Cynthia COLMELLERE
Institut de Radioprotection et de Sûreté Nucléaire
BP 17
92 262 Fontenay-aux-Roses
FRANCE
Tel : 33 (0)1 58 35 90 09

Université de Technologie de Compiègne
Laboratoire COSTECH
EA 2223
cynthia.colmellere@gmail.com

DESIGN ORGANIZATION TO MANAGE HIGH-RISKS SYSTEMS

THE CASE OF CHEMICAL INDUSTRY

Introduction

The contribution of organization to the reliability of complex socio-technical systems such as nuclear power plant, airplanes and chemical plants opened a research agenda more than thirty years ago. These organizations have two sides : The first one is the way these organizations, called *High-Reliability Organizations* or *HRO* (Rochlin 1996, 2001[1]), succeed in maintaining a high level of reliability. The second one is their *dark-side* (Vaughan, 1999), i.e. the way they produce by and in themselves mistakes, misconducts and disasters. To say it differently, in these organizations, accident is *normal* (Perrow, 1999 a). Two sorts of studies demonstrated that both sides are involved in risk management: analyses of daily activities performed by actors

[1] This article is a synthesis of the research done by Todd Laporte, Karlene Roberts, Gene Rochlin, Paul Schulman on *High Reliability Organizations*

working in these organizations (Bourrier 1999, Rochlin, 1996, 2001) and deep analyses of incidents (Perin, 2005) and accidents (Heimann, 1997, Perrow, 1999 a). These works concluded that reliability depends on structural and functional characteristics of organizations. They suggested ways to improve reliability. However, they didn't define precisely any type of organization able to prevent failures or accidents (Bourrier 2003, 2004). Actually, we don't know how actors modifying or designing high-risk socio-technical systems further or threaten reliability. Nevertheless, Charles Perrow studied organizational design principles (Perrow, 1999 a). He pointed out that engineers and technicians are not able to design organization in relation to the technology used. Two main reasons are identified : first, design is separated from exploitation and maintenance of installations. Second, engineers are submitted to social constraints : they try to fulfil objectives set up by their hierarchy that are mostly difficult to combine with the design of a reliable organization.

Studies cited above, especially those of Bourrier, Perin and Perrow are an invitation to deepen studies of design processes. More generally, research on the contribution of organization to reliability raises questions : How organizational design contribute to risk management? How engineers and technicians anticipate reliable organizations while designing installations?

This essay addresses specific aspects of the relationship between organization and risk by analysing how organizational design contributes to risk management. In this paper, we will focus on one case : a project pertaining to design a modification of installations assessed by regulation, in high-risk chemical industries.

To begin, we define *organizational design* in order to make clear the relationship between this concept and risk management. Then, we present the case studied and its specificities compared to cases analysed in literature. After, we sketch out the methodology used to gather and to analyse data. Then, we focus on two general results : first engineers and technicians anticipate organization but partly; second, maintenance of installations is forgotten by designers. For both results, we identified causes in the project organization, in social relations between actors participating in the project and more generally in social relations between actors of the different departments of the plant.

1. Organizational design and risk management

1.1. What is organization?

Before going further in this essay, it is necessary to clarify the concept of *organization*. On the one hand, we consider that actors participating in projects pertaining to modify installations design a formal frame for risky activities. This frame is composed of two interrelated parts: a *frame for action* and a *program of activities.*

The frame for action is a combination of structural characteristics of organization: allocation of task among services, between actors and between actors and technical devices; authority and control system; communication system, material and symbolic reward system; processes to manage competencies, general prescriptions (procedures of management, organization notes)…

The program of activities structures work in a more detailed way i.e. it concerns characteristics of activities: sequence of activities; complexity of activities; painfulness to perform activities; variability (due to working conditions, standards of materials); periodicity of activities; environment where activities are performed; documents that support activities (procedures, check-lists, handbooks…).

On the other hand, in a sociological perspective, we consider organization as a social construction: organization works and change through the way actors use it to perform their activities.

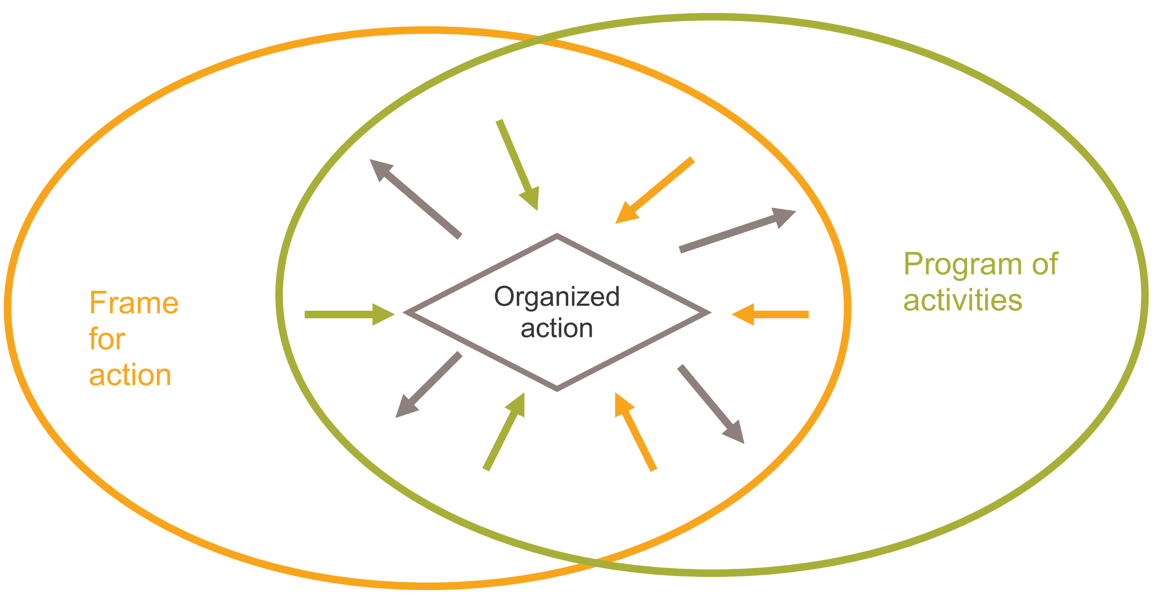

Figure 1: Organization as a *frame for action* and a *program of activities* supports organized action. Organization is modified by organized action.

1.2. Organization and risk management: connections

In this paper, we consider as a basic principle that we will be able to prevent organizational failures if we understand how strengths and weaknesses of organization are designed.

On the one hand, research done on *High Reliability Organizations* such as military navy, nuclear power plants and air traffic control identified specific characteristics. These organizations have to combine safety and economic performance. Their structures are complex and redundancy is often used. These organizations promote a flexible use of authority delegation, a specific organizational structure for crisis, a system to collect information on errors and a reward system for people who identify them, attitudes towards technical and organizational changes fitting with their consequences on organizational reliability and performance. In these organizations, competencies of actors are recognized whatever their level in the official hierarchy is (Rochlin, 2001). Moreover, according to this research, organizations have to be *flexible* and *self-designing* (Rochlin et al., 1987) in order to fulfil their objectives despite their complexity. Concerning their relationship with environment, these organizations have to conquer *social confidence* and *institutional constancy* (La Porte, 2001). This research gives some elements to improve organizational reliability but not to better technico-organizational design. According to Mathilde Bourrier (Bourrier, 1999), characteristics identified are not the only means to improve reliability. Moreover, recommendations about social behaviours raise questions : What characteristics of organizational design can support these attitudes ? What means do designers have to create these attitudes ? How can management maintain these behaviours?

On the other hand, analysis of accidents demonstrated that high-risk organizations are exposed to failures because of their structural, functional and cultural characteristics (Pidgeon and O'Leary 2000, Vaughan, 1996). Perrow outlined that accidents happened because organization is designed without considering its connections with technology. More precisely, Perrow questioned the social dimension of design choices. He pointed out that a poor organizational design is a consequence of the significance of the *design logic* focused on technical aspects, compared to the *operating logic,* centred on working conditions. Therefore, engineers reproduce organizational structures that threaten reliability : structures of politic authority, strong division of labour, concentrated authority, important human-costs for workers. Perrow demonstrated that the domination of the *design logic* results from four characteristics of the social structure where engineers are working. First, the preponderance of one of the two logics depends on the importance high-management gives it. For instance, if errors and failures threaten reputation and profits of the plant, like in civil aviation, high management prefers *operating logic*. These priorities depend on career objectives managers pursue. Most of the time, they have to satisfy production goals that force them to focus on speed, power and manoeuvrability of installations to the detriment of working conditions to operate and maintain installations. Second, high management organizes reward system according to his priorities and engineers are compliant with this system. Third, it is difficult for engineers and technicians to question choices done according to the *design logic* because of the separation between occupations and hierarchies especially between designers and operators. Fourth, failures don't give the opportunity to question the *design logic* because they are mostly interpreted as consequences of operators' errors.

Studies presented above pointed out that reliability depends on choices of organization. At the same time, they demonstrated the tightness of connections between organization, technology and risks. To say it differently, organizational design doesn't exist as a specific design work; it is embedded in design processes. Therefore, in order to understand organizational design we have to study the design process in its entirety. In the case studied, organizational design is performed while modifying installations i.e. while elaborating technical solutions complying with regulation.

In order to understand how design choices are constructed, it is necessary to study individual and collective contributions to design i.e. design practices and social relations between actors. First, we consider each level of the project organization: the project team, the Piloting Committee and the Industrial Direction. Moreover, we study relations between these entities and relations between actors working in these entities. Second, we focus on methods and tools used by designers. Engineers and technicians use methods, artefacts to anticipate risk. For example, to perform risk analysis, they use a specific method called Hazop (Hazard and operability studies).

Discussions during project meetings are based on plans and mock-ups that are modified according to evolutions and decisions.

2. Case Study: modification of installations

This paper is based on one project pertaining to modify installations[2]. We studied modifications for several reasons. Compared to classical design projects, modifications present some advantages. First, they last less time. Therefore, we were able to study this project during a long period in order to put in perspective the initial installation, the design process and the modified installation. Second, the project organization is rather simple and actors are less numerous. Therefore, analyses of individual and collective contributions and analyses of social relations were simplified. Moreover, modification made the study of the way project organization influences design practices and contributions easier. Third, as modifications are focused on a part of the installations, we were able to analyse the construction of socio-technical choices.

2.1. Methods: extensive field work :

To gather data, fifty semi directive interviews were conducted. We met actors of the project team, actors of Production and Maintenance departments, actors of the Piloting Committee.

25 project meetings were observed.

[2] In this paper, we present our research partly. Actually, we studied and compared two projects (Colmellere, 2008).

We observed activities performed on the post before modification and in the shop to which the post would be embedded.

We analysed documents used (procedures, regulations texts…) and designed (Plans, check-lists, handbooks …) during the project.

We focus on three situations of collective design that were important in the progress of the design process. We deeply analysed these situations as *vignettes* (Orr, 1996) : we finely analysed discussions and decisions in order to characterise the way each actor consider organizational characteristics and connect technology with organization.

2.2. CHEMITRY project : basic elements

We study a project pertaining to modify a post to pour A-acid from wagons to installations of the plant CHEMISTRY, in order to comply with regulation (SEVESO 2). This regulation requires prevention of major accidents and mitigation of their consequences. CHEMISTRY belongs to a huge industrial group. 146 people are working in this plant. CHEMISTRY is structured in 7 departments:

Production (Four shops, two main shops and two small shops, 60 people), Maintenance (20 people), Engineering Department and Inspection (40 people), Quality Occupational Safety and Environment Department (15), Direction (2), Human resources (6), Medical Department (3).

A-acid is very corrosive and dangerous for humans because small quantities kill (in case of direct contact, 10-15 ml are enough). Therefore, its transportation, packaging, production and use must be particularly careful. Population and environment are exposed to high-risk : the major accident is a leak of A acid. Operators are exposed to risks of serious burns especially when they work next to installations.

This project is also a way to reorganize the activities of the plant: the new installation will be attached to one of the two main shops. Before modification, operators performing packaging and working in the two small shops connect, disconnect wagons and do sealing control. Technicians managing utilities — i.e. water, electricity, steam for the whole plant — supervise clearing of wagons from their control room. After modification, the emptying of wagons will be supervised by operators of the main shop to which the new post will be attached. These operators will perform their common activities at the same time.

A project team is set up to design the modification. It is composed of **:**

A project manager who is engineer in chemical process security (Quality Occupational Safety and Environment Department), a civil engineering technician (Engineering Department), a control and computer technician (sub-contractor for the Engineering Department), a supervisor manufacturing (Production Department), the manager of the Maintenance Department, the manager of the Engineering Department.

A medical assistant and a technician responsible for safety participate in risks analyses meetings performed when the installation is designed in detail.

A Piloting Committee supervises the master project schedule, main design decisions and the way regulations and management rules are applied. This committee is composed of : The plant director, the Quality Occupational Safety and Environment

Department manager, the Production Department manager, the Maintenance Department manager, the Engineering Department manager. This committee submits main decisions to the Industrial Direction who allows credits for the project.

2.3. Project CHEMISTRY: specificities

Compared to cases analysed in literature, the project we studied presents some specificities. First, it is not as prestigious as new plants projects. Moreover it is not applied to high-risks innovating technologies, such as new nuclear reactors and spatial shuttles. Therefore, this project doesn't deal with classical issues in high-risk organizations such as bureaucratic constraints, organizational drifts (Journé, 2001) or *structural secret* (Vaughan, 1996). However, this project raises questions about organizational reliability. According to Perrow, modifications of installations, i.e. "*technological fixes", technology that compensates for, repairs or replace faulty technology" (Perrow, 1983, p.525)* threaten reliability.

" Fixes, including safety devices, sometimes create new accidents, and quite often merely allow those in charge to run the system faster, or in worse weather, or with bigger explosives. Some technological fixes are error-reducing […]. But other technological fixes are excuses for poor organization or an attempt to composite for poor system design. " (Perrow, 1999 a, p.11)

The study of this project reveals its main stakes.

First, this project concern not only risks for environment and people living near the plant but risks for workers also.

Second, this project present economic stakes because the post modified plays a main role in the plant performance: A-acid is the main raw material used to synthesize all chemical ingredients produced in the plant. If pouring activities stop, plant performance and profitability would be damaged. Moreover, it would threaten the plant's future because CHEMISTRY is facing restrictive investments because of the fragility of the Industrial Group.

From a sociological point of view, there are two main stakes : first, cooperation between actors of each entities involved in the project (the project team, the Piloting Committee, the Industrial Direction) and between these entities ; second, cooperation between actors performing connections of wagons and steam control and operators performing production activities in the shop to which the post is attached.

3. Results

3.1. Engineers and technicians anticipate organization

The project team fulfils main objectives of the project : the new post comply with regulation. In case of major accident, **accident consequences** beyond the boundaries of the plant are eliminated. With this new post, operators are able to pour enough A-acid to satisfy production goals. However, they designed several solutions in order to satisfy these objectives while taking into account successive economic restrictions imposed by Industrial Direction. At the end, the new post stays mainly manual, i.e. technical redundancies (automated systems, automatic valves) are reduced to the minimum. As a consequence, prevention of risks of burn for operators, detection of an A-acid leak and mitigation of their consequences depend mainly on operators' awareness.

3.1.1. Organization as a fragmented frame for action

One of the main results of our research is that **engineers and technicians anticipate organization partly**. We don't completely agree with scholars who outlined that engineers and technicians are not able to design organization fitting with the technology they defined (Perrow, 1983, 1999 a & b, Perrin, 2005). On the one hand, our analyses demonstrate that actors participating in the project anticipate some characteristics of organization as a *frame for action* and as a *program of activities*. In this paper, we develop the way they foresee organization as a *frame for action*. First, engineers and technicians anticipate **allocation of tasks between actors**. They anticipate operators' errors during transition between connection and sealing control activities, because of the crew change-off. Therefore, designers set up check-lists to help operators in checking the position of the numerous valves after connecting wagons and before doing sealing control. Second, engineers and technicians anticipate **authority and control system**. They worry about activities during week-ends, because the shop foreman who oversees activities in both main shops would have to supervise and assist operators performing connections and control sealing. However, designers don't anticipate any organizational or technical device but for each solution designed, they focus on avoiding pouring activities during week-ends.

Third, engineers and technicians anticipate **operators' competencies** especially for operators who will connect, disconnect wagons and do sealing control. They wonder about the adaptability of these operators who will have to perform routine production and packaging activities too. However, during detailed design, they don't define precisely how to develop and maintain those competencies.

Fourth, while discussing the level of automation of valves, engineers and technicians anticipate **distribution of tasks between man and machine**. Automatic valves allow operators to check their positions and to pull them from a computerized system. If valves are manual, operators have to do these operations directly on the installation. If manual valves are equipped with limit switches, operators can check their positions from a screen but they still have to pull them on the installation. On the one hand, engineers and technicians consider that automation prevents risks of acid leakage and protects operators by restricting actions next to installations. Therefore, they decide to keep automatic valves for emergency stops and to reverse the emptying process. On the other hand, engineers and technicians consider that automation can threaten risks prevention. Actually, automation keep operators far from installations but it constraints process check and control. Yet, physico-chemical properties of A-acid require checks next to installations. For instance, operators check temperature not only by using thermometers but by touching pipes also. A bubbling noise indicates that liquid A-Acid is turning into gas that is dangerous because gas corrodes pipes and causes leaks.

3.1.2. Organization as a frame for individual action

Engineers and technicians anticipate characteristics of organization. However, they don’t consider organization as a framework for organized action. They consider these **organizational characteristics in their formal dimension**. For instance, operators’ competencies are mentioned but training sessions contents and the means to insure and maintain those competencies are not anticipated. More generally engineers and technicians don’t take into account collective features, especially the way operators will cooperate and coordinate their activities. For instance, errors that could happen during the crew change-off are anticipated but the communication system to share information about the state of the installation is not.

3.1.3. Who anticipate what?

First, our analyses of project meetings showed that **characteristics of future organization** and activities **are introduced by actors** of the project team **working close to production activities**. The manufacturing supervisor is working for more than thirty years in the plant CHEMISTRY. He has a long experience in production activities using A-Acid. Moreover, for a couple of years, he manages pouring activities during the week. The young technician responsible for safety is far less experienced but he knows pouring activities very well because he performed them for two years. The medical assistant knows activities and risks associated to A-Acid because of his long experience (20 years) in the care of operators injured by A-Acid.

The civil engineering technician is working in Engineering Department for thirty years and he knows very deeply installations and activities performed in the plant.

Moreover, he is in good terms with operators of the Production Department. During design meetings, he supports their ideas most of the time and tries to find solutions when they identify problems about the way to perform activities. In this project, he is the only technical specialist who knows precisely the way activities are performed and the current problems production operators face. He considers that technical devices must be design to prevent risks for operators. For instance, he chooses to put valves 80 cm off the ground in order that, in case of an A-acid leak, the liquid can't reach operators' face.

By the way, how can we understand weaknesses in the way engineers and technicians anticipate organization ?

On the one hand, actors who represent operators can't participate regularly in project meetings. The manufacturing supervisor has to perform his daily activities. He is submitted to the rhythm of production activities that limit his regular participation to the meetings. He joins few meetings. Most of the time, he discovers new design choices that he doesn't always understand despite the help of the civil engineering technician. As a consequence, he doesn't feel at his ease to question choices made by technical specialists. Moreover, he feels as if design advances without his contribution.

The medical assistant and the technician responsible for safety participate only in risk analyses meetings. They outline their difficulties to understand how the future installation will work only on the base of plans. Moreover, they consider that opportunities to change choices are limited because design is fast frozen at this stage of the project. Despite the contributions of the civil engineering technician, they consider that engineers and technicians "*don't put the man in the centre of installations*". To sum up, main problem is that the participation of actors who represent operators is not really organized and limited to specific phases of the project when detailed design is fast frozen.

On the other hand, our analyses demonstrate that supports used and created during design limit the anticipation of future organization and activities. First, management project rules limit the contributions of people who represent operators. They prescribe the late contributions of the medical assistant and the technician responsible for safety. These rules plan design of training session for operators performing pouring activities just before the start-up of the post modified.

Second, plans created to represent future installations and their evolutions during design, limit the anticipation of activities and their collective dimension. Actually, plans respect neither dimensions nor distances. Therefore, actors can't foresee the spatial configuration of installations. Third, the method used to analyse risks of the future installation limits the anticipation of organization (Colmellere, 2007). Its basic principle is to study each phase of the process in order to identify risks associated. It considers operator as energy to action the process. Therefore characteristics of activities stay ignored. Moreover, this method considers organization only in its prescriptive dimension (Check-lists) and as a way to mitigate risks. Collective activities and coordination issues are poorly taken in consideration.

3.2. Maintenance in the blind spot of the design process

In this study, we noticed that there are **no discussions about current and future maintenance of installations**. The fact that designers don't pay attention to the future maintenance in project is usual. As a Maintenance technician said "*most of the time, we discover installations when production operators call us to repair or replace a pump*."

During fieldwork, we noticed that actors of Maintenance don't participate in design meetings. First, **this absence is socially constructed**. It is a consequence of conflicts between actors of the Engineering Department and actors of Maintenance about modification of installations tasks. Second, Maintenance technicians don't participate for **structural reasons**, particularly because of the **division of labour between Maintenance and Production**. Third, our analysis demonstrates that the **division of labour between Maintenance technicians and sub-contractors** damage the attention given to maintenance activities and to their constraints on the way installations function.

We identified several explanations. The first one is the development of subcontracting for routine maintenance. Therefore, actors of Maintenance break away from maintenance activities and maintenance follow-up. Causes are structural. There is no communication system between actors of Maintenance and subcontractors. As a consequence, actors of Maintenance don't know about maintenance repairs and interventions. In addition, there is no system to record maintenance operations and experience feedback on failures. Actors of the plant are loosing knowledge of installations. To sum up, because of the tasks distribution and the contractual relation, relationships between actors of Maintenance and subcontractors are very formal. Cooperation and construction of common competencies are limited.

Finally, choices to organize the design process ant discussions reproduce what Constance Perin called "*silos*" (Perin, 2005): the absence of representation of Maintenance and of its preoccupations in design choices reproduce the hierarchy embedded in the division of labour between Maintenance and Production and between actors of Maintenance and sub-contractors. However, organization of routine maintenance, division of labour between Maintenance and Engineering departments, record of maintenance experience feedback, are choices that reinforce not only current reliability but future reliability also. Actually, these choices directly impact design process and its organization.

Conclusion

The research presented above demonstrates that risks management begins during design of high-risk socio-technical systems.

In this project, according to Perrow, engineers and technicians fulfil objectives set up by their management. Actually, the installation designed satisfies main objectives : costs, performance, prevention of the major risk of accident and mitigation of its consequences. However, we demonstrated that engineers and technicians anticipate future organization partly as a *frame for action* and as a *program of activities*. This anticipation depends on actors' competencies, on social relations and on project organization. Our analyses outlined the importance of :1) the **regular participation** of actors representing operators , 2) its organization, 3) artefacts used to support design work. We insisted on the importance of : 1) social relations within the team project, especially between technicians and actors representing operators, 2) routine relations between actors of different departments (Maintenance, Production, sub-contractors) working next to installations modified. Actually, **the organization designed is a social construction, contingent of the project organization and of the plant organization**.

To conclude, our research demonstrates that studies on design process better our understanding of the way organizational forces and weaknesses are created. Moreover, it makes clear the role of engineers and technicians in design and the reasons why organization is still not designed as carefully as technology. If connections between organization, technology and risks are clearly identified, they are not anticipated as completely embedded during design. Designers of socio-technical systems often consider that the social component is a consequence of the use of technical devices. However, design organizations and practises are levers to improve organizational reliability and to manage risks in high risk socio-technical systems.

These results are important to understand how failures that cause accidents can be avoided. In that way, we tried to complete the research agenda opened thirty years ago by theorists of *HRO* and *Normal Accident*.

References:

Bourrier, M. (1999). *Le nucléaire à l'épreuve de l'organisation*. Paris : Presses Universitaires de France.

Bourrier, M. (2003). Facteurs organisationnels : du neuf avec du vieux. *Revue Annales des Mines*, *Réalités industrielles*, pp.19-22.

Bourrier, M. (2004). *Le risque organisationnel. Enjeux pour la connaissance sociologique*. Mémoire présenté pour l'Habilitation à Diriger des Recherches. Université de Technologie de Compiègne.

Bourrier, M. (2005). The Contribution of Organizational Design to Safety. *European Management Journal*, Vol. 23, n°1, pp. 98-104.

COLMELLERE C. (2007). La contribution de l'analyse de risques à la conception organisationnelle. *Colloque Risques industriels majeurs, sciences humaines et sociale*s, Laboratoire d'Etudes et de Recherches Appliquées en Sciences Sociales, Toulouse, 6-7 décembre 2007.

COLMELLERE C. (2008). *Quand les concepteurs anticipent l'organisation pour maîtriser les risques. Deux projets de modification d'installation sur deux sites classés SEVESO 2.*Thèse pour le doctorat de sociologie :409, Université de Technologie de Compiègne.

Heimann, L. (1997). *Acceptable Risks, Politics, Policy and Risky Technologies*. An Arbor, MI: The University of Michigan Press.

Journé B. (2001), "La prise de décision dans les organisations à haute fiabilité : entre le risque d'accident et le risque bureaucratique," *in* Honoré L. et Journé B. (Eds.), *Les cahiers de l'Artemis, n°3, Risques, Déviance et Discipline*, p. 101-126.

La Porte, T.R. (2001). Fiabilité et légitimité soutenable. In Bourrier, M. (Ed.) *Organiser la fiabilité*. Paris : L'Harmattan, pp.71-105.

Orr,J.E. (1996). *Talking about Machine : An Ethnography of a Modern Job.* Cornell University Press.

Perin, C. (2005). *Shouldering Risks. The culture of Control in the Nuclear Power Industry*. Princeton, NJ: Princeton University Press.

Perrow, C.(1999 a). *Normal Accidents, Living with High-Risk Technologies.* Princeton, New Jersey: Princeton University Press. (2ème édition avec post-face, 1ère édition, 1984)

Perrow, C. (1999 b). Organizing to Reduce the Vulnerabilities of Complexity. *Journal of Contingences and Crisis Management*, vol.7, n°3, pp.150-155.

Pidgeon, N., O'Leary, M. (2000). Man-made Disasters: Why Technology and Organizations (sometimes) fail. *Safety Science*, n°34, pp.15-30.

Rochlin, G. (2001). Les organisations « à haute fiabilité » : bilan et perspectives de recherche. In Bourrier, M. (Ed.) *Organiser la fiabilité*. Paris : L'Harmattan, pp.39-70.

Vaughan, D. (1996). *The Challenger Lauch Decision*. Chicago, IL : The University of Chicago Press.

Vaughan, D (1999). "The Dark Side of Organizations," *Annual Review of Sociology* 25, 271-305, 273.