

EFFECTS OF THE *COLUMBIA* SPACE SHUTTLE ACCIDENT ON HIGH-RISK INDUSTRIES OR CAN WE LEARN LESSONS FROM OTHER INDUSTRIES?

Yves Dien¹, Michel Llory²

¹Électricité de France, Recherche et Développement, 1, avenue du Général de Gaulle,
F – 92141 Clamart Cedex; yves.dien@edf.fr

²Institut du Travail Humain, Mas Saint Sauveur, Route de Torreilles,
F — 66430 Bompas; ith-llory@wanadoo.fr

INTRODUCTION

High-risk industries set up operating feedback systems as part of the accident or incident management process. For some industries, it is a mandatory requirement. The operating feedback (OF) system naturally involves managing the identification, recording and analysis of events, as well as decision-making to implement corrective actions in the light of technical, procedural and human weaknesses (involving the “human factors”) highlighted in the analysis. OF is one of the pillars of safety and security management. In theory, it helps reveal “failures” in the socio-technical system, which can be remedied so that — according to the standard phrase — such events “can never happen again”. In other words, OF is considered as an essential tool in the framework of prevention.

Considerable resources in terms of methodology and organization are needed to implement an OF system, in addition to the effort required for collecting, analyzing, formalizing and centralizing results when a company or group of companies manages a relatively homogeneous set of technical systems (for instance fleets of aircraft or ferries, nuclear power plants, or groups of oil refinery units).

Yet despite these substantial efforts, after several years of running OF systems, many managers and experts share the view that progress is very slow or has come to a halt. It is getting harder to establish convincing corrective action plans. In particular, the same human errors or series of similar technical breakdowns seem to recur. On the other hand, the same managers and experts seem to assign different causes to OF problems: considerable difficulty in working from the immediate direct causes to the root causes, bewilderment when faced with the need to take into account “organizational factors”, still referred to as “socio-organizational and human factors” in some industrial sectors in France, inadequate formalization of the operating feedback process, and the operators’ tendency to apply censorship concerning organizational problems and managerial errors in their relations with the Regulatory Authorities.

At the end of this paper we shall return to these OF problems in the light of the lessons learned from the Columbia space shuttle accident, and the results obtained more generally from analysis or the organizational approach applied to the operation of

socio-technical systems, and in particular to their failures (incidents and accidents). These days it is easy to see that the OF system in high-risk industries is highly structured, controlled and formalized. This burden of rules and regulations weighing down OF could be a serious obstacle to the emergence of a new form of analysis. The current OF does not usually leave much room for initiative and innovation in a particular socio-technical system, that is, “locally”.

THE CONTRIBUTION OF RESEARCH

It is useful and necessary in the first place to refer to studies and research work initiated in English-speaking countries roughly over the last quarter century. Early works include “**Man-Made Disasters**” by Barry Turner in the United Kingdom, 1978 (reprinted with Nick Pidgeon, 1997) [1] and “**Normal Accidents**” by Charles Perrow in the United States, 1984 [2]. In fact a collective and probably less well-known report that came out in 1982 deals with the human dimension of the Three Mile Island nuclear power plant accident which occurred in March 1979 [3]. In that report, two articles by Charles Perrow [4] and Todd Laporte [5] announced the future development of two trains of thought, two “theories” their upholders and supporters call the “**Normal Accident Theory**” (NAT), and “**High Reliability Organization Theory**” (HROT).

For HROT research workers and academics, the primary reference is the study of day-to-day life in organizations, and the conditions required to ensure continuously **reliable** (and safe) organizations [6]. For this paper, we shall not enter into the debate of the hasty, if not improper, confusion between reliability on the one hand and safety on the other hand, as studies referring to the “HRO” theory may suggest.

Efforts to improve **organizations** would therefore have to be based on observation of day-to-day modes of operation rather than incidents and accidents, which are infrequent and even exceptional or rare events. Steps towards organizational improvement are to be sought by observing and analyzing high-risk systems known to be reliable, (nuclear power plants, nuclear-powered aircraft carriers, and air traffic management organizations, in the United States). Organizational characteristics ensuring system reliability could be popularized and reproduced in the context of preventive actions. In the same way, Quality approaches (**Total Quality Management**, in particular [7]) are by nature able to guarantee these **reliable** organizational operations, based on progressive and systematic step-by-step approaches (as suggested by the “**DEMING wheel**”). HROT and Total Quality could help to develop what we would call a **differential** approach to the problems. In addition, their systematic nature **could** help to **transfer** the fundamental objectives of safety management to “everyday operations”, and away from operating feedback, which to some extent would seem to have gone as far as it can.

To be sure, we can see the value in having a deeper understanding of the common organizational phenomena of daily operations, which Diane VAUGHAN calls “the banality of organizational life” [9]. This understanding paves the way for some potential modes of local failure; it also leads, according to James REASON’s model, to the perception of local conditions likely to generate human errors and technical failures [10]. However, we

do not feel that it is adequate or even relevant to tackle potentially serious dysfunctions relying exclusively on the observation and analysis of “normal” day-to-day operations, minor incidents or slight disruptions. The sources of **minor** dysfunctions are extremely numerous, and we would not have sufficiently effective discriminating criteria available to **prioritize** major risks. Indeed, how can danger signals be prioritized against the “background noise” of daily life? How can the emergence of a serious disease be detected among the range of minor ailments and mild discomforts we frequently experience? How can the relevant symptom be identified in ordinary life situations? We need a **frame of reference**, an explicit one if possible, involving signs that occur in pre-accident or pathological situations. According to our experience, most of the time such references are made, although implicitly.

If we follow the NAT line instead, we may be led to adopt a pessimistic and ultimately defensive and fatalistic position; given that in the long run the accident is inescapable, unavoidable and **bound** to happen, it would be better to prepare for post-accident situations and the **crises** that accidents caused. Paths to progress would involve learning and possessing the means for crisis management [8]. In the extreme, such a position unfortunately leads to a shift of focus towards the secondary social manifestations of the accident, namely crisis management. An example of this type is provided by analysis of the crisis relating to the **Herald of Free Enterprise** ferry shipwreck, in which the fundamental aspects of accident prevention were overshadowed by crisis management commendations [11].

THE OPPORTUNITY OF THE COLUMBIA ACCIDENT

A possible alternative when faced with the current OF deadlock is therefore either to review the methodology of in-depth analysis, or to shift the focus of interest firmly away from management to normal day-to-day operation. It would appear to be **impossible to decide upon** an alternative stated in these terms, as it seems so difficult to grasp the complexity of organizations managing hazardous technical systems.

The accident of the **Columbia** space shuttle and the ensuing report of the **Columbia Accident Investigation Board (CAIB)** provide us with an opportunity for in-depth examination of accidents and, in the end, industrial incidents and failures, their analysis and, beyond that, the models of thought relating to an “event” and its dynamics (including the time before the serious disruption, i.e. during the “incubation period of the accident” [1]), the “normal” and “pathological” organizational phenomena, the local conditions and global organizational causes of accidents, as well as the processes of causality.

Indeed, we have strong reasons — strong hypotheses — for believing that the current problems of OF, its deadlock and a number of its failures arise from the **models** which inform our understanding of accidents and the **methods** implemented in investigations and analyses; so much so that in the end we can only find . . . what we have been looking for. In other words, various authors have come to question the paradigmatic foundations of safety and the place held by incidents and accidents in these foundations: Donald TAYLOR [12], Tom DWYER [13], and Michel LLORY [14] among others.

THE CIRCUMSTANCES OF THE COLUMBIA ACCIDENT

On 1 February 2003 the space shuttle Columbia disintegrated during its re-entry phase into the Earth's atmosphere after a 16-day mission on orbit around the Earth. The seven astronauts died in the accident.

The **Columbia** mission was the 113th space shuttle flight. The 25th flight was that of the **Challenger** shuttle, which broke up 73 seconds after launch on 28 January 1986.

The technical cause for the loss of **Columbia** was clearly identified. During the shuttle's ascent phase, 82 seconds after lift-off, a chunk of insulating foam separated from the Orbiter's bipod ramp located on the external fuel tank. This piece of insulating material struck the Orbiter's left wing at a high relative speed of about 800 km/h. The impact occurred on the leading edge of the wing, an area protected by a reinforced carbon-carbon plate of the shuttle's Thermal Protection System. The damage therefore occurred in a particularly vulnerable area: the air superheated during re-entry into the atmosphere reached a local temperature of around 2000°C. These gases penetrated into the left wing, leading to the melting of a spar, the loss of control of the shuttle, and ultimately its destruction.

An Investigation Board was immediately set up. The Columbia Accident Investigation Board (CAIB) set to work and handed in its conclusions at the end of August 2003 in an impressive document [15], drafted jointly by researchers and academics, including Karlene ROBERTS, editor of the joint work on the HROs mentioned above [6], and Diane VAUGHAN, who in 1996 had issued a detailed report on the decision to launch **Challenger** which led to the disaster [9]. In our opinion, this report constitutes a remarkable example of organizational analysis of an accident. As such, it may be considered a **significant turning point** in the history of industrial accidents, in "Accidentology", inasmuch as the CAIB clearly asserts its methodological position twice in the report in a similar fashion. We will quote here one of the CAIB's statements, since this quote very clearly expresses the "philosophy" of the investigation. At the beginning of Chapter 7, entitled: "The Accident's Organizational Causes", we read:

"Many accident investigations make the same mistake in defining causes. They identify the widget that broke or malfunctioned, then locate the person most closely connected with the technical failure: the engineer who miscalculated an analysis, the operator who missed signals or pulled the wrong switches, the supervisor who failed to listen, or the manager who made bad decisions. When causal chains are limited to technical flaws and individual failures, the ensuing responses aimed at preventing a similar event in the future are equally limited: they aim to fix the technical problem and replace or retrain the individual responsible. Such corrections lead to a misguided and potentially disastrous belief that the underlying problem has been solved. The Board did not want to make these errors. A central piece of our expanded cause model involves NASA as an organizational whole."

Indeed, although searching for the **direct causes** of the Columbia accident and reconstituting the physical phenomena which led to the disintegration of the space shuttle are an important CAIB objective, the **root causes** of the catastrophe also have to be determined. The CAIB therefore studied at length the technical causes of the accident (Chapter 3, p. 49–84) to have a good understanding of how it played out and to certify that scenario. It did not however “linger over” the identification of the persons responsible for the choice and/or installation of the heat-resistant material, although a “comprehensive” organizational analysis could have taken account of this aspect.

In fact, a thorough reading of the Investigation Board’s report [15] contains some major surprises. It shows, firstly, that the methodology of the analysis and its results — and consequently the lessons learned from the accident — cannot be dissociated. Likewise, the way of accounting for the progressive dynamics of the accident situation, what we might call the investigators’ illustrative rhetoric, is important as well.

The organizational analysis of the accident, as understood by the CAIB, is threefold:

- 1) Looking into NASA’s **history** for the **deep causes** of the accident,
- 2) Analyzing the various interactions between the units or companies involved in the preparation, management and safety of space flights, making it possible to establish the **organizational network** of the accident,
- 3) Going up into the higher-level management of the organizations involved in analyzing the influence of management on the development of the incubation period and the accident sequence, and in particular the decision-making processes which led to the accident.

The two fundamental questions determining the structure of the enquiry and the investigation report are as follows:

- 1) Why did shuttle flights go on despite the acknowledged possible shedding of fragments of insulating material and the risk this represented?
To answer this question, the CAIB goes back into the history of NASA’s Space Shuttle Program. History becomes a root cause of the accident (Chapter 8 of the report [15] is entitled: “History as cause: **Columbia** and **Challenger**”), in the sense that the arrangement, interweaving and development of certain organizational processes led to the safety organization of the flights and the flights themselves becoming vulnerable.
- 2) Why were no measures taken, or attempted, to better assess the consequences of the impact of the fragment of insulating material?

We notice that the Rogers Presidential Commission in charge of analyzing the Challenger accident asked two similar questions:

- 1) Why did space shuttle flights go on in spite of the (identified) “problem” of the boosters’ O-rings?
- 2) Why was the shuttle launched in spite of the engineers’ “doubts”?

Does not the parallel between the questioning of both the Investigation Boards suggest that we are facing two similar accidents? As the CAIB noted (p. 195), *“despite all the post-Challenger changes at NASA and the agency’s notable achievements since, the causes of the institutional failure responsible for Challenger have not been fixed. [...] the Board strongly believes that if these persistent, systemic flaws are not resolved, the scene is set for another accident.”* Then it added: *“Therefore, the recommendations for change are not only for fixing the Shuttle’s technical system, but also for fixing each part of the organizational system that produced Columbia’s failure.”*

On the second day of the Columbia mission, 17 January 2003, the impact of the fragment of insulating material had already been identified. The substantial size of the debris and the relative speed of the strike on the leading edge of the wing had already been correctly assessed. A team of engineers and experts belonging to NASA and the United Space Alliance (a joint venture between Boeing and Lockheed) had spontaneously created the Debris Assessment Team (DAT) in an **informal** way. It concluded that it was urgent to obtain higher-resolution images, or better “imaging”, of the area of impact on the wing, for a better assessment of the potential risks at the time of re-entry into the atmosphere on 1 February 2003.

Here the processes of interaction and discussion between the persons and the authorities involved are revealed, and more specifically the decision-making process which led the main managers of the Space Shuttle Program and Mission Management to **turn down** the official requests for DAT imaging, and miss the opportunity to relay and hand over the request to the Department of Defense (DOD), so that the persons in charge and specialists could send out the observation satellites at their disposal.

Consequently the enquiry and the investigation report refer, among other things, to an **historical reconstitution** approach to the events and processes involved in the accident, and also, regarding the duration of the Columbia mission in orbit, to the development of an **industrial ethnographic** study of the interactions between those involved in the accident. The ethnographic study and the quasi-police enquiry, of the 16 days of discussions and exchanges within the NASA organization and its main subcontractors, turned out to be very elaborate. Excerpts of reports of meetings, testimonies, and e-mail exchanges (generally reproduced in full, indicating their recipients), fragments of conversations, and extracts from the mission log were used intensively in this thorough reconstitution of the interaction and decision-making processes which ultimately resulted in refusing the imaging.

RECONSTITUTION OF NASA’S HISTORY AND THE FAILURE OF OPERATING FEEDBACK

The CAIB enquiry revealed that experience from space shuttle flights provided NASA with particularly rich and significant operating feedback. The detachment of insulating material and impacts on the shuttle system (including the Orbiter, the boosters and the external tank) had occurred during **every flight**, that is, during the 112 flights preceding the tragic **Columbia** flight. Among these 112 impact phenomena, the CAIB identified

14 significant detachments or impacts, that is, on about 12% of the flights. Six incidents concerned the loss of insulating foam which broke away from the left bipod ramp section on the external tank, the seventh one being that of **Columbia**. Of these 7 cases of insulating material separating from the bipod, six were registered by the CAIB as significant, i.e. causing significant damage to the Shuttle's Thermal Protection System, resulting in a major loss of insulating material. These figures demonstrate the frequency and seriousness of the problem. The historical examination of the reactions of NASA's managers and experts shows that there is a progressive decline in appreciation of the potential risk of debris strikes on the shuttle, as indicated by the table below (partly) reproduced from page 128 of [15]:

Diane VAUGHAN had defined this decline, with regard to the anomalies recorded on the booster's O-rings on flights before the 25th, that of the **Challenger** space shuttle accident, as a phenomenon of "**normalization of deviance**". The detachment of insulating material turned gradually from a Safety-of-flight-issue, in-flight Anomaly, or from an Out-of-family issue into an In-family issue or a re-use/maintenance turn-around issue, without in-depth studies and/or tests being carried out to confirm this downgrading of problems. The CAIB notes, in particular, that no trend studies in terms of statistics, were conducted to analyze impacts in the medium and long term or their location on the Orbiter, particularly with respect to vulnerable areas of the space shuttle (Thermal Protection System, landing gear, etc.), and no risk study was conducted to assess the probability and seriousness of sensitive impacts. The report thus notes that erroneous logic — relying on the success of past flights — which bypassed the strict requirements of technical analysis, prevailed in the arguments of NASA Management, the Shuttle Program and the Mission Management Team. The CAIB thus mentions, among other things (p. 181), that the Management was "**conditioned by success**: *Even after it was clear from the launch videos that foam had struck the Orbiter in a manner never before seen, Space Shuttle Program managers were not unduly alarmed. [...] The Shuttle Program turned "the experience of failure into the memory of success"*".

In addition, the managerial decisions made during the two flights preceding the fatal **Columbia** flight not only illustrate the breakdown of operating feedback and the well-known weaknesses in the analysis of the unfavorable events which occurred, but also the **pathogenic** organizational factors, to take up James REASON's terminology [10], weighing on NASA's overall design and safety practices. During the 111th flight of 7 October 2002 (see Table 2 below), a strong signal appeared [15] of insulating material detachment from the bipod (see Table 1). The action taken was not completed by the time the following flight took place, the 112th, and it was postponed to the period preceding the following one. But **once again** the repair was not undertaken and the 113th flight took place with a significant loss of insulating material from the bipod, leading to the accident on 1 February 2003.

Pressure on the schedules, partly due to "*A line in the sand*", according to the expression used in the Investigation Board's report, was caused by the launch date of Nodule 2 of the International Space Station, (planned) in February 2004, and played an

Table 1. Brief historical background of insulating material detachments and strikes on the space shuttle

Mission	Date	CAIB comments	Our comments
STS-1	12 April 1981	Lots of debris damage — 300 tiles replaced.	Significant damage occurred from the 1st flight
STS-35	2 December 1990	First time NASA calls foam debris a “safety of flight issue”, and “re-use or turn-around issue”.	
STS-42	22 January 1992	First mission after which the next mission (STS-45) launched without debris In-Flight Anomaly closure/resolution.	
STS-45	24 March 1992	Damage to wing RCC panel 10-right. Unexplained Anomaly, “most likely orbital debris”.	
STS-50	25 June 1992	Third known bipod ramp foam event. Hazard Report 37: an “accepted risk”.	8th “significant” event according to the CAIB
STS-56	8 April 1993	Acreage tile damage (large area). Called “within experience base” and considered “in-family”.	
STS-87	19 November 1997	Damage to Orbiter Thermal Protection System spurs NASA to perform 9 flight tests to resolve foam-shedding. Foam fix ineffective. In-Flight Anomaly eventually closed after STS-101 as “accepted risk”.	12th “significant” event according to the CAIB
STS-112	7 October 2002	Sixth known left bipod ramp foam loss. First time major debris event not assigned an In-Flight Anomaly. External Tank Project was assigned an Action. Not closed out until after STS-113 and STS-107.	13th “significant” event
STS-107	16 January 2003	<i>Columbia</i> launch. Seventh known left bipod ramp foam loss event.	

Table 2. Flights preceding the accident

STS 112 (111th flight) <i>7 October 2002</i> Strong signal of foam separation	→	STS-113 (112th flight) <i>31 October 2002</i> (Flight Readiness review)	→	STS-107 (113th flight) <i>16 January 2003</i> ACCIDENT
	→	STS-114 (114th flight) March 2003 approx.		

important part in the postponement of repairs to the faulty insulating material, particularly that located at the Orbiter's bipod mooring on the external tank.

MAIN PATHOGENIC ORGANIZATIONAL FACTORS

As we were able to demonstrate earlier [16], serious incidents and accidents are the perfect way to understand the functioning — and dysfunctions — of organizations managing high risks. It is a particularly valuable way inasmuch as there is also some repetition in accident patterns and **accident models**. This consistency, observed in phenomena and organizational factors, makes it possible to derive certain general lessons, or generic lessons, from accidents. Certainly, accidents are unique and unusual events, but they contain common pathogenic factors contributing to — or precipitating — the dynamics of the accident. These “factors” constitute a condensed and summarized description of micro-phenomena and local events that can be observed and/or detected and analyzed. Their presence is the evidence of an increased risk of accident, but does not imply its systematic or mechanical occurrence. It is likely that the sum total and linkage of these factors create a dangerous situation, especially when, in addition, the deterioration of the organizational safety conditions leaves aside the inadequacies and technical breakdowns, either because of unacceptable delays in resolving them, or because the solutions found are very **incomplete**, or only palliative, or finally, because the resolution of technical problems has been refused or overlooked, as we were able to see concerning the correction of the recurring problem of detachment of the insulating material, and the Debris Assessment Team's unsuccessful request for better “imaging”.

Furthermore, certain deterioration factors can be characterized by the depth of their impact, their intensity and their size. The staff may tolerate and compensate for some productivity-related pressures, but only up to a point; beyond that point, pressures may lead to local stress and overwork phenomena and interpersonal conflicts within the organization, and to the development of a climate of tension detrimental to safety; checks may be

neglected, and work teams may take risks in order to meet the demands of production and competitiveness.

Of the overall phenomena or factors found repeatedly in a great number of accidents, in addition to the failure of “operating feedback”, we can briefly mention four [17] described below:

PRODUCTION PRESSURES

Instructions and decisions, generally coming from the higher levels of the organization, tend to increase considerably the constraints of cost-effectiveness and productivity, and in particular to cut down on staff, costs and resources available to the staff, and to reduce the product delivery period. Naturally these constraints result in an increase in the pace of work and production. They become *pressures* when they are accompanied by chivvying, repeated watchwords, and when they appear as a priority concern, if not the only one.

The Investigation Board mentions such pressures on the schedules, budgets and staff of the Shuttle programs. “Faster, Better, Cheaper”, the new management method for space programs launched in the early 1990’s by Dan GOLDIN, the recently appointed NASA administrator, is entirely representative of the climate pervading NASA, which has a strong tendency to favor production — shuttle and space ship launches — over safety and which, moreover, remains strangely silent (we refer to Chapter VII of the “Report of the PRESIDENTIAL COMMISSION on the Space Shuttle Challenger Accident” entitled: “*The Silent Safety Program*”). We observe in passing the striking parallel between the organizational conditions which led to the **incubation** of the **Challenger** accident and those relating to the disintegration of **Columbia** [9], [15].

As noted by Sally RIDE (professor of physics at the University of California and first American female astronaut in space), who participated, 17 years apart, in the Investigation Boards of both the Challenger and Columbia accidents: “*there were “echoes” of Challenger in Columbia*”.

NASA has borne a great many changes — a “*torrent of changes*” according to the CAIB (p. 105) — which brought about deep imbalances in NASA’s organization. These were “*not one or two policy changes, but a torrent of changes. This was not evolutionary change, but radical or discontinuous change*”.

BREAKDOWNS IN COMMUNICATION

Slowness and distortions in communications, withholding of information, lack of in-depth debates about work problems and the risks incurred in specific situations are liable to create or promote specific “accidentogenic” situations [18]. Some authors were able to describe cases of pathological communications [19].

In particular, the CAIB noted a total lack of clear and open discussion between the Management of the Mission and the DAT with regard to the uncertainties and hypotheses of the analysis presented by the DAT, a lack of viable channels through which the

engineering community involved could express their opinions and receive adequate information, **insularity** within the Space Shuttle Program environment, a lack of exchange with sectors involved in other industrial activities, and “structural limitations” within the hierarchy of the Shuttle Program in both “bottom-up and top-down” exchanges [15].

EXCESSIVE FORMALISM

For about the last two decades, the development and enhancement of safety in hazardous systems have brought increased formalization of activities and industrial relations within the organizations managing these systems. ‘Procedurization’ has affected organizational processes in most businesses. Normalization, standardization and homogenization emerge as the powerful — and at times restrictive — watchwords which are also a response to the dysfunctions revealed by incidents. Although this significant trend towards formalization has the advantage of clarifying and organizing activities during the initial phase, it also makes the work more complex and work relations less flexible. Few writers have drawn attention to the dangers of “instrumentalizing” the work of the operators and managers, and work relations, although the phenomenon has been astutely analyzed with regard to society [20].

The weight of NASA’s hierarchical structure and culture, strongly influenced by formal debates (e.g. procedures of information exchanges), greatly contributed to preventing the full deployment of alarms voiced by the DAT, which led to the request for “better imaging” of the impact area where the insulating material detached from the external tank struck the **Columbia** Orbiter. For example, during the seventh day of the Space Shuttle mission, a member of the DAT wrote a e-mail: *“In my humble technical opinion, this is the wrong (and bordering on irresponsible) answer from the SSP and Orbiter not to request additional imaging help from any outside source. I must emphasize (again) that severe enough damage [...] combined with the heating and resulting damage to the underlying structure at the most critical location [...] could present potentially grave hazards. [...] Remember the NASA safety posters everywhere around stating, ‘if it’s not safe, say so’? Yes it’s that serious.”* [SSP = Space Shuttle Program] ([15] p. 157). In spite of the strong warning in the e-mail, he chose to **not** send it to anyone. When he was asked why by the CAIB, he explained that he did not want to jump the chain of command, i.e. he did not want to confuse the request for imagery. Indeed he had already raised the need to have a better imagery with one of his manager, he would defer to judgment of management on obtaining it. In the prescribed organization, one role of management is to communicate with “outsiders” (in that case with the Department of Defense — DOD –). This example illustrates how excessive formalism could lead to self-censorship. In addition, it shows how contributing factors could be closely related. It seems that this member of the DAT relied on efficiency of over formalized communication channels: in reality, use of official communication channels led to a breakdown, or at least a failure, in the communication.

One of Mission Management’s concerns, among others, seems to have been excessively centered on **playing down** the **arguments** against proceeding with the launches

after flights STS-87 and STS-112, notable for their substantial losses of insulating material (see Tables 1 and 2).

MARKED BIASES IN DECISION-MAKING PROCESSES

In a thorough, 55-page industrial ethnography study (Chapter 6), the CAIB tried to understand why DAT's official requests (three in all during the 16 days of the orbital mission) had not been granted. In this quasi-police enquiry, the CAIB thus exposes the organizational and managerial decision-making process, whilst it could have determined the seriousness of the damage to the Thermal Protection System of the shuttle's left wing, and organized the rescue of the crew or carried out emergency repairs. Among other things, the report highlights the managers' (erroneous) beliefs that the risks incurred were negligible and that if the damage was real nothing could be done to avoid the loss of the shuttle and its crew. The managers' sole concern seems to have been to avoid delaying the subsequent flights, to avoid slowing down the scientific experiments included in the 113th flight's mission (observation via satellites would have meant interrupting the experiments) and having to allot additional funds to the mission (satellite observation by the American DOD, would have entailed payment). At no time did the managers of the Shuttle Program and Mission Management try to get in touch directly with the DAT engineers or keep informed of the progress of their studies and analyses.

EXTRAPOLATING FROM THE LESSONS OF COLUMBIA

The **Columbia** Accident Investigation Board brushed aside the local and specific work situations, alternately, (meetings of the DAT with the Mission Management team, for instance) to place them in a broader organizational context, situated in turn within an historical evolution. Certainly, the phenomena analyzed during the CAIB investigation are unique and unusual, and as such not reproducible. But the organizational context shows blueprints, dynamics, characteristics, and typical patterns likely to be found in most serious accidents and incidents, which are referred to by the general expression of "organizational factors".

These recurring events and regular features provide the basis for transferring, or extrapolating, the lessons from a very specific accident — such as that of the **Columbia** space shuttle — to other industrial sectors. There were "echoes" of Challenger in Columbia; and there are numerous echoes of **Columbia** in most industrial sectors. What the impressive and highly detailed CAIB study suggests is that many unfavorable organizational phenomena involving safety often exist in organizations in a latent state, or they are contained and sufficiently controlled to prevent them from reaching dangerous proportions. Unfounded beliefs, censorship and self-censorship, well-known biases in decision-making, breakdowns and distortions in communications all constitute what could be called the **hidden or dark side of organizations** [21], [22]. These phenomena may become more pronounced, reinforce each other, link up, and "precipitate" with technical causes to generate an accident situation, like a dangerous chemical reaction [23].

The accumulation of empirical knowledge on recurring pathogenic organizational factors, and the various signs, symptoms and **local phenomena** generated by these factors help significantly to increase the potential for preventing serious accidents. **Detailed** accident reports, such as the CAIB report, that of the **Herald of Free Enterprise** ferry shipwreck in 1987 [24] and that of the Paddington train collision in a London suburb in 1999 [25], for instance, enable us to link **global** organizational factors with many local signs of deteriorating safety. The lessons from **Columbia** and other accidents, inasmuch as they are the object of extensive, meticulously detailed reports, can be used for the everyday Management of different hazardous socio-technical systems and in the search for dangerous signs of deteriorating safety, through audits and enquiries — not the standardized kind but the **ad hoc** “custom made” variety [26].

OBSTACLES AND RESISTANCE TO ORGANIZATIONAL ANALYSIS

A “sentinel system” for organizational factors of industrial accidents, incidents and crises was set up at the EDF Research and Development Centre [27]. The presentation of its work has prompted numerous lively and valuable debates and a shared feeling for possible spin-offs of this type of approach. The disintegration of the Columbia space shuttle, studied in the context of this “sentinel system”, has attracted the attention of the top management of EDF nuclear power plants. Consideration was given to which advantages may be gained by applying the organizational approach to analyze certain events occurring in nuclear power plants, which today are investigated using conventional methods and approaches.

However, at the same time, it is important not to overlook the difficulties in what constitutes a paradigmatic change in the analysis of incidents and accidents. When first discussing such difficulties, it is helpful to refer to what the philosopher and historian of sciences Gaston BACHELARD calls the **epistemological obstacles** — obstacles to the methods and grounds of knowledge [28]. At a given period, specific ways of representing a presumed problem may constitute an obstacle to knowledge of a higher level, such as for example the linear representation of chemical formulas, which was an obstacle to the construction of chemical formulas with a two-dimensional or three-dimensional structure, like the hexagonal structure of benzene finally discovered by Friedrich August KEKULE VON STRADONITZ. The need to reach into the core of organizations, to go back into their history, and bring out numerous details regarding exchanges between organization members, decision-making — or the absence of decisions, and specific striking events that are not necessarily directly perceptible, is very difficult for a number of engineers and experts who tend to favor formal approaches, accident patterns and mechanistic explanations. Organizational analyses require the identification and linking of large amounts of information which do not have the apparent solidity of physical phenomena (the fracture or failure of a component, for instance) and behaviors (an operator’s human error), and which cannot be confined within the structure of an **event-tree** which is very popular among French industries.

Organizational approaches also encounter obstacles of a social nature involving hierarchical power. Indeed, they induce more in-depth questioning than conventional

approaches to operating feedback. They turn the spotlight on organizational trends which essentially affect Management, as the CAIB report firstly points out NASA's managerial shortcomings, and in an insistent and implacable manner. There may then be fears that setting up such an investigation program in an organization might meet with strong opposition from managers, a question that G. BECKER raised in a relevant article [29].

Organizational approaches require debates, and a long process of maturity and acceptance. They cannot be satisfied with the "mechanistic" implementation of methods (just following a recipe) or the use of standardized tools "by rote".

Organizational approaches shake up the mechanistic and behaviorist paradigm of incidents and accidents, and more generally the pattern of operations – and dysfunctions – within organizations. They tend to throw a little light on this hidden or dark side of organizations, behind which serious accident and incident situations are likely to incubate. The acknowledgement of these difficulties and progressive familiarization with organizational analyses make it possible to move beyond the present stage of operating feedback, which some managers and experts consider to be stagnating. The lessons from the Columbia accident constitute — or may constitute — an important stage in this evolution, on account of the wealth of information in the CAIB report. Or must we resign ourselves to waiting for further serious events to occur before the necessary changes are made?

REFERENCES

1. TURNER B.A., PIDGEON N.F., 1997, *Man-Made Disasters*, Second edition, Butterworth Heinemann, Oxford, UK.
2. PERROW C., 1984, *Normal Accidents. Living with high-risk technology*, *Basic Books*, New York, USA. Second edition, Princeton University Press, Princeton, 1999.
3. SILLS D.L., WOLF C.P., SHELANSKI V.B., Ed., 1982, *Accident at Three Mile Island. The Human Dimensions, A Westview Special Study*, Boulder, Colorado, USA.
4. PERROW C., 1982, The President's Commission and the normal accident, In: D.L. SILLS, C.P. WOLF, V.P. SHELANSKI, *Accident at Three Mile Island. The Human Dimensions*, A Westview Special Study, Westview Press, Boulder, Colorado, USA, p. 173–184.
5. LAPORTE T.R., 1982, On the Design and Management of Nearly Error-Free Organizational Control Systems, In: D. L. SILLS, C.P. WOLF, V.P. SHELANSKI, *Accident at Three Mile Island. The Human Dimensions*, A Westview Special Study, Westview Press, Boulder, Colorado, USA, p. 185–200.
6. ROBERTS K.H., Ed., 1993, *New Challenges to Understanding Organizations*, Macmillan Publishing Company, New York, USA.
7. HORLICK-JONES T., 1996, Is Safety a By-product of Quality Management? In: D. JONES, C. HOOD, Ed., *Accident and Design*, University College London Press, London, UK, p. 144–154.
8. LAGADEC P., 1994, La gestion des crises, *Edisciences international*, Paris, France.
9. VAUGHAN D., 1996, *The Challenger Launch Decision. Risky technology, Culture, and Deviance at NASA*, The Chicago University Press, Chicago, USA.

10. REASON J., 1997, *Managing the Risks of Organizational Accidents*, Ashgate, Aldershot, UK.
11. ROUX-DUFORT C., 1999, Le naufrage du car-ferry “Herald of Free Enterprise” Une crise à double visage, *Les Annales des Mines. Gérer et Comprendre*, June 1999, p. 90–100.
12. TAYLOR D. H., 1981, The Hermeneutics of Accidents and Safety, *Ergonomics*, Vol. 4, No. 6, p. 487–495.
13. DWYER T., 1992, Industrial safety engineering. Challenge of the future, *Accident Analysis and Prevention*, Vol. 23, p. 265–273.
14. LLORY M., 1997, Human and work-centred safety: keys to a new conception of management, *Ergonomics*, Vol. 40, No. 10, p. 1148–1158.
15. Columbia Accident Investigation Board, Report Volume 1, August 2003.
16. LLORY M., 2002, *Le Crépuscule du “Facteurs Humains”*, Communication at the CSC Colloquium of CMP: “Le nucléaire et l’homme” Paris, 9–10 October 2002.
17. DIEN Y., LLORY M., 2002, Facteurs organisationnels des incidents, accidents et crises: première synthèse de la veille, EDF-R&D internal report HT-52/02/023/A, Clamart, France.
18. LLORY M., 2001, Entreprises à risques: de la communication interne à la communication externe. Un débat difficile sur les risques et la sécurité, In: P. HUPET, Ed., *Risque et systèmes complexes. Les enjeux de la communication*, P.I.E. — Peter Lang, Brussels, Belgium, Chapter IV, p. 79–96.
19. DEJOURS C., 1992, Pathologie de la communication. Situation de travail et espace public: le cas du nucléaire, Raisons pratiques, Editions de l’EHESS, Paris, No. 3, “Pouvoir et légitimité. Figures de l’espace public”, p. 177–201.
20. TAYLOR C., 1999, *Le malaise de la modernité*, Editions du CERF, Paris, France.
21. VAUGHAN D., 1999, The Dark Side of Organizations: Mistake, Misconduct, and Disaster, *Annual Review of Sociology*, Vol. 25, p. 271–305.
22. SAGAN S. D., 1993, *The Limits of Safety, Organizations, Accidents and Nuclear Weapons*, Princeton University Press, Princeton, New-Jersey, USA.
23. LLORY M., 1996, *Accidents industriels: le coût du silence. Opérateurs privés de parole et cadres introuvables*, Editions l’Harmattan, Paris, France.
24. Department of Transport, 1987, The roll on/roll off passenger and freight ferry *Herald of Free Enterprise*, Report of Court No. 8074 formal investigation, Her Majesty’s Stationary Office, London, UK.
25. Lord CULLEN, 2001, The Ladbroke Grove Rail Inquiry, Part 1 and Part 2, Report, HSE Books, Her Majesty’s Stationery Office, Norwich, UK.
26. LLORY M., 2002, Fiabilité et sécurité organisationnelles. Le diagnostic organisationnel, *Performances*, No. 2, janvier–février, p. 41–53.
27. DIEN Y., 2002, A Presentation of Incident, Accident and Crisis “Sentinel System”, EDF-R&D internal report, Clamart, France.
28. BACHELARD G., 1938, *La formation de l’esprit scientifique*, Librairie Philosophique J. Vrin, Bibliothèque des textes philosophiques, Paris, (for the original edition).
29. BECKER G., 1997, Event analysis and regulation: are we able to discover organisational factors? In: A. HALE, B. WILPERT, M. FREITAG, Ed., *After the Event. From Accident to Organizational Learning*, Pergamon Press, Elsevier Science, Oxford, UK, 1997, Chapter C.3, p. 197–215.