capacity* to adopt and implement promising IST. However, the firm was probably convinced of the value of having a trusted consultant do an external technology options search.

This was different in the Dutch pilots at HSSP and DSM. In these two Dutch cases, the company's motivation stemmed mainly from regular safety and operational problems in existing installations. The companies had already tried to resolve these problems themselves, even several times, sometimes with the help of external experts (DSM case), but only with limited results.

The Dutch companies stepped into the project because they did not want more external advice that did not work. They wanted to resolve their problems, and after the presentation of the outline of the proposed project, they liked the idea that in following the proposed methodology, they would start a process of bringing together the fragmented know-how in the firm (including the know-how from preceding attempts to solve problems), and integrate/compare that know-how with external expertise.

In these Dutch cases, due to the active involvement of a variety of in-company people, the feeling of *ownership* of the options generated was much stronger than in Greek cases. As a result, many serious options (in the HSSP case all serious options) were in fact adopted in principle, were included in an action plan that was approved by management — and that was partly implemented and partly in the process of implementation, at the time of the evaluation of the cases. In the HSSP case, several of the techniques that were introduced in the firm were also spontaneously used by the company people to make progress with some other environmental and quality problems they were facing. This shows that as a result of the process components in the methodology, they felt that they — at least partly — were the owners of these techniques, and they wanted to use it wherever it seemed useful. As mentioned before, however, cooperative brainstorming did not yield the identification of dramatic examples of inherently safer options.

Finally, we conclude that the motivation of the company, reflecting both the initial motivation and culture of the company, has an impact on the development of the willingness and capacity in the company. Another determinant is probably the role of the researchers/consultants: in the Greek business culture, the companies expect external expert advice, and the Greek consultants see themselves primarily as experts. In the Dutch culture, the companies are interested in expert advice, but also in support and improvement of internal processes. As a result, the Dutch consultants were much more regarded, and viewed themselves, as experts that had a role to play, not only as a source of technical know-how, but also as change agents in a possible shift from traditional safety towards ISP.

5.3. Attitudes towards inherent safety

Earlier, we reviewed the knowledge about the paradigmatic difference between inherent safety and secondary safety prevention. In this section we discuss the implications of these differences for what occurred in the pilot firms. It should be realised that at the time the project began, these firms were usually thinking in terms of traditional added-on safety. Inherent safer alternatives may easily be rejected in such a situation, as they usually interfere more intimately with the primary process (this can easily be regarded as a complicating factor). The associated benefits of inherent safety measures (in terms of improved operability, flexibility and economics) are different than the benefits of traditional safety approaches.

Therefore, the adoptions of inherent safety technologies, and a greater willingness to develop or adopt such options, require a change in attitude and mind-set of the persons involved (decision-makers and those who may influence those decisions). On the organisational level, attitudes, mind-sets, and the do's and don'ts are reflected in the company culture; an evolution in company culture may therefore also be needed; resistance to change can be expected.

In the Greek cases, where there was minimal participation of company representatives in the process of technical optional analysis, the mind-sets and attitudes of company people remained basically unchanged. It is therefore not surprising that ELAIS is still not sure what they will do with the inherently safer options identified. Resistance to adopt the options was clearly felt in some cases or departments.

In the Dutch cases, the process of options generation was predominantly organised as collective learning and inspiring effort. In this way, the persons involved more or less automatically widened their scope on safety, and expanded their thinking to include the inherent safety paradigm. Because this was organised as a collective process, the same was true for the local company culture.

On the other hand, the Dutch cases were both in existing facilities, and that fact limited the feasibility of inherent safety, conceptually. As a result, not only were inherently safer options identified and adopted, but at the same time some more traditional safety solutions were also identified and adopted.

This mix of inherent and traditional safety measures could be regarded as a weakness because the company was clearly not able to make a full paradigm shift towards inherent safety. On the other hand, it does not seem very realistic to think that such a shift was possible in companies with largely fixed technologies and businesses. We tend to regard it as one of the basic strengths of the methodology that inherent safety principles can be applied in existing facilities, and be supplemented by traditional safety measures. This demonstrates that inherent safety principles are easily accessible for existing companies, and easier to integrate into safety decision making and into SHE management systems and procedures [28].

5.4. Using inherent safety concepts to develop a common language in the firm

In the Dutch cases (HSSP and DSM), an important element was to bring together people from different functions and disciplines in order to develop a common understanding of the underlying technical problems of the technical and safety troubles they faced. This was successful, not only in the way that they jointly developed a deeper and broader understanding of their problems and options to solve them, but also in the way that the participants were — for the first time — able to communicate and cooperate effectively in this cross functional and interdisciplinary setting. The reasons for this success might have the following explanations.

> Safety was important to everyone, but it was the first time that they consequently reflected and discussed the inherent safety characteristics of their primary processes (instead of focusing on “additional safety measures”). Because an ‘additional safety measure’ may belong mainly to a certain discipline or function (e.g. maintenance), it may not be very interesting to discuss this with other persons who have other disciplines or functions within the firm. In contrast, inherent safety concepts address the characteristics of the primary process itself. This is the core business of the business unit, and is relevant to everyone.

> The inherent safety design principles (minimise, substitute, moderate, simplify and optimise layout) are sound and easy-to-communicate principles that can be understood with common sense. In this way, these inherent safety concepts can form a user-friendly common language for all *interested parties*, disciplines and functions.

This facilitates effective communication about the production processes and the associated hazards and preventive activities. As Argyris and Schön show [29], a common language is a prerequisite for organisational learning processes. Based on this project, we surmise that the inherent safety principles can function very well as the shared conceptual basis for organisational learning aiming at continuous safety improvement.

5.5. Economic considerations

In Section 1, we discussed the issue that, in general, there are no obvious strong economic incentives for accident prevention. However, when inherently safer technological options were identified in the case studies, and their feasibility was assessed, many options proved to have very short pay-back periods. For example, in the HSSP case, we used a standardised in-company feasibility calculation for the initial rough proposals in the first stage of the action plan. To everyone's surprise, all nine options turned out to have pay-back times of less than 1 year. From an economic perspective, they were expected to be very profitable. In the DSM case too, all options were economically viable. What might be the explanation of the clear existence of economic benefits without their being appreciated? In a period with ever-increasing competition, there seem to be some hidden but potentially very relevant economic incentives for inherent safety.

It is important to characterise the nature of the benefits. As expected, the benefits of having potentially less accidents and incidents do not appear great, due to the expected low frequency of incidents and accidents to begin with (and even less in companies that are proficient in safety). However, most benefits yielding positive outcomes from inherently safer options stemmed from the realistic expectation of having to spend less time trouble shooting. This implies a greater on-line time of the facility, but it also lowers the costs of maintenance and repair activities, including the associated costs for replacement of components. In other words, inherent safety is associated with *greater reliability of production*, and of economic optimisation of operability and maintenance of existing installations. In sum, there certainly are economic incentives that arise from these aspects, but these incentives by themselves are currently not leading the way to inherently safer approaches.

5.6. Methodological implications for firms at different stages of development

At the start of our research project, we developed a general methodology to be tested in the pilots. Gradually, we adapted this methodology to better reflect the idiosyncratic cases of the respective pilot cases. It turned out to be important for our methodology whether the methodology is applied in plants (1) with existing and continuing operations, (2) with existing operations in transition, or (3) which are preparing and designing new facilities/operations. The methodological differences between retrofitting or expanding existing facilities and designing new facilities are presented in Table 2.

In the category of existing installations, a further distinction can be made between installations that remain operational, and installations that are almost at the end of their

Table 2
Methodological implications for facilities at different stages

Existing installations (retrofit or expansion)	New installations	Implications for the methodology: expect differentiation in
Existing or remaining (safety) problems may motivate the company for inherent safety in parts of the facility/unit	Safety problems are known only at the design stage, or from similar existing installations	The *motivation / willingness* at the start to consider inherently safer concepts and options
Management, workers and contractors are there and have experiential know-how; they can and should be involved	The design is basically a design engineer's activity. Top managers are involved in go/no-go decisions only	The *participation of people* and feeling of *ownership* during the project
External consultants can have important expert and process roles, if they are knowledgeable in inherent safety	External consultants, experts in inherent safety, may be needed	The (process) *role of the external consultants*
Alternative technological options that require a rather fundamental change of the installations are easily rejected for conceptual, and economic reasons	Alternative technological options can be relatively easy integrated (and with few additional costs) into the design	The *nature* of the alternative technological options taken into consideration, and the *feasibility* thereof
		In existing plants only input changes, and minor process/re-engineering changes, are likely to be adopted

life cycle and in transition (preparation of new installation, or substantial innovation and/or expansion).

In installations in transition, it may be more difficult to find feasible options for inherent safety, but on the other hand, the company may be eager to know what inherently safer options might be relevant for a future plant with possibilities for innovations/expansion of output. Conceptually, the end of the current plant life cycle approaches the start of the next new plant life cycle.

5.7. Strategic integration of different approaches

Companies are confronted not only with inherent safety options, but also with options for cleaner production/pollution prevention, quality improvement, etc. Furthermore, companies have to make choices as to whether they will invest in inherent safety or cleaner production (i.e. primary prevention), or in added-on safety measures, end-of pipe technologies (i.e. secondary prevention). The choice between these kinds of options will be made on performance advantages and other trade-offs. Most likely, in every company, a mix of options/measures will be adopted, which is intended to be the optimum mix in terms of safety, economic factors, and other trade-offs.

It is therefore vital for inherent safety methodologies to pay attention to the non-safety trade-offs, and, to a certain extent, to the compatibility of inherent safety approaches with cleaner production/pollution prevention on the one hand, and traditional safety on the other. In the INSIDE toolkit [30], the tool has therefore been developed towards an *Inherent SHE* Toolkit. The methodology developed in this research project starts with a clear focus on inherent safety, but clearly showed itself to be very compatible with other safety approaches, and with environmental and quality considerations.

Evaluating the project, it is very striking that the methodology seems to address environmental safety, occupational safety and process safety in a balanced way. It seems easy to integrate inherent safety with environmental or quality management considerations. The opposite is certainly not true: in an investigation of the impact of cleaner technology databases, some cleaner technologies were shown to introduce new hazards into the working environment [26]. One possible explanation of the findings in this project is that we were, from the beginning, very much aware of both the close link and relevance of inherent safety with cleaner production. It is not clear whether we unintentionally imparted this vision to the firms, or whether it is intrinsic to our methodology and the concepts used therein.

5.8. Flexible strategic management and continuous improvement

Technical installations seem static, but they sometimes develop gradually. Changes are made regularly. They are usually minor changes, but are sometimes more substantial. Throughout time, gradual changes may lead to a substantially different installation, where capacity has expanded, process conditions are modified, and many components differ from the original design. To guarantee safety in this gradual change process, change management, which is closely related to the management of maintenance, is an important element of safety management. Every change does, however, not only form a potential threat to safety, but is in principle also a potential *opportunity* for the introduction of inherent safer elements in the plant. Moreover, it can be an opportunity for continuous (safety) improvement, even if alternative technological processes are not very likely to be introduced in this way.

The two Dutch cases started with a focus on existing problems in the companies, which were not solved by normal maintenance. The technical or maintenance managers and workers played an important role in the option generating process and in the adoption of the options. We therefore regard our methodology a potentially useful tool for flexible strategic management, aiming at continuous safety improvement via the systematic adoption of inherently safer technological options.

5.9. Conclusions

The experience in the implementation an ISP approach demonstrates in all four cases that substantial progress towards inherent safety can be realised in economically attractive ways. This progress is evidenced by the number of inherently safer technological options identified, but also by the nature of the intervention, that — especially in the two Dutch cases — showed that it can contribute substantially to the *willingness* and *capacity* develop and implement inherently safer options by the companies, and in this way facilitate continuous improvement in SHE Management. (The reader is referred to the project report [31][8] for descriptions of the specific technologies investigated in the partner firms and the solutions suggested).

The research shows that there is a great potential for methodologies on improving inherent safety that can be integrated into SHE Management systems. The newly developed concept of *ISP*, that was developed during this research project, shows itself to be viable, and can contribute to a strategic policy of companies and governments aiming at IST. A basic strength of the concept is that it not only addresses technological aspects of safety, but managerial, organisational and human aspects as well. In this way, the Inherent Safety concept can go beyond the technological domain and becomes a tool for strategic SHE Management.

6. Relevance of findings to Seveso II, the IPPC directive, and environmental management systems

The Guidelines to Seveso II suggest that firms should adopt inherent safety approaches as the preferred strategy over traditional safety measures [17]. Our research shows that inherently safer options can be generated in the design of new facilities, but they can also be identified for application in existing installations, both facilities undergoing retrofit and facilities contemplating expansion. The evidence shows that in all four cases, with a systematic ISOA/TOA, a number of useful and economically viable inherent safety options can be identified. Therefore, both these types of analyses by industrial firms should be systematically encouraged.

From the perspective of the EU IPPC directive [18], the present study is relevant in two ways. First, inherent safety includes a concern for the environment. Inherent safety is a needed complement to the traditional cleaner production/pollution prevention approaches, because the latter too often neglects sudden and accidental releases. Secondly, the solutions database that is now being developed to support the implementation of the IPPC Directive, should preferentially promote technologies that both prevent gradual pollution *and* are inherently safer. As a second best strategy, a similar EU Database of IST could be developed, but the separation of gradual pollution and sudden/accidental releases is not ideal.

From the company practice perspective, the methodology presented offers a practical and economically attractive tool that may be integrated in the company's SHE Management system. It can be used to comply with Seveso II and IPPC, and initiate or contribute to the process of continuous improvement towards inherently safer, healthier, and cleaner production.

7. Recommendations for national and international policy

We recommend the promotion of the concept of ISP via the dissemination of governmental policy statements and publications, and through legal instruments, where

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[8] For a copy of this report, contact G. Zwetsloot at g.zwetsloot@arbeid.tno.nl.

appropriate. This should be complemented by the development of training/education on ISP for policy makers and inspectors in the areas of accident prevention (both for occupational and environmental accidents). Further research in the development of ISP methodologies should be encouraged in the research programmes of the European Commission.

The establishment of economic incentives (e.g. tax incentives) or requirements for firm-based review of inherently safer technological options should seriously be considered as a major policy option. This review should be conducted both at an overall process/scope-of-production level and at the level of the engineering of hardware in actual installations, when firms start to plan new or expanded production. We would argue that both an ISOA and a TOA should be encouraged by including them as highly recommended analyses in the next expansion of Seveso II guidance documents issued by the EU [17]. Additionally, where appropriate as in the case of particularly hazardous operations, these analyses should be made mandatory through the expansion of existing EU directives, including Seveso II and the IPPC Directive [18], and in Environmental Management Systems, both those of the EU [19] and those of the International Standards Organisation (ISO) [20].

Because the concept of ISP can easily include Inherent Safety, Health and Environment (Inherent SHE), this also calls for collaboration between national and international policy-setting bodies concerned with occupational safety and environmental safety.

A second cluster of recommended activities concerns development of supportive Information Technology Tools. This could include:

- the development of databases for IST;
- the creation of a central website giving access to most relevant databases and information sources on inherent safety;
- the integration and/or cross-linking of databases for Cleaner Production/Pollution Prevention and ISP [26]; and
- the screening of databases for Cleaner Production/Pollution Prevention for compatibility with inherent safety.

Furthermore, we recommend the creation of international networks of companies and knowledge centres to work on the development of ISP. Expansion of the UNEP Cleaner Production Centres to integrate Inherent Safety with Cleaner Production/Pollution Prevention should be encouraged [26,27].

In our report to the EU Commission, which sponsored this research, we also develop guidelines for industrial firms based on our field research. The reader is referred to that report for a fuller discussion [31], as well as for descriptions of the specific technologies investigated in the partner firms.

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