FRENCH MINISTRY OF ECOLOGY, SUSTAINABLE DEVELOPMENT AND ENERGY

ACCIDENT ANALYSIS OF INDUSTRIAL AUTOMATION
PART 1/3

ARIA
dgpr srt barpi

CONTENTS

Cover page illustration: Destruction of the BUNCEFIELD (UK) oil terminal subsequent to the successive malfunction of two level controls (ARIA 31312)

1. ACCIDENTS INVOLVING SENSORS IN THE INDUSTRY

For a long time, direct human observation was the sole means available to detect an accidental situation or drift in process operations. Then, sensors and other recording instruments made it possible for technicians to monitor the dynamic dimension of the phenomena. As the first step in any automated system, detection is also one of the most critical since it provides the information required for human or computerised decision-making that affects the safety of industrial processes and installations. Between 1981 and 2009, according to OREDA reliability database recordings, 42 % of automated control and safety malfunctions at the facilities of 10 international petroleum groups were due to sensor failure (vs. just 8 % for processing functions and 50 % for actuator functions, based on a panel of 987 sensor models, 907 valve models and 10 control logic unit models).

What tremendous progress has been made from the mercury thermometer, read visually by a technician, to the 'intelligent' temperature probe capable of self-correction and self-diagnosis, configured remotely and communicating by bus with the controller !

Wireless networked level controls (BANNER ENGINEERING, ARR)

The use of sensors in the world of industry has grown substantially over the past several decades. A survey conducted among 119 industrial sites in France with automated processes (chemicals, oil and gas, water, food processing) revealed that 42 % of these facilities had expanded the number of sensors implemented in 2001, whereas only 0.9 % of respondents had lowered their reliance on sensors, for a 1.5 % average annual increase in sensor use [1]. This survey also indicated that, on average, a typical site employed over 2,000 sensors. Growth in the sensor market was evaluated in 2008 at 6 %/year [2].

Several factors explain the penetration of these devices within industry, namely : technological evolution or, in some cases, revolution (miniaturisation, digital processing, the communicating bus, new materials); reduced production costs (e.g. the price of magnetic flow meters dropped by two-thirds between 1993 and 2003 [3]); and regulatory trends in France and throughout Europe (i.e. MMR and MMRi regarding risk control measurements, risk mitigation for Technological Risk Prevention Plans, fundamental safety-related elements contained in the Seveso Directive, self-monitoring requirement for IPPC- classified facility discharges, the ATEX and Machinery Directives) [4].

While these technological developments have provided an undeniable breakthrough in the area of process and installation safety (through for example the self-diagnosis of malfunctions), the paradox is that they have also raised new challenges for industrial facility managers [5]:

- **How to identify the technology best suited for process and installation risks?** For example, seven distinct technologies exist for a flow meter or level control, and each of these features a unique sensitivity, time lag, and installation and maintenance constraints ([3, 6]);
- **How to determine interactions between the components of a new sensor technology and its functionalities?** This challenge necessitates defining failure modes and establishing a reliability threshold [7];
- **How to manage increasingly complex sensor maintenance?** This challenge entails determining the type (i.e. internal vs. subcontracted) and extent of this maintenance effort;
- **How to cope with the obsolescence of heterogeneous sensors in place?**

In terms of accident analyses, these upgraded and more accessible sensors have most likely led to a reduction in the frequency of accidents caused by human negligence (e.g. overflows, dosing errors). On the other hand, this widespread use of instrumentation requires, more than ever before, promoting strong in-house expertise in terms of specifications and maintenance, as demonstrated by the 2005 accident at the Buncefield oil terminal (featured on the cover illustration): the employees assigned to perform maintenance were unfamiliar with the operating protocol of the overflowed tank's high level gauge and inadvertently deactivated it during a routine test [8].

1.1 Study methodology

This study is based on an analysis of French accidents catalogued in the ARIA database with enough information to develop a good understanding of the event (causes, circumstances, consequences). These accidents have provided a «primary» sample of the 20,329 total accidents involving French classified facilities entered into the base as of December 31st, 2011 (accounting for 50% of all listed accidents). A search by keywords related to the sensor (synonyms, by-products), coupled with an analysis of each accident's summary, helped to narrow this sample to accidents meeting the following criteria:

- One or more sensors were responsible for triggering the accident;
- One or more sensors exacerbated the accident (due to malfunction or, more exceptionally, when functioning properly);
- The absence of sensors either caused or exacerbated the accident (if this absence was explicitly cited in the accident analysis and if the installation of a sensor was planned subse quent to the accident).

The «secondary» sample obtained in this manner (consisting of 640 cases) was ultimately narrowed down to four industrial sectors, identified by their legal industrial sector code (NAF code, yielding 345 cases), for which the degree of automation is considered higher than the average of other sectors: chemicals and pharmaceuticals, food processing, refining, and metallurgy. Note that the ARIA base does not catalogue accidents and incidents regarding nuclear facilities (which are handled by the french ASN/IRSN bases) or workplace-related accidents (french EPICEA base). Therefore, the restricted scope of the ARIA base may tend to under-represent certain sectors of activity that are nonetheless heavily automated (e.g. nuclear power plants, automobile manufacturing and packaging), and so they have not been selected for the present study.

Moreover, since ARIA is based on events, rather than on reliability data (as are the OREDA, PERD, IEEE and EXIDA bases), the data collected and the accident summaries do not always provide precise information on the criticality or technical cause of sensor defects, technology or the level of device maintenance. It is also possible that a bias has been introduced across these four sectors of activity since information feedback on accidents may vary substantially from one sector to the next as a result of: the number of installations in service, the kind of relationship built between BARPI (manager of the ARIA base) and representatives of the various sectors, and the legal environmental classification of the affected facility (e.g. Seveso-rated sites are more closely monitored).

The Influence Factor (Rinfl)

The influence factor is a statistical tool designed to evaluate the influence of a particular element on a given statistical population (e.g. the French population): this base population is referred to as the «complete sample». A «specific sample» can then be extracted from the base according to a specific criterion (e.g. age, religion). The influence factor for the target element is subsequently calculated by comparing the % frequency of element presence within the specific sample (% Samp_specif) relative to its frequency of presence in the complete sample (%Samp_complet), expressed as follows:

Rinfl =% Samp_specif / (% Samp_complete + % Samp_specif)

with :

- ***Rinfl>0,5 : the studied element exerts greater influence on the specific sample than on the complete one;***
- ***Rinfl=0,5 : the studied element, by exerting the same influence on both the specific and complete samples, has a neutral impact;***
- ***Rinfl<0,5 : the studied element is exerting less influence on the specific sample compared to the complete sample.***

Within the scope of this study, the complete sample represents either all accidents occurring at classified facilities in the ARIA base or all accidents within a given sector covered by the base (e.g. chemical industry). The criteria for defining a specific population of accidents are based either on an affiliation with a given industrial sector or on a precise accident-related characteristic (type, consequence, circumstance). The key focus of this analysis is, of course, the influence of the sensor, by investigating its deficiency or its absence at the site of the accident.

Reminder: This mathematical indicator is not at all correlated with the expression «under the influence», which acknowledges that a sensor's measurement has been disturbed by a physical magnitude (see Glossary on p. 28).

1.2 Accident statistical overview

The secondary sample under study comprises 3.1 % of all accidents at classified facilities contained in the ARIA base (i.e. the primary sample). This percentage is higher than for the previous study conducted in 1996 that focused on all defective automation (sensors, data processing, actuators) : this prior percentage equalled 1 % and encompassed the four-year period since launch of the ARIA base.

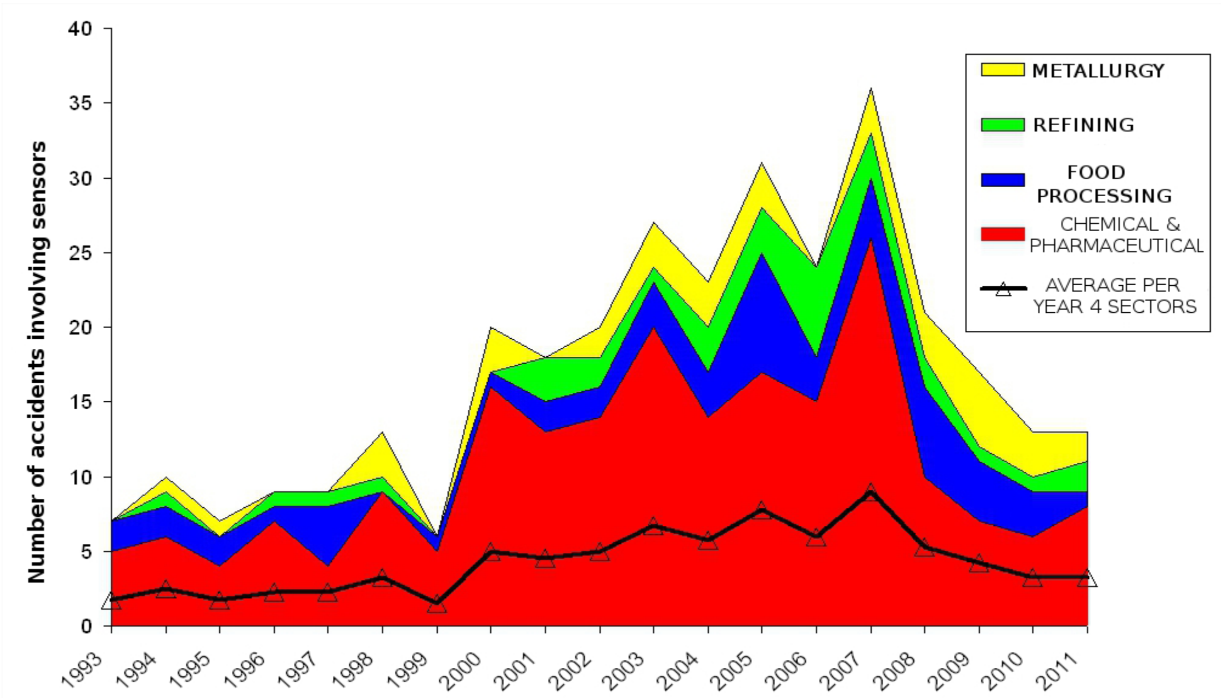
This increase in the number of sensor accidents is confirmed in Figure 1, which highlights a doubling in the average annual number of sensor accidents between the periods 1992-1999 and 2000-2008 for the four sectors studied herein. In absolute terms however, the percentage of sensor accidents remains small compared to all accidents in the base, owing to several reasons:

- The high level of sensor reliability, as illustrated by the data listed in Table 1, especially in comparison with the human and organisational factor, which is involved in the majority of all industrial accidents (63 % of accidents catalogued in the base through 2010 [9]);
- Technological evolution also allows for the remote detection or self-detection of malfunctions or drifts prior to accident occurrence. Moreover, the majority of so-called «safety» sensors (whether for prevention or protection) are increasingly independent of automated controllers or utilise a different technology than process sensors: their malfunctions therefore only produced accidents on rare occasions;
- The percentage of accidents caused by a critical sensor malfunction is, in reality, less than 3.1 %: out of the 345 accidents involving sensors within the four targeted sectors, 43 % (i.e. 150 cases) could have been avoided entirely or at least had their impacts mitigated by the presence of an appropriate sensor. The absence of an appropriate sensor may prove just as likely to trigger an accident as the malfunction itself !

Table 1: Frequency of malfunctions and sensor-related incidents at 192 French industrial sites in 2001 [1]

Malfunction or failure (as percentage of surveyed facilities)	during installation	during operation
unusual	32 %	15 %
quite rare	64 %	80 %

Figure 1 *Annual number of accidents involving sensors by sector of activity (1992-2011)*



1.3 Detailed accident analysis

1.3.1 By sector of activity

Tableau 2 : Breakdown of industrial sectors studied within the sensor-related accident analysis

	% of accidents involving sensors	% of all industrial faclities accidents in the base for 1992-2010 [10]	% of sensor accidents involving failure for the sector	% of sensor accidents involving abscence for the sector
Chemicals-Pharmaceuticals	34	12	55	45
Food Processing	8	7,5	51	49
Refining	5	2	57	43
Metallurgy	5	3,5	56	44
Total or average for the 4 sectors	52	25	55 (average)	45 (average)

Of the four sectors examined here, Chemicals-Pharmaceuticals is the most heavily represented in the sensor-related accident sample, as it is among all accident entries in the ARIA base, due to the large number of operating sites as well as the diversity of their processes (see Table 2). In this sector, the use of sensors is unavoidable since processes are often quite complex, utilise hazardous materials or reactions and feature reaction parameters that in some cases are unknown or capable of varying over time (see example on page 8).

The Food Processing sector occupies second place in the ranking of sensor-related accident frequency, even though the presence of sensors in this sector is probably lower than any of the other three, yet this ranking matches the statistical breakdown for accidents overall (Tables 2 and 3). The percentage of accidents reporting a lack of sensors is slightly higher in this sector than the others (Table 2, last column).

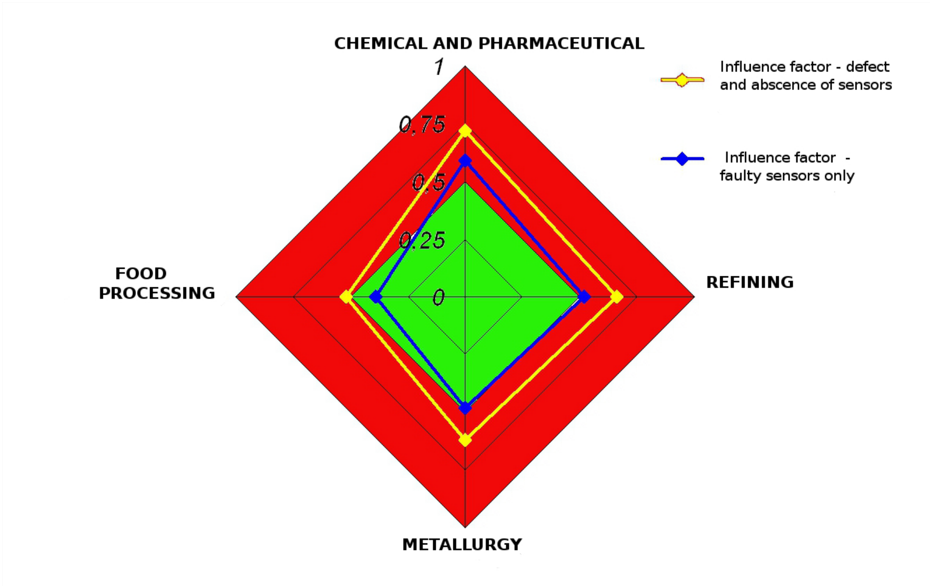
Table 3 : Rate of sensor penetration in selected French industrial sectors [1]

Sector	National	Oil and Gas	Food Processing	Water treatment
Average number of sensor per facilities	2009	6097	570	360

The Refining sector offers only a limited absolute number of sensor-related accidents, yet the accident rates tied to sensor use in Refining remains significant when compared to this sector's representation in the ARIA base (Table 2), despite the small number of French sites compared to the other sectors (13 sites managed by eight different operators throughout the study period). This observation is explained by the high rate of sensor use in the sector (Table 3). The Metallurgy sector profile is nearly identical to that of Refining.

Chemicals-Pharmaceuticals account for one-third of all «sensor-related» accidents listed in the base, while the other three sectors studied constitute less than 10% each. For all sectors analysed, it can be stated that the presence of a sensor adapted to the specific risks at hand would have avoided or at least mitigated nearly half of the accidents recorded

Figure 2 *Influence factor of sensors in the accident rates of the four targeted sectors*



Calculation of the influence factor for accidents related to the «Chemicals & Pharmaceuticals» criterion indicate that the nature of the defect and absence of sensors together exert a major influence on the sector's accident rate (Rinfl = 0.72 - Fig. 2). By focusing exclusively on the «faulty sensor» element, a notable influence is apparent in the accident likelihood (Rinfl = 0.59). These results may be explained by: the high sensor utilisation rate characteristic of the sector, the diversity of existing installations, and operating conditions that tend to be more extreme than in other sectors. Such findings might also suggest some of the difficulties involved in specifying and maintaining a fleet of highly diverse sensors (see Section 2).

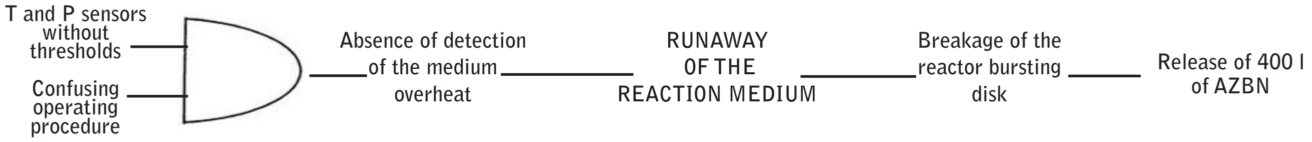
In the Refining sector, the influence factor calculation reveals that malfunctions and an absence of sensors also exert a significant influence on this sector's accident trends (Rinfl = 0.66). When taken alone however, the «faulty sensor» element accounts for a relatively minor influence (Rinfl = 0.52). These results highlight the considerable homogeneity of sensors installed at refining sites, as such facilities tend to be less diversified than Chemical industry equipment. Moreover, a rigorous sensor specification and maintenance protocol might explain the observation of such a weak influence from malfunctions on accident rates (see Section 3). These results confirm the importance of sensor use to ensure the safety of this sector's installations and processes (see page 8 for a sample accident description).

For the Food Processing sector, the calculation of this influence factor demonstrates that sensor malfunction and absence cause a minimal impact on this sector's accident trends (Rinfl = 0.52), with this outcome due more to the lack of an appropriate sensor than to malfunctions themselves (Rinfl = 0.39 for the «faulty» element on its own). Overall, the sensors installed throughout this sector tend to be adequately maintained and adapted to the risks inherent in food processing activities, though we should not overlook the fact that sensors in this sector might be less diversified and less critical than the two previous sectors. Nonetheless, these results show that greater reliance on sensors adapted to the sector's risks helps improve installation safety or at least mitigate accident severity.

The influence factor calculation for sensors in accidents tied to the «Metallurgy» sector suggests that malfunctions and missing sensors have a substantial influence on this sector's accident rates (Rinfl = 0.62). When solely considering the «faulty sensor» element, this influence becomes neutral in accident terms (Rinfl = 0.48). Despite a less strategic role played by sensors in the safety of this sector's installations, the results still show that more use of sensors adapted to the given risks would help improve facility safety or reduce the severity of accidents.

CHEMICALS - RUNAWAY REACTION (ARIA 24570)

June 11, 2003



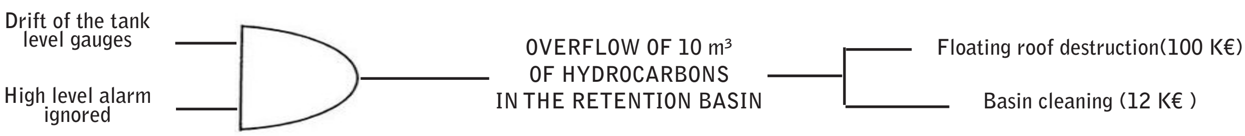
A runaway chemical reaction inside a pharmaceutical plant was caused by the excessive heat from a mix of cyclohexane/methylcyclohexane, N-bromosuccinimide and azoisobutyronitrile (AZBN). The reactor's safety disc ruptured and 400 litres of mix were discharged into the atmosphere. In accordance with the operating protocol, which called for maintaining the mix at a temperature of between 15° and 20°C, the technician heated the reactor with steam at 0.5 bar and then started working on another device. The temperature of the mix reached 56°C within 10 min, at which point the technician stopped heating and stirring the reactor. Since the high pressure level (0.35 bar) had been exceeded, the safety disc ruptured at 0.5 bar shortly thereafter; the temperature was then 70°C. The workshop foreman, who remarked a temperature rise of the reactor up to 84°C two minutes hence, immediately initiated the emergency shutdown routine. This accident was caused by the absence of both temperature regulation and an alarm on the existing sensors, in addition to an inaccurately written operating protocol. Shutting off the stirrer constituted an exacerbating factor by virtue of limiting heat transfer possibilities. The former reactor, which had not been dedicated to this reaction, contained inappropriate safety barriers: a temperature threshold set at 150°C, **missing temperature regulator and pressure/temperature alarm triggers.** The risks studied had been focused on handling AZBN, thus inducing reaction deviations that had not received adequate attention.

OTHER RELEVANT REFERENCES :

Reaction medium temperature	Aria 3725, 5140, 25240, 30323, 32460
Reaction medium pressure	Aria 7069, 26974, 32796
Reagent flow rate	Aria 4708, 27516
Stirring of the reaction medium	Aria 6784, 32460

REFINING - TANK OVERFLOW (ARIA 36101)

January 18, 2009



Inside a refinery, the floating roof tank used in the production of 98-octane gasoline had since 2:30 am been filled with the basic ingredients (butane, naphtha base, alkylate, ETBE) entering into the mix at an average flow rate of 630 m^3/h. At 2:23 pm, a high level alarm (alarm button plate by mechanical contact with the floating roof relayed to the control room) was activated while the gauge was indicating a level of 10.04 m for a high level mark set at 14.6 m. Nonetheless, the tank continued to be filled and at 4:45 pm, the gauge posted a level stabilised at 11.135 m. An error message notifying the disagreement between tank status (filling) and gauge stability was sent to the control room. A technician was deployed to the site and observed a gasoline spill within the retention basin. The instrument supervisor then stopped the filling process and alerted emergency services [...]. The tank's foam boxes, blocked by the secondary joint of the floating roof that had derailed from its track, were no longer in working order. The operator estimated at 10 m^3 the quantity of hydrocarbons spilled into the basin, which also contained rainwater. Total property damage to the tank roof was appraised at €100,000, while clean-up costs amounted to €12,000. An inspection of the tank's structural integrity along with expanded monitoring of groundwater was undertaken after detection of a thick layer of hydrocarbons floating at the level of the piezometers installed around the retention basin. ***The tank overflow was caused by both a defect in the level gauge (due to a 4-m offset, a malfunction known since 10th January yet went uncorrected) and failure to comply with the procedure imposing pump shutdown upon activation of the high level alarm***.

OTHER RELEVANT REFERENCES :

Aria 10418, 22404, 23139, 23309, 26506 , 26604, 29711, 29903, 32579, 32680, 32693, 35882, 36101

1.3.2 By category of sensor

For the needs of this study and in light of information available in the accident descriptions on file, five major sensor categories have been defined as a means of collating the various types used within industrial settings:

1. Physical parameter sensors: temperature, pressure, density, weight, etc.;
2. Spatial parameter sensors: state, position, level, depth, interface, etc.;
3. Sensors for detecting abnormal phenomena: flame, smoke, ATEX-rated atmosphere, hazardous gaseous/liquid/solid substances, video-monitoring, etc.;
4. Kinematic parameter sensors: flow rate, velocity, acceleration, vibration, rotation, mechanical stress, etc.;
5. Physicochemical parameter sensors: pH, rH, conductivity, resistivity, radioactivity, intensity, voltage, metal content, etc.

Chemical Reactor fitted with sensors (BARPI)

The first three categories are the most frequently involved in the accidents of our four targeted sectors: each category accounts for between 18 % and 50 % of all sensor-related accidents within these sectors (Table 4). When combined, these three categories comprise over 90 % of all accidents inventoried in our sample. These results are consistent with the profile of sensors currently used in French industry, with temperature and pressure sensors being much more widely used in comparison with flow rate and level controls [1]. Sensors dedicated to abnormal phenomena are often cited in accident reports given their importance in accident prevention and mitigation. The category of sensors designed for measuring kinematic parameters seems to be proportionally less present in the population of sensor-related accidents (from 3 % to 9 %, depending on the sector) than its actual use frequency (16 % for flow rate sensors in 2002, [1]), resulting perhaps from a reliance on more robust technologies.

The frequency with which these various sensor categories are listed in accident descriptions seems to be consistent with their respective rates of installation throughout French industry, except for the more limited presence of kinematic parameter (i.e. flow rate) sensors

An assessment of the distribution of accidents relative to either a deficient or missing sensor (Table 4) shows that only the spatial phenomena-type sensors (primarily level controls) are more regularly cited for their malfunctions rather than their absence. Such a finding may be explained by the fact that industries have tended to prefer level sensors based on a mechanical operating principle as opposed to an electronic or magnetic principle (at least until 2005 [6]), and it is known that mechanical devices are more prone to wear, fouling and jamming, e.g. level measurements using a float or plunger for liquids, vibrating rods or rotary grates for solids.

Level controls tend to be much more present than other types in accidents «involving a sensor», especially those occurring in the Refining sector (39 % of the sector's total sensor-related accidents)

The physical parameter sensors lie at the core of industrial process designs and safety features for the Chemicals-Pharmaceuticals, Food Processing and Metallurgy sectors (all of which involve the handling and transformation of hazardous substances), hence their importance in the accidents studied (Table 4). Such is also the case for sensors dedicated to abnormal phenomena for all four sectors as regards installation safety. The spatial phenomena (level control) sensors are more specifically involved in Refining accidents (transfer of inflammable and explosive substances), while physicochemical parameter sensors are more readily found in Chemicals-Pharmaceuticals accidents (i.e. process control).

Table 4: Breakdown of sensor-related accidents by sensor category per sector of activity

% of accidents involving sensors in the sector	Chemicals & Pharmaceuticals		Food processing		Refining		Metallurgy	
	failing sensor	missing sensor	failing sensor	missing sensor	failing sensor	missing sensor	failing sensor	missing sensor
Physical parameter	20	22	22	21	15	3	19	25
Abnormal phenomena	14	16	15	23	21	6	10	21
Spatial parameter	15	7	16	10	39	8	20	11
Kinematic parameter	5	4	0	6	0	0	3	0
Physicochemical parameter	7	6	2	0	3	0	3	4

Except for the Refining sector and spatial parameter sensors, it can be observed that a significant proportion of accidents could have been avoided or resulted in only minor consequences had an adapted sensor been installed. For the most part, Refining accidents entail defective sensors, which confirms that the sensors used in this sector are adapted to meet process monitoring needs (applicable to both the physical and spatial parameter categories) and refinery safety needs (abnormal phenomena detection sensors).

Again with the exception of Refining, a higher rate of sensor utilisation specifically for the purpose of detecting physical parameters and abnormal phenomena would serve to reduce the occurrence and seriousness of accidents

1.3.3 By type of accident

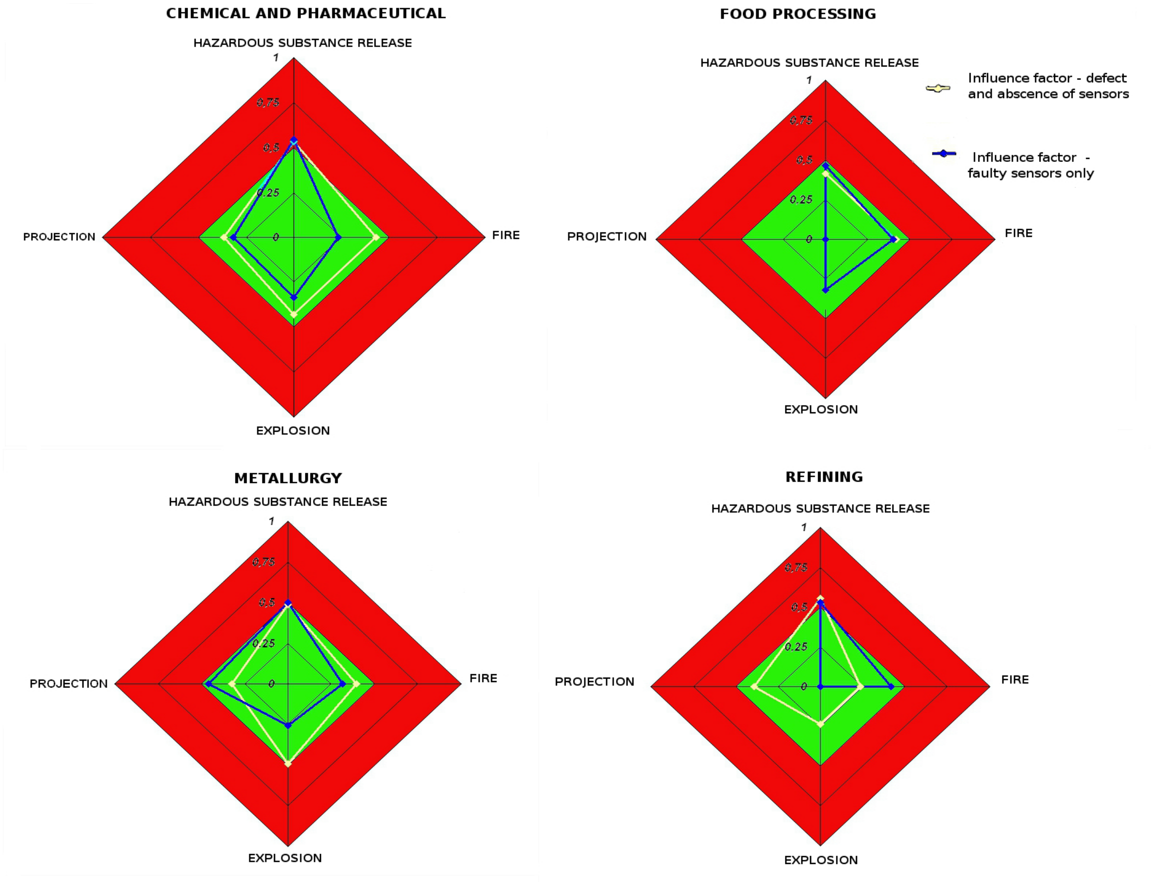
The sensors' influence factor for the restricted sample of sensor-related accidents identified by the criterion «type of accident» has been calculated for each of our four sectors; the complete sample is thus composed of all sector accidents entered into the ARIA base. For each sector, this factor is computed twice: first with the full specific sample (i.e. all accidents involving sensors due either to their malfunction or absence), then a second time with the specific sample limited to just those accidents caused by sensor defects. A comparison of these two results illustrates the extent to which a greater sensor use rate would influence the sector's accident typology.

The influence factor calculation for Chemicals-Pharmaceuticals demonstrates that sensor malfunctions/ absence is not an element responsible for generating accidents involving fire, explosion or debris projection (Rinfl < 0.4 - Fig. 3). This observation however does not hold for accidents of the «hazardous substance release» type, in which this element appears to slightly favour occurrence (Rinfl = 0.55). This type of accident is actually the most frequently encountered in the sector (58 % of all Chemical-Pharmaceutical accidents entered in the base, vs. just 39 % for all sectors combined [10]). In this particular sector, the majority of sensors are employed in order to avoid this very type of accident (leak outside of a storage zone or manufacturing machinery).

This observation remains unchanged for the Refining sector, where sensor deficiency / absence shows an even more neutral effect than for Chemicals as regards accidents of the «hazardous substance release» type, although this type happens to be the most frequent sector-wide (i.e. an Rinfl near 0.5). The finding is similar for Food Processing and Metallurgy as well (Rinfl < 0.5, including missing sensors).

For each sector, a comparison of the influence factor found in accidents caused by sensor malfunction and that found in accidents caused by either malfunction or absence reveals that sensor absence influences the occurrence of all types of accidents, except in the Food Processing and Metallurgy sectors (i.e. an Rinfl both «with and without sensors» < 0.5) and for fires in the Refining sector (Fig. 3).

Figure 3 *Sensor influence factor per type of accident per sector*



This influence factor calculation confirms that the presence of sensors at installations helps reduce the frequency of the most serious types of accidents (i.e. fire and explosion), yet seems to exert only minimal influence on accidents involving leaks of hazardous substances, which remain the most common

Table 5 shows the involvement of process control sensors and installation safety monitoring sensors in the various types of sensor-related accidents in each sector.

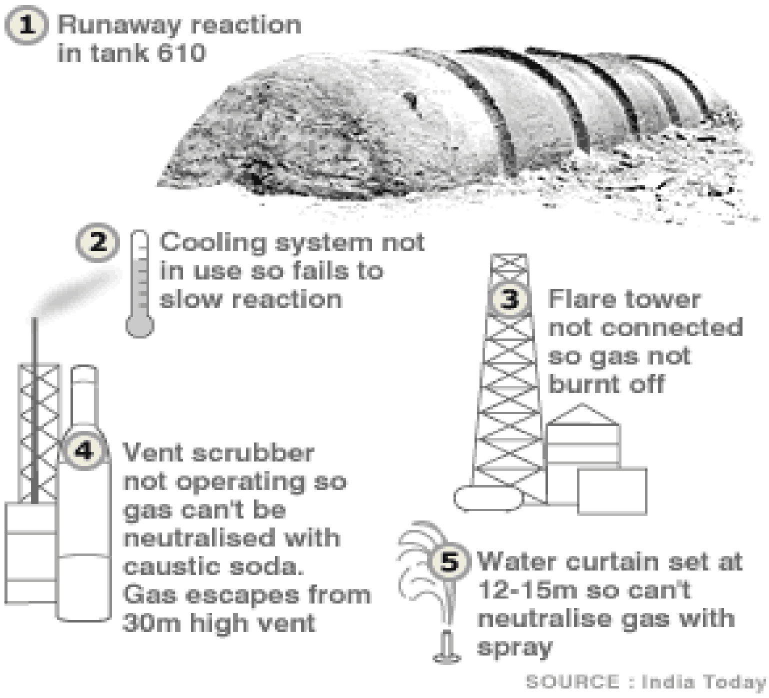
Except for Food Processing, process sensors are most often involved in high-frequency type accidents in the targeted sectors (i.e. hazardous substance leak, accounting for over 68 % of all recorded accidents). This table confirms the critical nature of process sensors in reducing accident occurrence in the Chemicals-Pharmaceuticals, Refining and Metallurgy sectors. Table 5 also demonstrates that process sensors are used much more extensively than safety sensors.

In contrast, for Food Processing, safety sensors are more often involved in the most widespread type of accident (i.e. fire, accounting for 51 % of all recordings).

The limited references to safety sensors in Refining accidents serves to confirm the reliability of these sensors as well as their high penetration in the sector.

With the exception of Food Processing, process control sensors are much more involved in sensor-related accidents than sensors dedicated to installation safety

the BHOPAL disaster (ARIA 7022) illustrates the importance of process sensors, as out of order pressure / temperature / level control sensors prevented the early detection of the runaway reaction occuring in tank 610



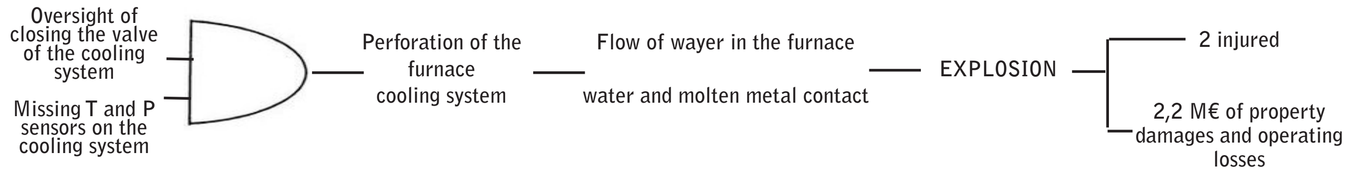
The data listed in Tables 4 and 5 also confirm that greater use of safety sensors would help reduce the occurrence or seriousness of Metallurgical accidents (fire detection, gas detection). In fact, this category of sensor is at the origin of 85 % of accidents in this sector connected with an absence of sensors. For the accident presented on page 13, which took place inside a steel mill, at least three different types of sensors were missing (temperature, pressure, hydrogen detection). Such is also the case in the Food Processing sector, where a lack of safety sensors (fire detection, ATEX and NH_3 toxic gas detection for refrigerated warehouses) is responsible for 70 % of «missing sensor» accidents. The accident described on page 13 offers a case in which the presence of sensors on certain devices would have avoided a serious accident.

Table 5 : Breakdown of sensor-related accidents by type of accident, sector of activity and type of sensor

% of accidents involving sensors in the sector	Chemicals & Pharmaceuticals		Food processing		Refining		Metallurgy	
	Process sensor	Safety sensor	Process sensor	Safety sensor	Process sensor	Safety sensor	Process sensor	Safety sensor
Release of hazardous material	48	18	21	15	79	9	49	18
Fire	9	7	13	38	15	15	9	8
Explosion	7	6	2	4	0	3	8	6

Greater use of safety sensors adapted to the risks of the activity would make it possible to reduce accident occurrence in both the Food Processing and Metallurgy sectors

METALLURGY - ABSENCE OF SENSORS (ARIA 33059)
June 8, 2007

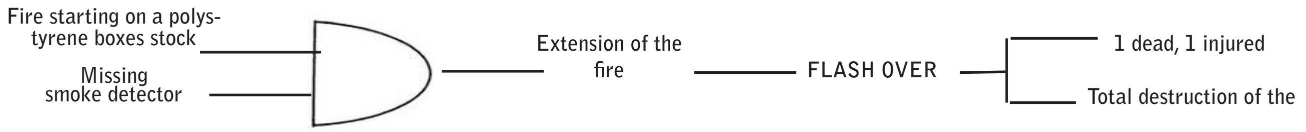


In an electric steel mill, the control technician assigned the (70-tonne) melting furnace noticed blue flames on the monitoring camera images, which signalled the presence of water in the furnace. He closed the safety guard in front of the glass partition separating the control cabin from the furnace enclosure and proceeded by evacuating all sector employees. A violent explosion occurred a few seconds later following contact between water and the molten metal. During the afternoon of the same day, a water leak had been noticed on two coolant return hoses running along the furnace vault.

One hose had been changed. To remedy the deficiency of the other hose, it was decided to activate the backup return circuit; since the water valve on this circuit had not been opened, the cooling system malfunctioned, causing a tube to be perforated and water to flow into the furnace. Two employees sustained slight concussions and had to be hospitalised; they were released that same evening. Property damage was extensive: the «dog house» doors (furnace enclosure) fell off, suspension tie rods on the furnace vault broke, and portions of the smoke absorption device were projected inside the building. The total cost of property damage from this accident was estimated at €1.64 million, while operating losses amounted to €630,000. During their investigation, classified facilities inspectors noted the following: inadequate organisation of maintenance work on water supply hoses for the furnace vault (procedures, coordination of subcontractors, monitoring, etc.); **onsite instrumentation incapable of efficiently controlling vault cooling** or integrity of the water circuit (lack of temperature or pressure variation measurement); and an absence of backup cooling circuit instrumentation. The site operator adopted the following remedial action plan: implementation of backup circuit instrumentation, revision of maintenance organisation, **installation of a hydrogen detector, completion of a study on cooling circuit control system for the purpose of improving efficiency tracking**

OTHER RELEVANT REFERENCES : Aria 36083

FOOD PROCESSING – MISSING SENSORS (ARIA 37738)
January 18, 2010



At around 3 am, on the 2nd floor of a 1,000-m² facility specialised in the cooking and packaging of shrimp sold as a frozen food for retail outlets, a fire that broke out on a stockpile of polystyrene boxes released thick black smoke. A temp employee sounded the alarm and immediately shut off the gas feed line to the cooking appliance; then, two technicians who had arrived two hours prior to restart service on the site's two production chains, along with nine other employees who had begun their shift 15 min earlier, evacuated the premises. Emergency services were at the scene when around 3:30 am a flashover ignited the entire building, causing the structure to collapse. Blasted onto the ground floor, one of the two fire-fighters trying to contain the fire with a nozzle was killed; his body was found under the rubble 45 min later thanks to a search device installed using a dog handler and thermal camera. The second fire-fighter was burned on the face but managed to escape. A medical-psychological emergency unit treated the three other fire-fighters, all of whom were in a state of shock. It was feared that the flames would spread to a nearby storage zone containing nitrogen bottles. This intervention mission mobilised a total of 60 fire-fighters and lasted several hours. The emergency team shut off the refrigeration installation circuit, which was being supplied by a tank containing 1 tonne of chlorine-fluorine refrigerant, then successfully brought the blaze under control around 7 am using six nozzles, one of which was mounted on a ladder. A specialised subcontractor pumped the chlorine-saturated water that had covered some 150 m² of basement area up to a depth of 50 cm. The building was destroyed and 30 employees faced possible redundancy. The plant, founded in 1991, was undergoing expansion (500 m² / €600,000 of capital investment), with the corresponding works slated for completion in May 2010. The operator had planned on upgrading alarms to meet code requirements once the expansion project was terminated. According to the Head of Maintenance, **the premises used to store cardboard packaging and pallets of polystyrene boxes had not been fitted with a smoke detector.**

OTHER RELEVANT REFERENCES : Aria 18964, 20484, 31239, 35997

1.3.4 By accident consequences

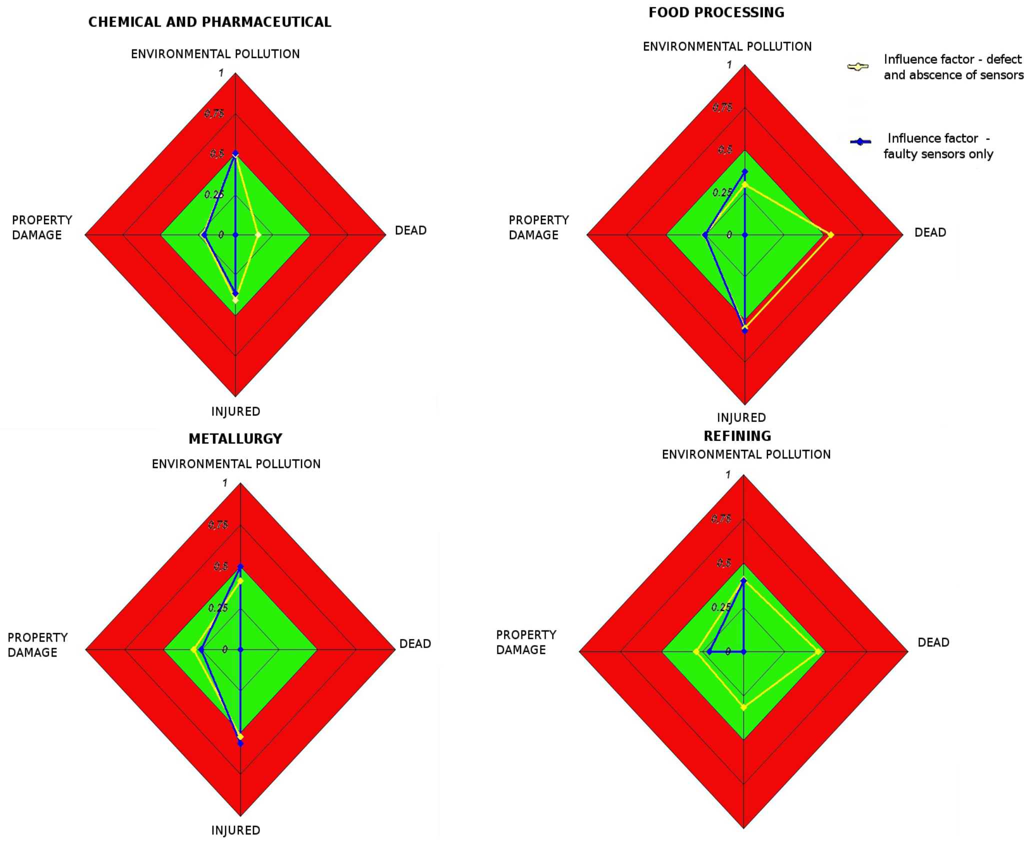
The influence factor for sensors on the specific sample of sensor-related accidents, as defined by the «accident consequences» criterion, has been calculated for each of the four sectors; the complete sample is thus considered as the full set of sector accidents entered into the base. For each sector, two calculations of this influence factor were conducted: the first used the entire specific sample (i.e. all accidents involving sensors as a result of their malfunction or absence), while the second calculation focused on the specific sample limited to just those accidents caused by sensor malfunction. The comparison of these two results highlights the extent to which a higher rate of sensor usage might affect the consequences of accidents arising in each given sector.

The influence factor calculation for Chemicals-Pharmaceuticals and Refining indicate that sensor malfunction/absence does not exacerbate consequences for accident victims or property damage (i.e. Rinfl < 0.4 - Fig. 4). This outcome differs however for Chemical-Pharmaceutical accidents causing «environmental pollution», since the influence here appears to be slightly positive (Rinfl = 0.53). Such a consequence turns out to be quite commonplace for this particular sector, no doubt in connection with the high frequency of sensor-related accidents involving the release of hazardous substances (see p. 10); in 47 % of all cases, these accidents led to an environmental pollution. For the Refining sector, the heavy human toll of the accident from two decades ago, presented on p. 15, offers an rare exceptional case of the consequences due to sensor absence in this sector.

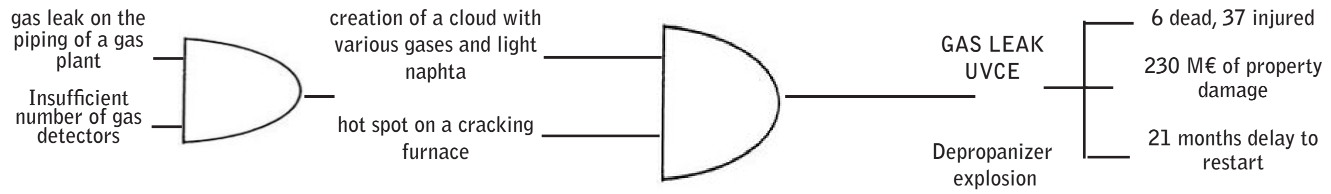
While sensors are apparently beneficial in reducing the seriousness of human consequences from accidents in the Refining and Chemicals-Pharmaceuticals sectors, such is not the case for the Food Processing and Metallurgy sectors

Observations are quite different for both Food Processing and Metallurgy since sensor malfunction/absence stands out as a parameter that may raise the frequency of accidents with human casualties (Rinfl > 0.55 for «deaths» and/or «injured» - Fig. 4). A campaign to add sensors for improving employee protection thus seems to be an effective strategy for mitigating the human consequences from accidents occurring in these sectors, as illustrated by the second accident presented on page 15.

Figure 4 *Sensor influence factor per accident consequences per sector*



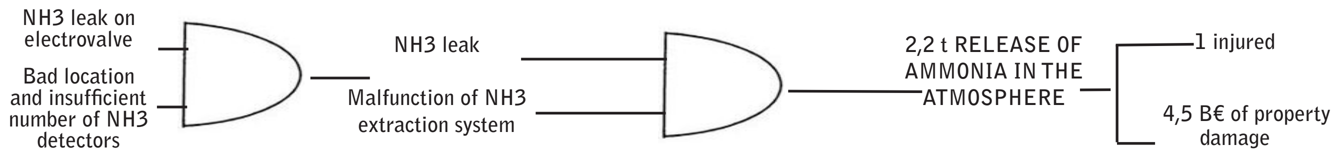
REFINING - SERIOUS ACCIDENT (ARIA 3969)
November 9, 1992



An extremely violent explosion occurred at 5:20 am inside a refinery that was operating under normal conditions. Felt as far as 30 km, this explosion was followed by several others. The internal emergency plan was activated and external responders arrived at the scene. The «red plan» was also triggered, with 250 fire-fighters mobilised. The fire was finally brought under control at 1:30 pm. The human toll was very high: six dead and 37 injured, including one seriously among the personnel and two injured fire-fighters. The site was completely devastated over a 2-hectare zone, and windows were shattered within a 1-km radius outside the plant (some panes blown out up to 8 km away). A judicial investigation was carried out; its conclusions pointed to a gas leak that occurred on an 8-inch diameter pipe in the gas plant (gas processing tower operating at 10 bar, in association with the cracking unit). The unconfined vapour cloud causing the explosion (UVCE) was evaluated at 12 tonnes of a mix containing various gases (butane, propane) and light naphtha. Due to a domino effect, the depropanizer subsequently exploded (resulting in a fireball) and six fire outbreaks were recorded, including one on a tank 200 m away. To contain the 5,000 m² of ignited building space, 150 m³ of emulsifier were introduced. The unit's control room was entirely destroyed (and three of its technicians killed). Total damage was assessed at over €230 million. The site restarted activity in 1994. During the nine ensuing years, the operator invested an additional €192 million in the facility, a quarter of which was allocated to improve site safety. The control room was replaced by a bunker-type structure, **the number of gas detectors greatly increased** and the pipe inspection programme strengthened.

The Mède accident is one of the very few serious ones (in terms of human and financial losses) to strike France's refining sector in the past few decades.(Aria 3969, SDIS 13)

FOOD PROCESSING - SERIOUS ACCIDENT (ARIA 10165)
June 11, 1997



In a slaughterhouse's attic space, a 2.2-tonne ammonia leak occurred on the solenoid valve of a ground meat freezer return circuit. Employees were evacuated for 24 hours, 40 neighbours were confined within a 500-m safety perimeter and 20 fire-fighters (including a chemical emergency squad) installed a water curtain. The leak was stopped two hours later by closing valves; premises were ventilated for 30 consecutive hours. NH3 odours were perceptible up to 1 km away. A technician suffered a malaise and had to be hospitalised; property damage and operating losses were valued respectively at €3.9 million and €600,000. An expert appraisal was conducted: the refrigeration unit, which had been operating for one month, was using 8.5 tonnes of NH3. The solenoid valve, held in place by eight bolts, had no fitting but instead a new type of DN150 flat seal (it was decided to forego asbestos joints), which broke due to NH3 pressure. Dynamometric measurements indicated less clamping on two of the bolts. Locknuts were advised in order to lock the clamping [...]. Experts concluded that the leak was being fed, since the upstream valve had been manually opened and not completely closed prior to the accident. The venting hatches designed to discharge NH3 to the outside were inoperable (electrical connection anomaly). The inspection revealed several compliance failures: an internal plan not validated by emergency services and without written instructions to implement intervention measures, evacuate site personnel and call first responders; **a general sound alarm not coupled to NH3 detectors (whose planned number and locations did not provide a detection system capable of guaranteeing personal safety)**; and inadequate individual protective gear and personnel safety training in the use of NH3.

OTHER RELEVANT REFERENCES : Aria 18964, 20484, 21960, 32239

1.3.5 By accident-related circumstances

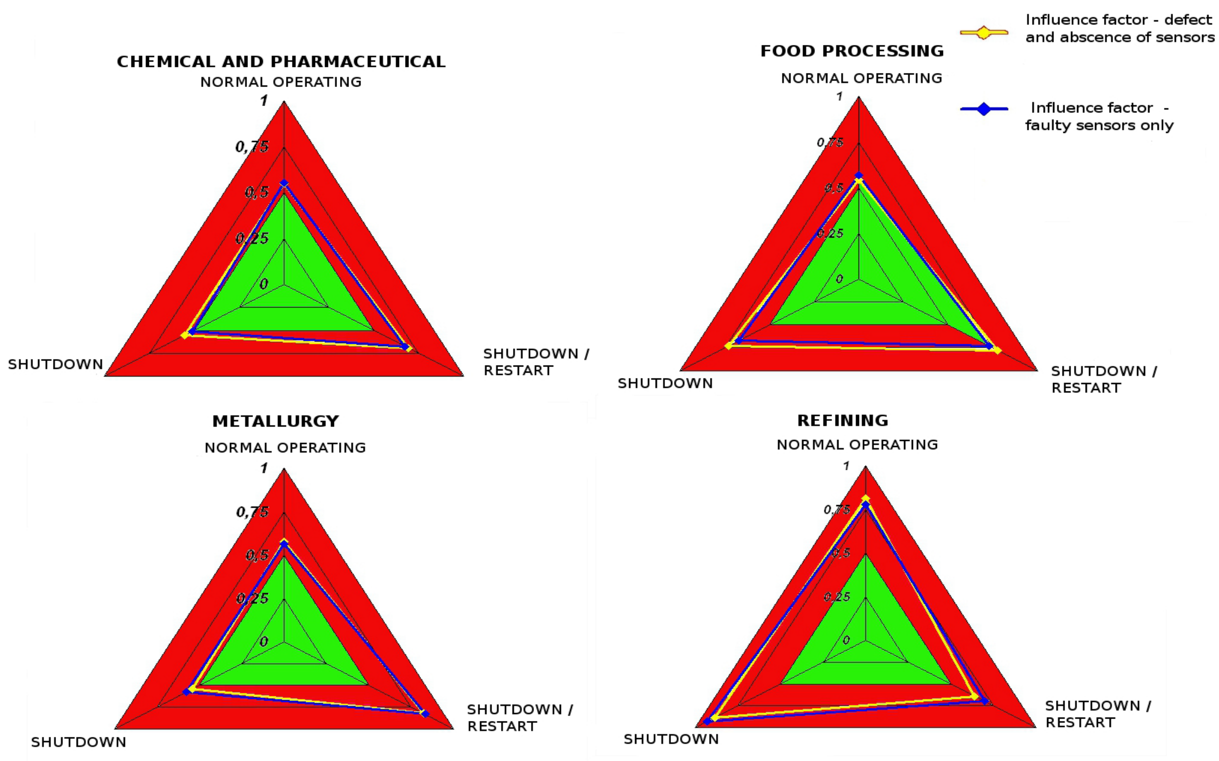
The influence factor for sensors measured on the specific sample of all sensor-related accidents, as defined by the «accident circumstances» criterion, has been calculated for each of our four sectors of activity; the complete sample is thus considered to be the full set of sector accidents entered into the ARIA base.

As shown in Figure 5, the installation shutdown/restart phases provide the circumstances whereby sensor malfunction/absence exerts a significant influence on accident occurrence rates (i.e. Rinfl > 0.75 for all four sectors). This observation may be explained by the fact that sensors tend to be designed specifically and maintained for normal operating phases of industrial installations, during which safety is effectively overseen by operators; in contrast, the shutdown or restart phases expose situations not systematically included in sensor specification, installation or adjustments (see the examples relative to sensor adjustments on page 20).

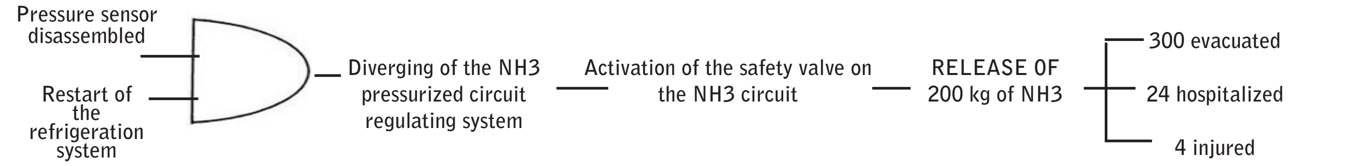
The periods of refinery shutdown also create circumstances in which sensor malfunction/absence may exert a strong influence on accident rates (Rinfl > 0.92 for accidents with sensors). As illustrated by the accidents presented on page 17, an installation restart sometimes reveals maintenance anomalies that arise more readily during a down period (fewer employees, maintenance personnel distinct from operating staff, reliance on subcontractors), such as forgetting connections, shunts, damage or even neglecting to clean the sensor.

Installation shutdown/restart phases seem particularly conducive to accident occurrence when sensors are involved. Such is also the case during shutdown periods in the Refining sector

Figure 5 *Influence factor for sensors on accident circumstances by sector*



CHEMICAL INDUSTRY - RESTART (ARIA 36660)
August 13, 2009

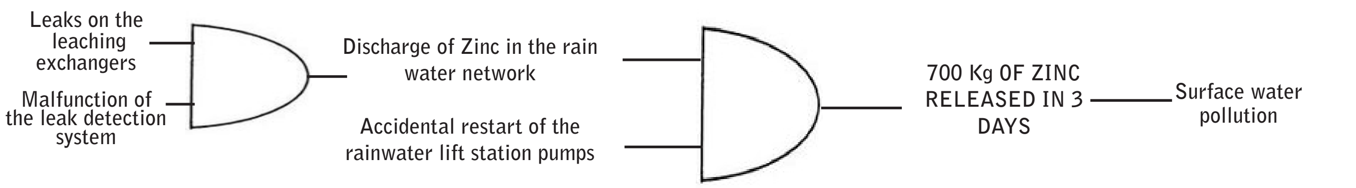


Ammonia was released through a vent within a carbon dioxide liquefaction workshop at a chemical plant [...]. 300 employees had to be evacuated [...]. A total of 24 individuals suffered discomfort, four of whom required hospitalisation as a precaution. The workshop was devoted to liquefying CO_2 with support provided by a refrigeration circuit delivering 5 tonnes of ammonia. **With the shop in a down period, a pressure transmitter had been disassembled the previous day in order to proceed with maintenance on the high-pressure NH_3 compression circuit.** This transmitter, which was performing a dual function, made it possible to regulate refrigeration circuit pressure at a recommended value of 13 bar and thereby ensure installation safety with a trigger value set at 14 bar. **The workshop resumed operations the following morning while the transmitter was still being repaired**. With no regulation or safety protection in place, the system diverged and the NH_3 circuit rose in both temperature and pressure. The circuit safety valve was activated, and 200 kg of NH_3 were discharged through a vent 17 m high.

OTHER RELEVANT REFERENCES : Aria 14163, 2900, 32798, 33308, 34319, 35320, 38488

River pollution subsequent to a sensor malfunction (ARIA 26665, Dreal Haute-Normandie)

METALLURGY - RESTART (ARIA 26895)
January 21, 2004



In a metallurgy plant, water containing zinc spilled into a canal **upon resuming plant operations after a period of regularly-scheduled maintenance on both the leaching and electrolysis lines.** The site had installed a network to handle polluted rainwater that was connected to a lift station to allow for transfer to a storage basin and neutralisation-sedimentation facility. The former lift station pumps, which provided for direct discharge (i.e. without treatment) into the canal, were kept in place for use under exceptional circumstances. On the day of the accident, leaked volumes on the leaching exchangers flowed into this rainwater network and, following a pump handling error, were discharged without treatment for three days into the canal; in all, 700 kg of zinc spilled into the natural environment. An investigation found that the handling error was allowed to occur due to unauthorised onsite retention of the former pumps. The Classified Facilities Inspectorate also recorded **a malfunction in the leak detection system** as well as in detection transmission to the automated process controller [...]. The operator adopted several remedial measures: replacement of the exchangers, displacement of the conductivity recording, recycling of the condensates from evaporators, locking or electrical regulation of the former pumps, and implementation of a dedicated facility-use procedure. An order issued by the local government authority with additional prescriptions imposing, among other things, pump closure.

OTHER RELEVANT REFERENCES : Aria 14203,18135

A more detailed analysis was carried out regarding the causes of malfunction among the sensors involved in accidents recorded in the secondary (i.e. «with sensor») sample for each targeted sector, accounting for 57% of all accidents considered in the present study. These causes may be classified into three major categories:

- **Sensor noncompliance with the expected function:** specification error (ergonomics, design, materials, sensitivity, measurement accuracy, etc.); adjustment error (detection threshold, indication, time lag or sampling frequency); and inappropriate location (risk of clogging or leak on the sampling lines, non-representative measurement);

- **Sensor malfunction:** installation or connection error, harsh weather event (lightning, frost, wind, humidity, etc.), clogging/fouling/jamming, loss of utility, deliberate or non-deliberate shunt, corrosion/rust (of the sensor body, tapping, cables or sensor casing connections), other unidentified malfunctions;

- **Erroneous sensor information:** flawed calibration, measurement drift (poisoning of the catalytic cells, dormancy of the electrochemical cells in the gas or fire detectors), and electromagnetic disturbance.

These three categories of sensor malfunction serve to analyse in greater depth each sector's «sensor-related» accidents in order to draw pertinent lessons.

2.1 Is the sensor adapted to the expected functionality?

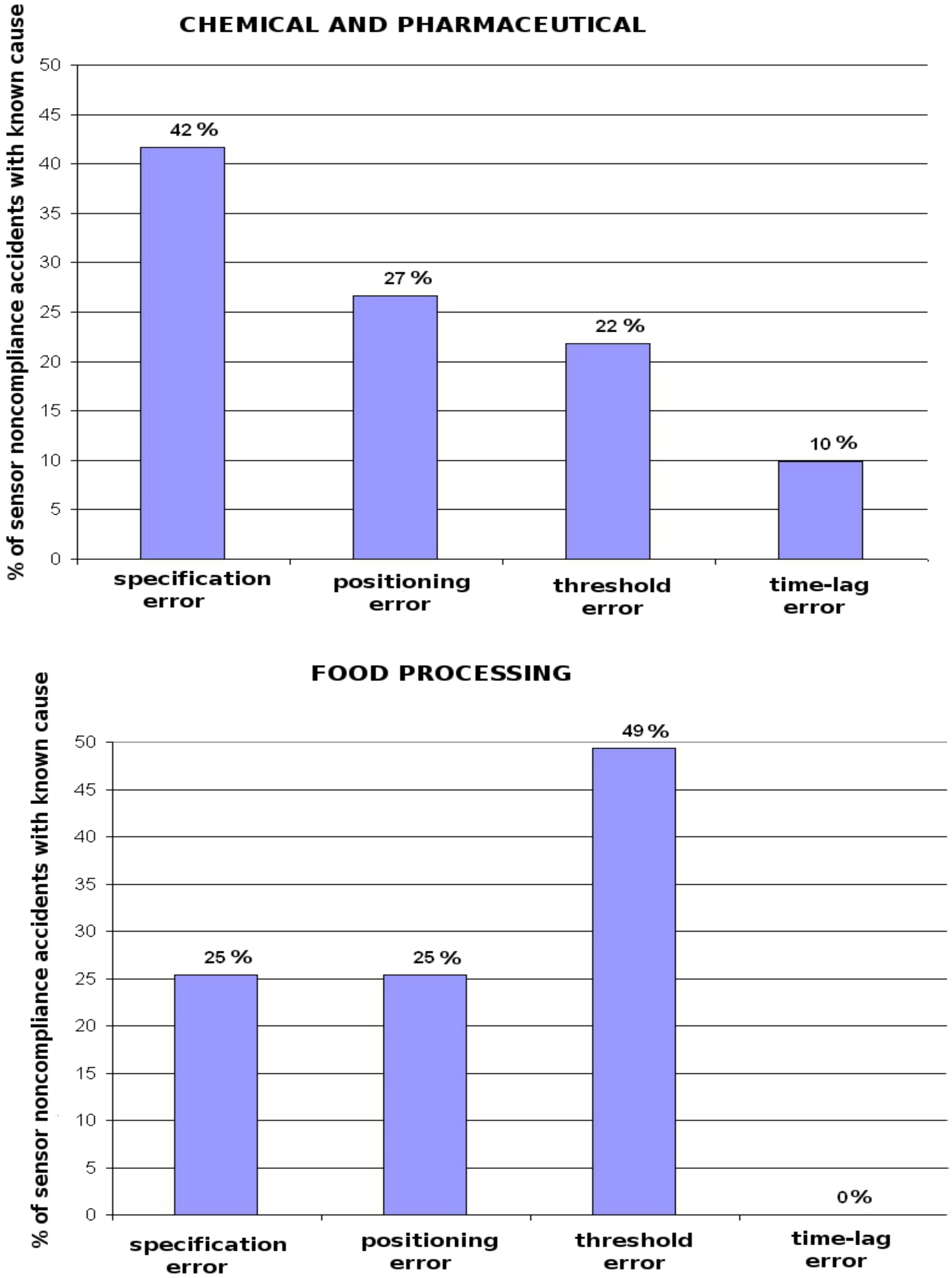
Sensor noncompliance with the intended function accounts for up to 31 % of all accidents tied to a defective sensor, depending on the given sector. A survey conducted in 2002 on 192 French industrial sites indicated that sensor configuration errors were responsible for 35 % of sensor malfunctions encountered on installations [1]. Moreover, according to the French Users' Association of Measurement, Regulation and Automation Equipment, 39 % of the 107 automated devices in operation (comprising 89 % sensors and tested over a five-year campaign) did not comply with specifications when placed under reference conditions and moreover 74 % of these devices remained noncompliant when tested under influence quantities of the measurement [10]. Lastly, in 2003, Britain's HSE Agency, upon analysing 34 serious accidents involving automated industrial control systems, estimated that 44 % of sensor malfunctions were due to specification error and another 15 % to installation error [11].

In the Chemical-Pharmaceutical sector, 31 % of accidents with sensors were caused by sensor noncompliance under operating conditions, mainly due to errors of sensor specification, adjustment or installation. For the Food Processing sector, this percentage also came in at 31 %. Three accidents illustrating such compliance problems in these sectors are presented on p. 20, while Figure 6 provides a breakdown of the various categories of noncompliance for both these sectors.

Over 30% of all Chemical-Pharmaceutical and Food Processing accidents involving defective sensors are due to a selection error : incorrect specification, adjustment or positioning error, inappropriate measurement range

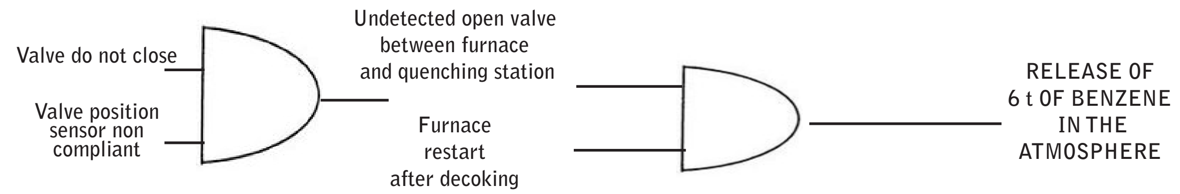
Wireless sensor protected against bad weather conditions (Banner Engineering, ARR)

Figure 6 *Specification errors in sensor-related accidents in both the Chemical-Pharmaceutical and Food Processing sectors*



Few accidents due to noncompliance were identified in the Refining and Metallurgy sectors. Specifications errors thus appear to be rarely implicated in these two areas. A more robust standardisation of instrumentation, combined with greater installations and processes homogeneity than those found in the Chemical sector, might explain this finding (procurement policy applied by major groups across all sites, greater attention paid to equipment feedback thanks to reliability oil industry databases such as OREDA).

CHEMICAL INDUSTRY - SPECIFICATION (ARIA 32798)
February 14, 2007

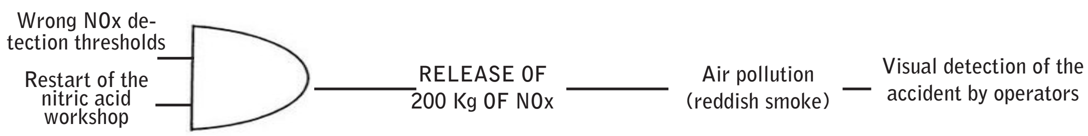


At a chemical plant, a major hydrocarbon leak occurred upon restarting a furnace on the steam cracking line following a maintenance period (for decoking) [...]. The transition phase between decoking and furnace restart required handling two valves [...]. At the time of the accident, a mechanical problem prevented closing the first valve, which was not detected by either the controller or site personnel. Under these conditions, the valve between the furnace and the quenching station was open, thus facilitating a release into the atmosphere of 6 tonnes of cracked gas generated by the quenching station [...]. The analysis of deficiencies conducted by the operator placed blame on a broken coupling between the electric motor and decoking valve rod. **Moreover, the end-of-stroke design, which relied on detecting a number of rotations in the motor component and not on the valve rod's physical position, did not allow detecting the unclosed valve...**

OTHER RELEVANT REFERENCES :

Inappropriate sensor (relative to reactions, products, risks)	Aria 10164, 18942, 22103, 23745, 26432, 31670, 31734
Undersized sensor	Aria 15295, 19964, 24935, 38129
Insufficient sensitivity	Aria 19964, 23898, 24935 29418, 30725, 34256, 35293
Poorly-positioned sensor	Aria 14163, 16632, 19242, 30226, 32253

CHEMICAL INDUSTRY - ADJUSTMENT (ARIA 33308)
June 18, 2007

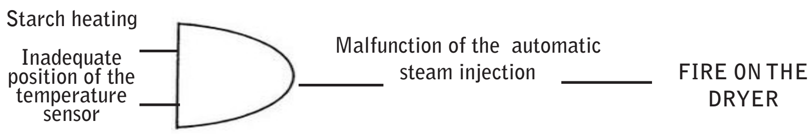


In an ammonia and fertiliser manufacturing plant, 200 kg of nitrogen oxides (NOx) were released into the atmosphere through the nitric acid workshop chimney upon restarting the workshop after a two-week shutdown for maintenance [...]. This release continued for 50 min until the operator was able to identify the cause of the incident: a defective HNO3 titre measurement device placed at the outlet of the nitrogen removal system (before conveying HNO3 to the storage zone) [...]. The Classified Facilities Inspectorate noted t**hat the high level alarm setting relative to NOx emissions had not been adapted to start-up phases (saturation of the NOx analyser during unit restart and relay measurements ignored).** Only the reddish smoke wound up alerting the operators...

OTHER RELEVANT REFERENCES :

Improper detection threshold	Aria 5906, 7150, 21104, 22206, 24122, 24570, 27937, 28774, 30691, 33308
Inappropriate time lag	Aria 17253, 19548, 38732

FOOD PROCESSING - POSITION (ARIA 10165)
June 11, 1997



Fire broke out at the base of a starch dryer. This accident was likely due to an accidental build-up of starch that underwent abnormal heating. **Given the inappropriate position of the temperature sensor**, the automatic steam injection designed to avoid this type of incident had not functioned properly.

OTHER RELEVANT REFERENCES : Aria 34205 (oil depot)

2.2 Will the sensor operate as intended?

Automatic cleaning nozzle for a redox sensor (CERLIC,ARR)

A second type of failure involves sensor malfunction, even in cases where the sensor has been correctly specified and adjusted. Depending on the sector under study, this malfunction accounts for 60 % to 80 % of the causes of operational deficiency. The survey conducted in 2002 on a sample from throughout French industry demonstrated that sensor assembly errors and cabling problems at the time of installation constituted 52 % of the causes of sensor failure encountered in industry, outpacing by a wide margin the intrinsic sensor manufacturing defects (33 %). During the operating phase, sensor failures are mainly due to the wear of mechanical parts or parts in contact with processes (43 %), as well as to electronic malfunctions (38 %)[1].

Accidents exclusively linked to sensor malfunction represent between 48 % (Chemical industry) and 80 % (Refining) of the accidents «with sensors» across these four sectors. For all «with sensor» accidents in which the cause of sensor failure is known, and for those sectors with a significant number of «with sensor» accidents, Table 6 shows that these causes stem primarily from organisational errors due to a lack of sensor control or maintenance: clogging/fouling/jamming of the detection devices, sensor set-up or connection errors, shunts, corrosion or oxidation.

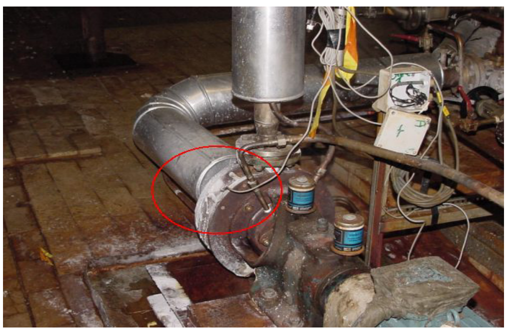
The majority of the accidents studied involving sensors stem from a malfunction, which in over 2/3 of the cases has a known cause pertaining to human or organisational error (faulty control or maintenance, shunt)

Causes that are truly external to the industrial facilities, like a loss of electric power and harsh climatic events, typically represent less than one-third of the known causes of malfunction. Three accidents illustrating the causes of sensor failure in the Chemical-Pharmaceutical and Food Processing sectors are described on page 22.

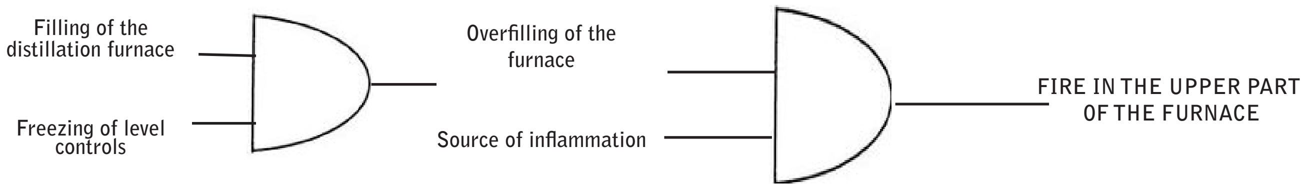
Table 6 : Primary causes of sensor malfunction in accidents in two sectors

Causes	Chemical-Pharmaceutical	Food Processing
Total of accidents due to sensor malfunction	48 %	66 %
Percentage of accidents involving sensor malfunction where the cause is known		
Clogging / Fouling / Jamming	34 %	29 %
Installation-Connection	10 %	29 %
Shunt	10 %	29 %
Loss of utility	10 %	14 %
Corrosion-Oxidation	14 %	0 %
Harsh climatic event	21 %	0 %

A process temperature probe failure is responsible for burns sustained by a technician during maintenance work (ARIA 30723, Dreal Nord Pas de Calais)



REFINING - HARSH CLIMATIC EVENT (ARIA 23309)
December 14, 2001

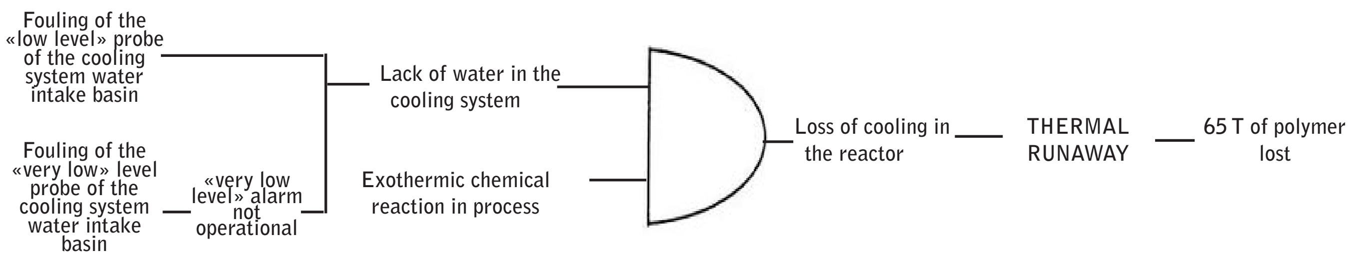


Fire broke out on the upper part of a refinery's vacuum distillation furnace. The blaze was brought under control very quickly from the control room by performing an emergency shutdown of the unit, which was then restarted after 48 hours of down time in order to analyse the situation and conduct a full battery of safety tests. **The incident was probably due to the freezing of several sensors, resulting in liquid hydrocarbons entering at an excessive flow rate.**

OTHER RELEVANT REFERENCES :

Frost / Thunderstorm / Lightning	Aria 7508, 19683, 25147, 33293, 37499

CHEMICAL INDUSTRY - FOULED DEVICES (ARIA 18339)
July 22, 2000

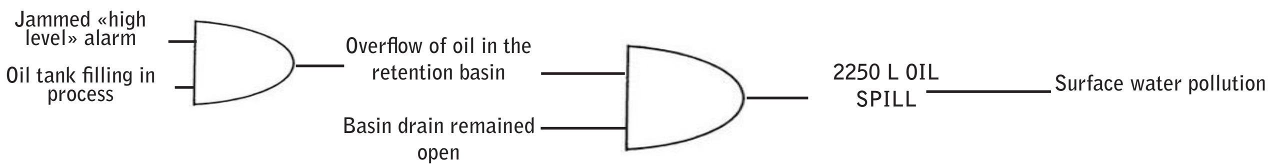


At 10.40 pm, during a copolymerisation reaction in a plastics manufacturing plant, the operator in the control room detected an abnormal temperature increase to 125 °C on one of the reactors. The visual display in the control room confirmed the request for cooling. An operator then went to the cooling tower to check the water level in the pool, and noted that the water was at the «very low» level: the industrial make-up water supply was no longer operating. The operator was unable to reprime the cooling pumps. The control room operator initiated the emergency procedure in case of reactor runaway... The procedure proved to be inefficient... As stipulated in the emergency procedure, a reaction inhibitor was then introduced to prevent the product from solidifying before the reactor was completely emptied into the «dump» tank placed be low the reactor, i.e. 65 t of styrene-acrylonitrile mixture. At the time of emptying, the limits of the process had been reached ...The thermal runaway of the reaction was due to a lack of water in the reactor's jacket circuit connected to a low level in the water-receiving tank associated with the atmospheric cooling tower. **The operator inspected the tank and noted that 2 vibrating blade sensors were fouled. The failure of the «low» level sensor did not allow the tank's water makeup valve to open automatically. As regards the «very low» level sensor, its fouling was such that the control room alarm was not triggered.**

OTHER RELEVANT REFERENCES :

Fouling / Clogging / Jamming	Aria 7768 , 10905 , 19683 , 25057, 27585, 27905 , 30920 , 22211 , 30226 , 30726
Corrosion / Oxidation	Aria 19687, 22103, 32733

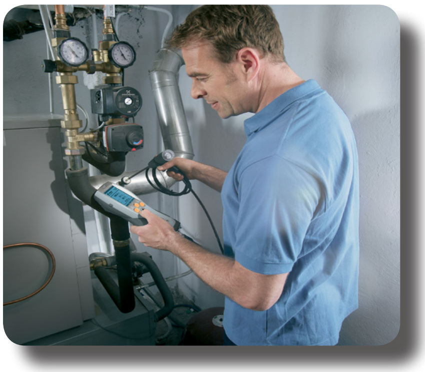
FOOD PROCESSING - JAMMING (ARIA 6198)
December 31, 1994



In a food processing company's premises housing electric generating sets, a 2,250-litre fuel oil tank overflowed into its retention basin subsequent to the malfunction of a high level alarm **(due to a jammed float of level control)**, triggering automatic shutdown of the supply pump. 1,000 litres of fuel oil flowed out from the retention basin, whose drain had remained open. This hydrocarbon spill polluted the CERE River over a 2 km stretch, then extended to nearly 8 km on the DORDOGNE River.

2.3 Does the sensor provide accurate information? ?

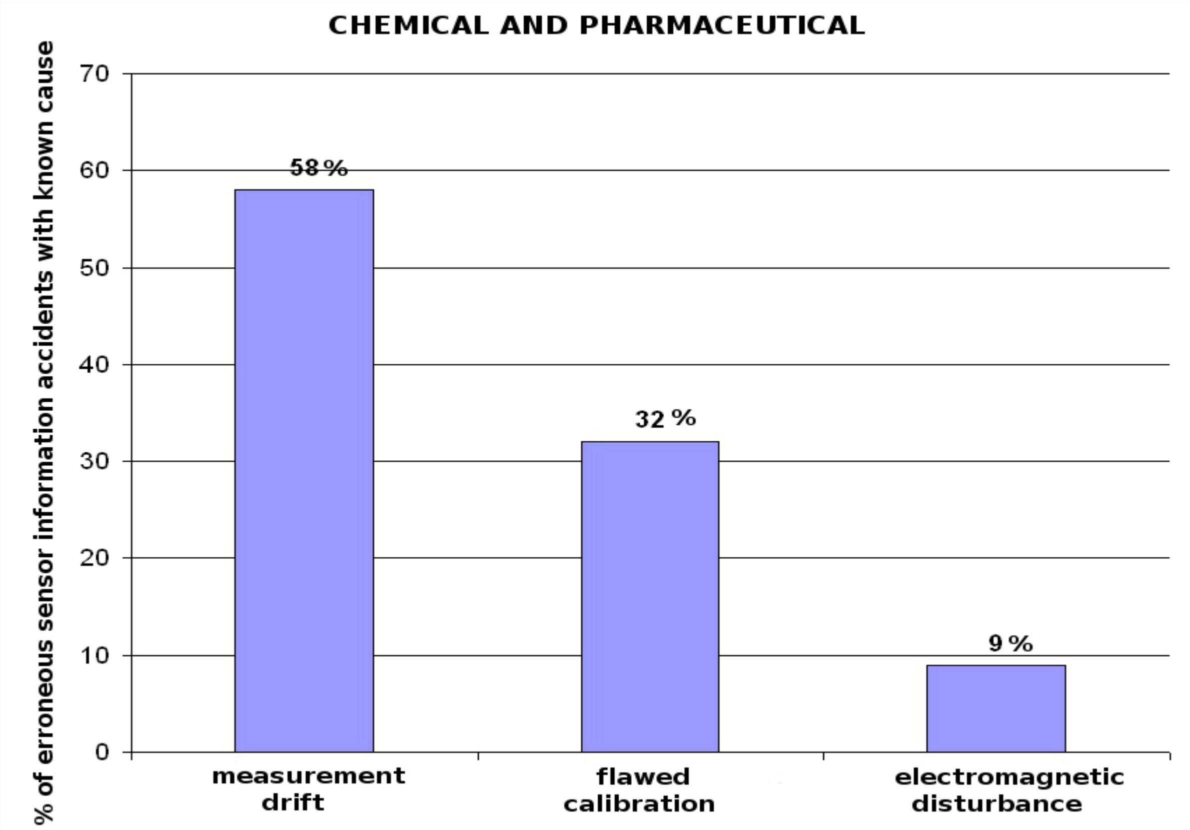
A third type of failure, and no doubt the most difficult to detect, encompasses false detections by a sensor that in turn create or exacerbate an accident situation. For the four sectors studied herein, this type of failure pertains to between 11 % and 30 % of the accidents «with sensors». During the operating phase, the survey conducted in 2001 at 192 of France's industrial sites showed that 27 % of sensor failure were due to a deviation in metrological performance of the sensor involved: inaccurate calibration, measurement drift, etc. Over 70 % of the sites surveyed calibrate their sensors with a periodicity determined by their own experience, and just 3 % of them adopt the periodicity recommended by the sensor supplier. Moreover, nearly 7 % of sites only undertake calibration should a sensor problem arise [1].



Calibration of a flow meter (Testo Inc., ARR)

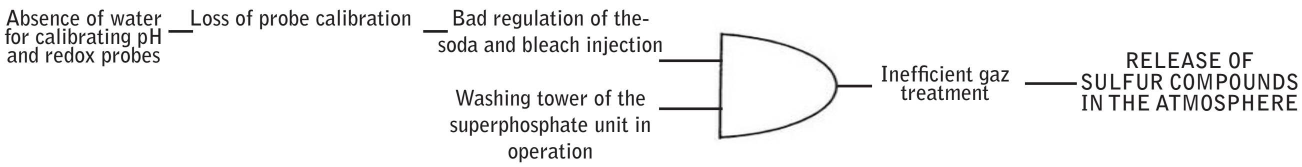
This cause of failure accounts for more than 20 % of all « with sensor » accidents catalogued in the Chemical-Pharmaceutical and Refining sectors. The exact cause of false sensor detections is however only rarely reported in the ARIA base summaries. For the Chemical-Pharmaceutical sector alone, Figure 7 indicates that the problem is basically one of measurement or calibration drift; only one case of electromagnetic disturbances has been identified. In assuming that this sample of accidents is representative of other sectors as well, the majority of false detections causing accidents may be due to a problem of sensor calibration or drift. We note that, depending on the type of sensor and intensity of its use, metrological controls may be conducted at very short intervals; such is the case for the industrial pH-meter whose electrode ages quickly and whose calibration must be carried out daily during periods of intense use. A few examples of accidents caused by false sensor detection are given on page 24.

Figure 7 *Primary causes of false sensor detection in the Chemical-Pharmaceutical sector*



False detections are involved in over 20% of sensor-related accidents in the Chemical-Pharmaceutical and Refining sectors, with the majority of these detections involving a problem of measurement or calibration drift

CHEMICAL INDUSTRY - CALIBRATION (ARIA 33707)
September 3, 2007

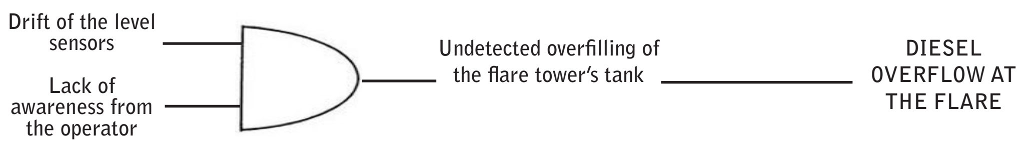


Around 7:30 pm, the atmospheric discharges of a fertilizer manufacturing plant intoxicated three employees at a neighbouring facility, all of whom were hospitalised suffering from headaches. The next day, new odours were notified as of 6:50 am by the neighbouring plant. The superphosphate unit was shut down at 8 am, and this step eliminated the foul-smelling emissions. The unit's odour treatment installation was verified, the three Venturi tubes were drained and the pH and redox probes were replaced as a precaution. The unit's restart did not trigger any new detection of foul odours. **Erroneous pH and redox probe settings from the previous afternoon led to this accident. A leak on the washing machine's recirculation pipe, which was supplying water to the pH/redox probe measurement bowl, prompted a maintenance service call and the loss of probe calibration subsequent to an absence of water in the measurement container.** The failure of these probes to regulate soda and bleach injection into the washing tower lowered the efficiency of the gas treatment system installed on the superphosphate unit that had been loaded chiefly with sulphur compounds.

OTHER RELEVANT REFERENCES :

Poorly-calibrated sensor	Aria 733, 2137, 11107, 32470, 33487 34256
Measurement drift	Aria 10905, 11665, 30178, 34319 37175
False detection	Aria 2684 , 4908 , 25057, 29767 , 31490 31734, 33310 , 33626 , 33838

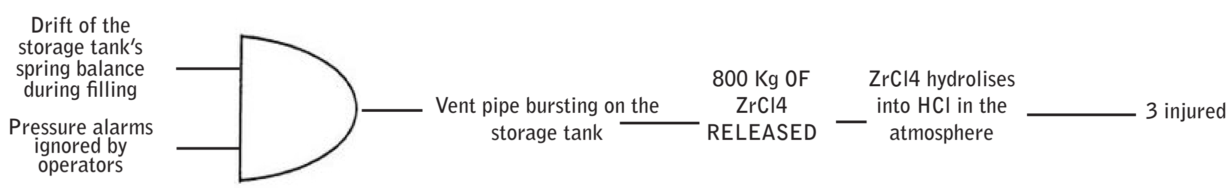
REFINING - MEASUREMENT DRIFT (ARIA 23139)
March 24, 1986



In a refinery's hydro-desulfurization unit, hydrogen sulphide (H_2S) was detected in desulfurized fuel oil subsequent to an irregular level reading, thus leading to an erroneous assessment of the situation. Once the re-boiling temperature had been raised, H_2S was observed to disappear in the fuel oil. Shortly thereafter, fuel oil began spilling at the flare head once the flare tower's tank had been filled. **This overflow was also due to an improper setting of the level alarms**, an anomaly that had gone undetected by the refinery's Head Operator.

OTHER RELEVANT REFERENCES : 26631 (calibration), 36101, 36113, 41148 (measurement drift)

METALLURGY - MEASUREMENT DRIFT (ARIA 32640)
January 10, 2007



Between 5,000 and 8,000 kg of zirconium tetrachloride ($ZrCl_4$) were spread inside a carbochlorination unit at a chemical plant after a vent pipe burst on the storage tank. This chemical product mainly spread within the workshop, yet a portion did reach the outside. During $ZrCl_4$ cleanup beyond the facility, a hydrogen chloride (HCl) cloud formed by means of hydrolysis. Three employees with a neighbouring company were in a state of discomfort and sent to the local infirmary for observation. The analysis of accident causes revealed that the instrumented system associated with the pressure sensor had only been coupled to one of the two compactors feeding the tank. The transfer of $ZrCl_4$ thus continued for a full hour following both the disc and pipe break. Moreover, control room agents had not responded when the pressure alarms repeatedly tripped, preferring instead to trust the spring balance data, which indicated a 132-tonne filling level for a 150-tonne capacity; **the most recent metrological control carried out on these spring balances had been conducted six years prior.**

OTHER RELEVANT REFERENCES :

Poorly-calibrated sensor / Measurement drift	Aria 13837 , 20753 , 32640

Conclusion

Accidents involving sensors represent only a small proportion of ARIA base accidents (3% of total entries), while those caused by critical sensor failure account for less than 2%.

The presence of sensors has made it possible to reduce the frequency of occurrence of fire and explosion type accidents, especially in those sectors handling hazardous substances (Chemicals, Refining).

Except for the Refining sector, the accidents studied demonstrate that there is still room for improvement in terms of safety by raising the installation rate of sensors, provided that they are correctly specified and installed.

The involvement of sensors in accidents is more pronounced outside the normal operating phases: restarting, stopping, or shutting down.

More than half of all sensor-related accidents are due to a malfunction, as two-thirds of all identifiable causes stem from either human error or improper organisation, e.g. lack of maintenance, poor connections and shoddy cleaning...

For those sectors most heavily equipped with sensors, false detections lie at the origin of over 20% of all accidents involving sensor failure; false detections tend to arise from either measurement drift or faulty calibration.

Despite being less widespread than temperature and pressure sensors, level controls are involved in more than 20% of all accidents analysed, regardless of sector of activity. Their mechanisms make them prone to jamming and clogging.

3. CONCLUSION AND RECOMMENDATIONS

This study has demonstrated the globally positive effect of sensors on accident trends observed in the targeted sectors. This effect however does not release operators from the responsibility of conducting a strategic assessment of the number, technology and role of sensors in ensuring process and installation safety.

The study has also underscored the importance of a strict specification procedure for installing sensors adapted to the products used in the process, as well as to both the environmental and process operating constraints.

Moreover, once sensors have been commissioned, their efficiency over time will depend on the stringency and quality of the human and technical organisation in place in order to handle follow-up inspections and maintenance: ongoing servicing, periodic testing, calibration, connection controls, modification of the process, etc.

Back in 1994, an industrial automation specialist stated the following: *«We're losing the habit of reflecting and remembering that the control system, however outstanding it may be, is still prone to intrinsic error and is ageing. We entrust these computerized systems with more than they should be handling.»*

Recommendations by sector

	Place of the sector in accidents involving sensors	Abscence of sensors	Fire / explosion accident	Victims	Stop or restart phases	Inadequate specification	Inadequate maintenance	False detection	RECOMMENDATIONS
CHEMICAL PHARMACEUTICAL	++	+	-	- -	++	+	+	+	• Incorporate sensors into risks analysis so as to mitigate accident severity. The sensor is a key instrument used to reduce these sectors' accident rates. • The use of sensors in the sector can be improved even further (process controls, safety). • Focus on sensor behaviour during installation shutdown and start-up phases. • Pay special attention to the organisation implemented for the sensor life cycle: **Specification:** adaptation to processes, their environments and the types of potential risks; **Maintenance:** frequency, metrology, cleaning; **Works-related:** monitoring (connections, metrology)
FOOD PROCESSING	-	++	-	-	++	+	+	/	• A higher sensor use rate for the sector, particularly as regards safety sensors adapted to the sector's risks (e.g. toxic leak, fire, explosive atmosphere). • Be attentive to sensor behaviour during installation shutdown and start-up phases. • A stricter maintenance organisation must be implemented (60% of the sector's sensor-related accidents are caused by malfunction).
REFINING	-	- -	- -	- -	+++	-	++	+	• Though the accident statistics confirm the high rate of sensor usage as well as the adaptation of sensors to risks and processes, additional maintenance efforts appear to be necessary, given the extent of sensor use and application: 80% of the sector's sensor-related accidents are due to malfunction. • The focus of these efforts must be on a more stringent organisation and resources allocated to maintenance, aimed especially at level controls. • More attention shall be given to sensor behaviour outside normal operating phases (extended down time).
METALLURGY	-	+	-	-	++	-	++	/	• Increase the use of sensors throughout the sector, in particular safety sensors adapted to sector-specific risks (leak of hazardous substances, fire). • More attention shall be given to sensor behaviour during installation shutdown and start-up phases. • A more stringent maintenance organisation must be introduced (70% of all sector accidents involving sensors are due to malfunction).

+++ : high rate of accident (for this criterion)
++ : important rate of accident
+ : significant rate of accident
- - : low rate of accident (for this criterion)
- : poorly significant rate of accident

- **ATEX Directive :** This European directive (94/9/EC) is applicable to protective devices and systems intended for use in potentially explosive atmospheres, i.e. capable of becoming explosive, subsequent to certain local and operational parameters, due to the presence under atmospheric conditions of a mix with air containing flammable substances in gaseous, vapour, fog or dust form. This directive pertains to all types of equipment, whether electrical or non-electrical (mechanical, pneumatic, hydraulic, etc.) provided the presence of a distinct source of ignition. This directive has been transposed into French law via Decree 96-1010 adopted on 10th November, 1996.

- **«Machinery» Directive :** This European directive is applicable to all new machinery introduced onto the European market. The term «new machinery» implies equipment introduced for the first time on the European market. The goal of this legislation is to ensure a high level of safety for such devices and thereby streamline their unrestricted circulation. The first machinery directive was issued in 1989 and labelled 89/392/EEC; it underwent subsequent modifications and the current legislative text is referenced 98/37/EC.

- **HSE :** Health and Safety Executive, the HSE is a British governmental agency created in 1974 in order to enact legislation relative to workplace health and safety issues.

- **Classified facility :** An industrial facility classified as environmentally sensitive is a stationary installation whose operations present risks for the environment. Its definition is established in Book V, Title I, Article L 511-1 of the French Environmental Code (codification of the 19th July, 1976 Law).

- **Influence (factor) :** see page 4.

- **Influence (sensor influence quantity):** Influence quantities vary from one sensor to the next since they depend on the physical process being implemented. Magnitudes of either the mechanical or thermal type are identified, as are electrical magnitudes. Two types of classifications may apply :
  - **atmospheric influence quantities :** physical magnitudes independent of the measurand (e.g. temperature, relative humidity, magnetic field). Temperature causes specimen dilatation and modifications to electrical properties. Pressure and force variations cause deformations. Magnetic fields might induce parasite electromotive forces.
  - **power supply influence quantities :** electrical parameters (current, voltage, frequency) of the sensor supply circuits.

- **IPPC :** The IPPC (Integrated Pollution Prevention and Control) European Directive was published in 1996 with the primary aim of ensuring a high level of overall environmental protection with respect to water, air and soils (at the beginning of 2012, this directive was being replaced by the IED Directive).

- **PPRT :** This Technological Risk Prevention Plan, established by French Law No. 2003-699 enacted on 30th July, 2003 relative to the prevention of technological and natural risks as well as compensation for damages, was drawn up and approved by the State under Prefect authority. The objective of a PPRT plan is to respond to difficult situations carried over from the past involving urban planning as well as to better structure future urban development around existing SEVESO sites, for the purpose of ensuring personal safety and protection.

(in French, unless otherwise specified)

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TECHNOLOGICAL ACCIDENTS ONLINE

Safety and transparency are two legitimate requirements of our society. Therefore, since June 2001, the website www.aria.developpement-durable.gouv.fr hosted by the French Ministry of Ecology, Sustainable Development and Energy has been offering to both professionals and the general public lessons drawn from analyses of technological accidents. The main sections of the website are available in both French and English.

Under the general sections, the interested user can, for example, inquire for the governmental action programmes, access large excerpts of the ARIA database, discover the presentation of the European scale of industrial accidents, become familiar with the ''dangerous substances index'' used to complete the ''communication on the spot'' in case of accident or incident.

The accident description, which serves as the raw input for any method of feedback, represents a significant share of the site's resources : when known, event sequencing, consequences, origins, circumstances, proven or presumed causes, actions taken and lessons learnt are compiled.

Over 250 detailed and illustrated technical reports present accidents selected for their particular interest. Numerous analyses, sorted by technical topic or activities, are also available. The section dedicated to technical recommendations develops various topics : fine chemistry, pyrotechnics, surface treatment, silos, tyre depots, hot work permits, waste treatment, material handling, etc. A multicriteria search engine enables getting information about accidents occurring in France or abroad.

The website **www.aria.developpement-durable.gouv.fr** is continually growing. Currently, more than 40 000 accidents are online, and new theme-based analyses will be regularly added.

As the first chapter of an accident analysis devoted to industrial automation within the ARIA base, this study examines in detail a selection of 345 accidents involving sensors which occurred within the sectors of Chemicals-Pharmaceuticals, Refining, Food processing and Metallurgy. These four sectors all make use of materials and processes that present major technological risks and a high penetration rate of automation.

An in-depth analysis of these accidents, sector by sector, serves to draw lessons aimed at reducing accident frequency and severity related to this equipment. The generic nature of these lessons simplifies their transposition to any industrial facility that relies on sensor use.

These lessons are intended to build awareness among individuals involved in industrial installation safety, regardless of their specific role. Moreover, this study shows that the underlying cause of a majority of critical sensor malfunctions responsible for or exacerbating accidents can be found in dysfunctions in the organisational chain throughout the sensor life cycle.

The summaries of catalogued events are all available at the site:

www.aria.developpement-durable.gouv.fr

Office for analysis of industrial risks and pollution
5 place Jules Ferry
69006 Lyon - FRANCE
Phone : + 33 426 286 200

Department for technological risks
General Directorate for Risk Prevention
Ministry of Ecology, Sustainable Development and Energy

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