L'ORGANISATION DE L'ENTREPRISE ET DU TRAVAIL

LORS DES TRANSFERTS DE TECHNOLOGIE

OCTOBRE 1992

VERSION ANGLAISE

THE WORKER FACED TO COMPLEX

AND DANGEROUS SYSTEMS

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A. WISNER

SUMMARY

The in-depth study of several recent disasters gives an understanding of the real situation of workers in complex and dangerous situations.

The determining causes of the Bhopal disaster can be traced to the level of bad technical and industrial decisions, followed by substantial financial losses which provoked the dismantling of the human and technical safety system.

The design of the information and monitoring system of the Three Miles Island nuclear power station was unable to provide a diagnosis of breakdowns in good time. In effect, three breakdowns, which were not inter-linked, constituted an incomprehensible disturbance.

At Chernobyl, it was the electricity production system itself which was at fault as well as the weakness of the containment system. Moreover, experiments were carried out under circumstances that were highly detrimental to safety.

As regards two American nuclear power stations, we describe to what extent the differences in management styles increase the diversity of risks.

THE WORKER FACED WITH COMPLEX AND DANGEROUS SYSTEMS

Summary by A. WISNER *

I - INTRODUCTION

Several accidents, particularly dramatic in terms of their scale, have been described in detail over the last few years: Three Miles Island, Bhopal, Chernobyl, Challenger at Cape Kennedy, etc. The study of these disasters has definitively ruled out the predominance of the behaviour of operators as the cause of the accident.

For some considerable time already, the French school of ergonomics had shown the multiplicity and inter-relation of the causes by constructing a tree of causes (Leplat and Cuny, 1979; Leplat, 1985). As regards Bhopal, the correct application of this method was done by Grenouillet and coll. (1986). However, the analysis is usually limited to factors inside the establishment where the accident takes place. The anthropotechnological approach, which enables the technology transfer to be studied, suggests that the origin of disasters should be sought further afield. As such, we move from the level of the functional responsibilities of operators and their management to those of the designers and installers of the technical system, then to those of the persons who determine the economic and social, or even political, conditions under which the dangerous system was designed, installed and operated.

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* Professor of Ergonomics and Neurophysiology of Work at the Conservatoire National des Arts et Métiers, 41, rue Gay-Lussac, 75005 Paris

The Bhopal disaster gives a particularly convincing demonstration of the hierarchy of responsibilities. We shall then consider two other disasters mentioned previously (Three Miles Island, Chernobyl) in lesser detail after comparing the condition of two accident-free nuclear power stations. In the second part, we shall see the cognitive and psychic difficulties which face workers in dangerous situations.

II - THE BHOPAL DISASTER (1984)

This disaster caused several thousand deaths and was studied in a very competent and objective way by Indian technical journalists, in particular Praful Bidwaï. A good compilation is contained in the book by Padma Prakash (1985), published in Hong Kong, which can now no longer be found. The article by Grenouillet and coll. (1986), mentioned previously, summarizes the central aspects. P. Lagadec (1986) compiled the reactions of Chemicals manufacturers in regard to Bhopal. The main lessons which can be learned from these works are as follows:

1) <u>The initial industrial error</u>. A joint venture, an international project between the American Union Carbide multinational firm and the State of Madhya Pradesh, a State located in the centre of the Republic of India, was set up to finance the Bhopal Plant which was intended to produce an insecticide: Sevin or Carbaryl. The investment totalled 250,000,000 rupees (the rupee is worth around two French francs).

However, two things were going to undermine this investment. First of all, insecticides in the category to which Carbaryl belongs were selling less and less; secondly, the Bhopal plant could only produce at a competitive price if it performed all the chemical transformations, i.e. producing the two bodies which were necessary to synthesize Carbaryl. Although the industrial production of M.I.E. synthesis (Methyl Iso-cyanate) was well mastered, the same could not be said for the other component, Alpha-Naphtol, at least as regards the process used at Bhopal. This process was only known at a semi-industrial level. We know that the switch from the semi-industrial level to the industrial level is a difficult operation. Risking this at Bhopal was an error in a region which is far from the main scientific and industrial centres. After two series of tests (1979-1980, 1981-1982), the production of Alpha-Naphtol had to be stopped at Bhopal. This product had to be imported and the plant faced inevitable losses. In 1983, instead of an expected profit of 76,500,000 rupees, there was a loss of 50,000,000 rupees on turnover of 150,000,000 rupees, with the production of Carbaryl representing only one-third of capacity. For 1984, previous to the disaster, losses of 40,000,000 rupees were forecast for a turnover of 120,000,000 rupees.

2) A blind money-saving policy. This policy concerned the removal of vital safety systems and the reduction of staff quality and numbers.

M.I.C. is an unstable product which can polymerize if its temperature rises. This rise may take place when phosgene gas and water appear, even in minimal preparation, in the presence of metal. Polymerization itself gives off a lot of heat and the gas pressure increases dangerously. During the disaster, the temperature of the tank probably reached 200°. The gas pressure should have been 13 bar. It was around midnight when the safety valve was opened by a displayed pressure of 3.8 bar. In fact, all this was rather vague since there was no thermometer or barometer.

The role of the temperature rise in the MIC tanks is so critical that this product has to be kept at 0° during storage. Yet, for money-saving reasons, refrigeration of the tanks was stopped five months previously.

In order to avoid a disaster, it was planned that, in the event of a pressure rise, the gas would go through washing towers where it would be neutralized with soda. But one of the towers had been put out of action and the other was controlled manually.

Finally, gas which escapes should be able to be burned off thanks to the permanent presence of the pilot flame of the flare. But the flare had been switched off when the plant was shut-down, although the tanks were full.

The alarms had been switched off "to avoid bothering the neighbourhood" since they would have been activated constantly due to the absence of most of the safety systems. This is probably the reason for the fatal delay in warning the population (2.15 a.m.). The alert was actually given at 9 p.m. by a maintenance team. At 11 p.m. the situation was acknowledged as serious and at 0.25 a.m. it was considered as desperate and the storage area was evacuated.

One last serious technical element was the practically total stoppage of the purchase of spare parts supplies.

At the staff level, the situation was just as dangerous. The management had offered bonuses to encourage engineers and operators to leave. Half of the most qualified and the longest-serving managers and workers left the company. Since the training credits had disappeared, workers were transferred from the Alpha-Naphtol plant to the M.I.C. plant without being given technical training. Therefore, replacement staff had no technical training and the preparation of qualified workers dropped from 90% to 25%. Staff cuts were made on the most important monitoring stations in the plant.

The situation was already very bad in 1982. The plant had prepared a "Safety Week". Ten accidents took place over a period of seven days and on the 7th day, while the week was supposed to end with a ceremony, three accidents forced the management to cancel the celebration.

In the 1983 company agreement, it was agreed that in each of the three teams, there would only be six workers out of 11 at the M.I.C. (Methyl Iso Cyanate) plant and three out of 10 in the Sevin plant. For maintenance, the number dropped from six to four. For operation managers, the drop was between 25 and 45%, with 80 taking early retirement out of a total number of 200 job cuts. The others agreed to take lower-paid jobs.

In the M.I.C. control room, there was only one operator left, not enough to monitor 70 indicators in an emergency situation. In addition, he did not have a procedures manual in the event of an emergency, such as the unexpected pressure increase in the M.I.C. tanks. For reasons of industrial secrecy, the instruction manuals were locked in a cabinet and only the operations manager had the key.

One of the most dangerous effects of the staff cuts was the obvious lack of maintenance: leaking pipes, valves which did not close properly and were not repaired, the stoppage of anti-corrosion checks, reactors which were not fully drained (emptying, cleaning then aeration) before repair work. And yet this negligence had already caused the death of a worker in 1981 through phosgene gas intoxication.

To summarize the precise circumstances of the accident, an isolated and poorly trained operator was faced with a process provoked by impurities (phosgene) linked to insufficient cleaning and perhaps a water leak due to a leaking pipe or a valve that was not properly closed. This very exothermic process was not slowed down by the cooling system, which had been stopped, and was not signalled by the extinguished pilot flame or the sound signals which were switched off. The gases produced were not neutralized in sufficient quantities due to the shutdown of the washing towers and were not burned off by the flare which was switched off.

3) A badly designed plant. Inexcusable design errors had already been made even before the plant turned out to be unprofitable.

- Each tower for gas neutralization using caustic soda (vent gas scrubber) was designed for a flow rate of 85 kg per hour and a maximum pressure of 39.7 psi ($2 kg/m^2$) at 120°C. Yet the gas escaped at 20,000 kg per hour at more than 200°C. One of the towers was closed down. Furthermore, the dimension of the flare bore no relation to the flow rate noted.

- Very little technical redundancy was noted in this dangerous plant. This modern plant had old monitoring techniques. In 15 vital locations, there were no indicators or recorders. The number and the location of alarms and emergency stops were unsuitable. Serious errors were noted from the elementary ergonomics viewpoint. On the same control panel, indicators in PSI and kg/cm^2 were found arbitrarily.

The temperature of the M.I.C. tank was indicated from -25° to 25°, while, with no cooling system in a hot country, it was much higher than 25°. In any event, the thermometer did not work! The pressure indicator only gave a reading up to 2.5 kg/cm^2 , the alarm level.

- In fact, this plant was well below the safety level of a lot of older Indian plants.

4) <u>Trade union persecution</u>: For some considerable time, company workers had expressed their concern about the dangers of the Bhopal plant.

Following the death of a worker due to phosgene intoxication (1981), trade union leaders organized a 15-day hunger strike in order to obtain better compensation conditions. Several trade union leaders were sacked. The various trade unions at the Bhopal plant had talks with the plant's Indian and American directors in order to obtain better safety conditions. In particular, they asked the Government of Madhya Pradesh to have the plant classified as dangerous. A poster campaign was organized in the town of Bhopal in order to point out the dangers to which it was exposed.

In 1983, tension in the company rose again: four trade union leaders were locked inside a room during working hours to avoid contact with other workers and the verification of safety defects. Three months were thus used for "special training".

Another incident was characteristic of the worries of the workers. Originally, Union Carbide had demanded a special supervisor for the MIC plant which was considered as very dangerous.

When the qualified supervisor was moved to Bombay and replaced with someone who was unqualified and, in addition, was given responsibility for everything else, the trade unions protested vehemently; this was followed by sanctions.

Three months before the disaster, a worker was mutilated in an accident. A trade unionist who denounced the negligence on this occasion was sacked with no protest from the trade unions.

5) Lack of action by the Authorities

The safety valves had released M.I.C. into the atmosphere every four to six months since the plant had started to operate. In 1974, cattle which had drunk water polluted by the plant started to die. This pool, located 2 km from the plant (but right in the middle of a shantytown) was surrounded by an area with no vegetation. Six months before the disaster, the planning department of the Madhya Pradesh Government had classified 18 industries as dangerous, but not the Union Carbide plant, although the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) indices were 10 to 100 times higher than the accepted limit. These measurements were taken by the pollution control department.

In fact, political circles had long been aware of the seriousness of the situation at the Bhopal plant, surrounded by shantytowns. A civil servant from the safety department had asked for the plant to be moved more than 10 km away from Bhopal. This represented a very costly measure for Union Carbide and for the Madhya Pradesh Government. But it was probably an inefficient measure since the plant was initially located 3 km from the town and had attracted a large population of migrants. The shantytowns which formed in this way would undoubtedly have reformed around any new site.

The role of the town of Bhopal should have been to prevent these shantytowns appearing. But that was socially impossible. A contrary solution was chosen for political reasons, that of attaching the shantytowns to Bhopal shortly before the disaster.

6) Why so many deaths? It appears that those in charge of the plant could not imagine the shut-down plant being the source of an enormous gas leak which actually came from a tank in poor condition which had no refrigeration. In addition, they only warned the police and set off the siren two hours after the start of the leak when everything had ended. The plant workers who had understood the phenomenon and who knew the wind direction were able to protect themselves. Therefore, the populations of the shantytowns were not warned in time, did not know the right direction of the leak and did not have any means of transport.

Another major cause of the high mortality was the affirmation, repeated for five days by the management and the industrial physicians, that it was not a serious incident. Yet M.I.C. can be used as combat gas. It provokes considerable irritation of the conjunctiva and the respiratory tracts. Pulmonary oedema can lead to asphyxiation. In addition, when it comes into contact with water secreted by the system, methyl isoyanate decomposes and produces hydrocyanic acid which is lethal (by cellular anoxia). It is not known if this serious mistake by the company management in regard to toxic risks was linked to a concern to deny responsibility or, more probably to ignorance of the various toxicity aspects of M.I.C. Among the aggravating circumstances, mention could be made of the poor health system in Madhya Pradesh, particularly in the field of industrial toxicology, although the head of the forensic medicine department of the Hamidia Hospital (Dr. Heere Schandra) made a correct diagnosis the first day as regards asphyxia by M.I.C. and intoxication by H.C.N. Finally, the extreme denutrition and poor sanitary condition of the populations of the shantytowns were also aggravating circumstances.

7) Does Bhopal concern us? The motive here is not to question human solidarity, but to measure our responsibilities and the risks which we run. Since the disaster, and in relation to the main financial difficulties encountered by Union Carbide due to this, we know that the Farming Chemicals Division of Union Carbide was bought by Rhône-Poulenc. Perhaps the directors of the La Littorale plant, near Béziers, now have the information which they were refused after the disaster. Yet, this French plant uses M.I.C. to produce an insecticide.

From a general viewpoint, everyone should be worried when the financial difficulties of a company lead to safety being jeapordized and efficient safety systems being removed or qualified and experienced staff being dispersed. This is particularly serious in the case of complex and dangerous systems, whose operation we are studying here, and even more serious when it concerns systems which are badly designed from the ergonomic viewpoint and, due to this, require intensive and complex cognitive activity from groups of operators. Yet, we know that this activity is rarely formalized and sometimes denied. Finally, refusal to hear the workers and their representatives is another way of disconnecting the safety systems which, in this case, are the company's social systems.

Finally, the delay in informing the populations, the police and the doctors could be compared with what happened recently after the accidents which took place in the Sandoz chemical plant in Basle and, previously, in the Italian chemical plant of Seveso which belongs to the Swiss group Hoffman-Laroche. Then again, in a more general way, can an accident which took place in a plant in difficulty in an industrially developing country be compared with what happens in three other major disasters which took place in the technical arsenal of the two super powers: the USA and the USSR?

III - NUCLEAR SAFETY

Can major technical-economic errors - like those observed in Bhopal - be found in the complex technical systems installed in highly industrialized countries in the very centre of their essential activities?

Are there serious negligences leading to critical reduction of safety in costly plants belonging to the world's largest companies?

Unfortunately, the answer is yes in both cases:

1) SAFETY NEGLIGENCE IN PLANTS THAT ARE BADLY RUN. A Wall Street journalist, D. Wessel (1987) gives the best or, in any event, the clearest description of the contrasted effects on safety of two conceptions of plant management. The two plants are situated in Massachusetts and Connecticut, 130 km apart. They are GENERAL ELECTRIC boiling water reactors with a similar capacity (670 and

600 megawatts) delivered in 1970 and 1972 which belong to very large firms. Pilgrim belongs to Boston Edison and Millstone belongs to Northeast Utilities. On the other hand, the operating differences are considerable: P (Pilgrim) produced at 53% of its capacity and M (Millstone) produced at 68%. The average annual exposure of all workers (1984/1986) was 1949 rems for P and 645 rems for M. Low-radioactivity waste in 1984/1986 was 1,700 m3 for P and 609 for M. Finally, the fines imposed by the N.R.C. (Nuclear Regulatory Commission) totalled $660,000 for P and none for M between 1972 and 1987. The result of this situation was that the Pilgrim power station was closed in April 1986 for an undetermined period.

The main elements of criticism of the Pilgrim plant are as follows:

2) <u>Serious maintenance negligence</u>. When P was shut down, there was a backlog of 12,000 repairs which had not been executed. Fifteen months after the shutdown, half of them had been done. None of them was vital. But these negligences showed the inability of the P management to control maintenance.

There was so much broken fire-fighting equipment and so many violations of the fire-fighting regulations at P that the management of the plant had to recruit supervisors for the permanent supervision of 72 critical points in the plant.

2) Unfavourable working conditions. Apart from the most serious aspect - radiological contamination three times higher at P - situations that are dangerous in terms of their duration were also noticeable. There was the case of the control room operator at P who worked 97 hours in a single week. But this is only an extreme case. The N.R.C. report affirms that: "For years, P only operated by forcing staff to do a considerable amount of overtime. On the other hand, at M, for 16 years there had always been enough staff for one week out of six to be dedicated to training."

3) Mismanagement. The N.R.C. closed P and other nuclear power stations not because of technical faults, but because of their mismanagement, something which is totally new. Discussions of the reliability of operators seem a world away when an N.R.C. report affirms that "the "worst" operators were given responsibility that is totally excessive in regard to reality."

D. Wessel considers that these management errors are located very high up in the hierarchy. It appears that the Boston Edison company, which had only one nuclear power station, considered it like a power station producing electricity as with any other source: coal or oil. Unlike fossil energy plants, nuclear plants require management skills which determine the changes of assignment between the plant's management and the technical management and even the firm's general management. This was the case at M. but not at P. where the director was not considered as worthy of belonging to the general management.

Such a situation affected the work of the technical management at M. There were only two technical managers over a period of five years. At P. there were three technical managers in its last year of operation. At Pilgrim,the technical director was rarely seen in the control room and, furthermore, it was not the same person who monitored operation when the plant was working and when it shut down for supplies or repairs. On the contrary, at Millstone the technical director visited the control room nearly every day to check the log book and chat to the operators. This visit was highly recommended to the plant's technical director by the Northeast Utilities vice-president for nuclear operations.

Even further upstream, D. Wessel notes that there are four nuclear plants in Northeast Utilities, which justifies significant management and expertise. This was not the case at Boston Edison which only had one plant.

2) NEGLIGENCE IN THE DESIGN AND MAINTENANCE OF THE TECHNICAL SYSTEM OR HUMAN ERROR - PERROW AT THREE MILES ISLAND

There is no clear connection between the situation at Three Miles Island (T.M.I.) just before the accident and those described previously since it was actually the accident at T.M.I. in March, 1979, which triggered the type of study described by Wessel (1987).

However, the origin of the accident at T.M.I. was analyzed in a remarkable way by Perrow (1982). He showed that work analysis, and more generally analysis of the situation, was able to pinpoint the limited extent to which the operators' "errors" could be held responsible and to show the importance of design and construction errors, as well as the poor condition of the technical system linked to the insufficient means of the maintenance system.

"Operator error is frequently cited as the most frequent cause of the accident. This thesis is worth examining in detail, for it hides more than it explains. Because of the complexity of the "transient" (this technical term indicates a loss of coolant, rather than anything temporary or ephemeral), it will be necessary to simplify the account. The transient originated in a problem with filtering resin from water flowing to the steam generators that create steam that drives the turbines. The problem had occurred twice at the plant, and the system was being repaired. This time, the blockage caused a pump to stop (or trip), thereby automatically tripping the turbines and activating some other emergency pumps, but the pipes from the emergency pumps had erroneously been left blocked during maintenance work two days before. (This is one case of gross operator error, but like everything else that went wrong, not too significant in itself). The core then started to overheat, because water was not flowing through the steam generator to remove heat from the separate coolant system in the core. The reactor scrammed, as designed, stopping the fission process (though there was still "decay heat" generated in the core). As the reactor heated more and pressure increased, a pressure operated relief valve (PORV, sometimes referred to by its Dressler Industries trade name "electromatic relief valve") opened as planned to alleviate the increasing pressure. The reactor pressure returned to normal (we are now 13 seconds into the transient), but the PORV did not reseal, even though the indicator on the control panel indicated that it had. The operators assumed the valve had closed. Because the valve remained open, a loss of coolant accident occurred, as coolant for the core was passing through the open valve and draining into a tank. The operators knew that there had been a brief accident that had tripped the turbine and scrammed the reactor. They did not know they were in a LOCA for almost two and one-half hours. By then the damage had been done.

Meanwhile, the pressure of the coolant had dropped, and it was in danger of turning into steam unless it stayed under pressure. The high pressure injection (HPI) pumps came on as designed, forcing water from an emergency tank into the core coolant. The operators saw that the level of pressure in the pressurizer rose rapidly. Not knowing they had a LOCA, they cut back on the pumps to prevent the pressurizer vessel from becoming a solid mass of water, which could rupture the reactor coolant system. Retrospectively, this is seen by all commentators as the major error. Operators did not realize the significance of a corresponding drop in pressure in the core itself; it was not filled with liquid coolant, as they assumed, but with a mixture of steam and water than contained many voids or bubbles. Operators at a Davis-Besse plant a year earlier also experienced a jammed PORV and also did not know they were in a LOCA, so they also cut back on the HPI. Fortunately, there was no damage.

How could the TMI operator not have discovered that the core was being uncovered and superheated? There is no direct reading of the level of coolant in the core; a Babcock and Wilcox official testified that it would be difficult to provide, too expensive, and would create other complications. Although there were several indirect measures, each proved to be faulty or ambiguous. A drain-tank pressure indicator would have suggested a LOCA, but it was located on the back side of the seven-foot control panel; unaware that they were in a LOCA, the operators had no reason to look at it. The temperatures on a drain pipe would have indicated the problem, but the operators had been discounting these readings prior to the accident because the drain pipe had leaky valves, and they assumed that a particularly high reading had been caused by decay heat. What about the drop in pressure in the core itself? This indicator of core pressure was next to the indicator showing a rise in pressure in the pressurizer. These two indicators were supposed to move together; therefore, it was inconceivable to the operators that one would drop as the other rose. They believed the indicator that measured pressure in the pressurizer and throttled back on the HPI; they discounted the indicator that measured core pressure, as they thought that the indicator said the PORV had closed because pressure had briefly risen in the core and then fallen off and because the pressure decline could have been due to a sudden injection of cold water. Finally, they were accustomed to receiving faulty readings - there were several during the transient - so they relied on those that made sense and discounted or explained away those that did not. Finally, it should be noted that the control room quickly filled with managers and engineers and none of them knew that the problem was a LOCA. This evidence came from the commission hearings. Regarding the operators, the commission concluded that there was a "severe deficiency in their training" because they failed to realize they were in a LOCA; that they were "oblivious" to the danger of uncovering the core; and that two readings "should have clearly alerted the operators that TMI-2 had suffered a LOCA". However, Commissioner Theodore Taylor, a theoretical physicist from Princeton University, argued specifically that there was no way for the operators to know what kind of accident they were experiencing when they cut back on the HPI. Taylor noted that the decision to cut back on the HPI must be made **before** one can know that it would be the wrong decision. Despite these considerations, the commission report supported the retrospectively reached industry judgement of egregious operator error. So widely accepted is this view that the British Secretary of State for Energy referred to the cause of the accident as "stupid errors".

Consider the situation: 110 alarms were sounding; key indicators were inaccessible; repair-order tags covered the warning lights of nearby controls; the data printout on the computer was running behind (eventually by an hour and a half); key indicators malfunctioned; the room was filling with experts; and several pieces of equipment were out of service or suddenly inoperative. In view of these facts, a conclusion of "severe deficiency in training" seems overselective and averts our gaze from the inevitability of an accident even if training were more appropriate.

Normal accidents have banal causes. Almost all of the many things that went wrong during the transient had gone wrong before; none was catastrophic in itself. However, banal causes become bizarre events in complex, tightly coupled systems. During an accident, these causes are incomprehensible (or will be to some set of operators at some time, regardless of training). For this reason, there have been many nuclear accidents and there will be more."

The very remarkable document by Perrow, from which we have just made a long citation, shows the great difficulty which operators have in forming a functional representation of the system, an operating image, as soon as one or more anomalies take place. Perrow also pointed out the multiple means used by operators to improve the very poorly conceived situation and help form the operating image. Citing Perrow once again: "Plant policies, plant designs and equipment all contribute to operator error. The woefully inadequate control panel is a case in point. It is the operators who have exhibited ingenuity in using colored tape, home-made control knobs and home-made supplemental equipment to highlight the logic of the system which is so haphazardly displayed by equipment manufacturers and ignored by the NRC. The most complete study of the problem, conducted by Lockheed, concluded that operators work under severe handicaps. Operators err, it seems, in not being able fully to surmount the inadequacies and complexities of the equipment they must use."

3) DANGEROUS PROCESS, IMPERFECT CONSTRUCTION AND ORGANIZATION BREAKDOWN AT CHERNOBYL

As in the other cases examined in this text, the Chernobyl accident was due to multiple causes situated at distances more or less remote from the event itself: choice of a dangerous process, weak containment systems, insufficient checks and automated systems and organization breakdown.

In nuclear power stations, data are complex by nature and it is not always possible to find out the truth due to technical rivalries of great commercial importance. However, it clearly appears that the R.B.M.K. process (boiling water reactor moderated with graphite) used at Chernobyl had intrinsic instability which appears to have played an important role during the accident.

As written by Gauvenet (1986) the weaknesses of the reactor are due, first of all, to its very principle, since the moderator is in graphite, it is kept operating at a high temperature and the coolant is water. At a high temperature, in the event of a serious incident, this water may break down in the presence of the zirconium of the fuel pipes and this produces hydrogen which creates a risk of explosion and inflammation of the graphite. In addition, when the amount of steam contained in the water increases in terms of the temperature and the pressure, the number of neutrons produced in the reactor rises instead of decreasing, as is the case in most reactors known: it is said that the vacuum coefficient is positive; this provokes serious instability since the reactor could race if special measures are not taken to avoid this phenomenon.

There is also instability in the space of the core since the fuel elements are not greatly interlinked and act as if they were in small, practically independent reactors.

Other aspects have been discussed as regards Chernobyl. They concern the design and construction of the cement containment systems. In particular, the insufficient thickness and weight of the base is noticeable. It was this insufficiency which threatened to pollute the region's underground hydraulic network. We also know than the concrete containment vessel was too small and its walls were too light and too thin. It broke open and released radioactive elements into the atmosphere when it exploded, unlike the Three Miles Island plant where the containment vessel resisted and avoided a disaster in the USA on the scale of that in the USSR.

It is difficult to know if the cement containment systems were underestimated in terms of their design or if the construction companies and the Ministry to which they were responsible only executed the plans partially.

A process as dangerous as R.B.M.K. operated for a long time with no accident. However, multiple information readings should have been taken as regards operation and it should have been equipped with automated systems more sophisticated than those at Chernobyl. In fact, a lot depended on the quality of the know-how and strategies of the power station's operators and management.

The immediate determinants of the accident were two-fold. First of all the reactor power was increased immediately before the test for reasons of network operation.

The low-power operation required by the test then became practically impossible to achieve before a certain time due to the Xenon effect. It should have been shut down (Gauvenet, 1986).

The test team, which came from Moscow, was determined to carry out the test immediately and had exorbitant powers. Due to a lack of sufficient training and information, this team switched off vital safety systems, in particular those which were specifically intended to solve the problems posed by the reactor itself. The result was that, under the special operating circumstances linked to the on-going test, the reactor's power increase was impossible to control since the control systems had been switched off. Explosions, lasting fires and the rejection of radioactive products into the atmosphere were inevitable.

Secondly, the staff could not take any action due to serious representation conflicts. In ergonomics, we know very well that there are several levels of representation of phenomena in a complex system:

- that of physicists or chemists whose general character enables a good level of explanation of the principle, but does not take into account the contingencies linked to the actual systems which had been chosen,

- that of the designers of the technical system who had followed a clearly logical approach, often backed up by complex calculations and who rarely allowed for the assumption of distortion of this diagram in the concrete reality of operation.

- that of the plant's technical managers who knew part of the adaptations which they were forced to accept but who, too often, like the technical director of the Pilgrim plant, only had a rather abstract view of operation of the plant.

- that of operators who are aware of all the questions raised by the doubtful operation of indicators and of the system itself. It is easy to imagine how much difference there was between the representation of operators at P., who were more or less aware of the 12,000 repairs which were overdue, and the representation of their technical director.

The choice is obviously a lot more serious when there is a clash between the 1st and 4th representation. The scientists from Moscow who had taken control suspended the action of the safety systems and directed the operation in a dangerous way. Nobody, neither them nor the operators, still had a concrete representation of the phenomena or could take effective action to bring operation back to normal.

We know that the French rule is that of absolute control by the director of the nuclear power plant, even in the case of tests. No matter how valid a rule is, it should never be enough to reassure. The reality should be noted day after day.

IV - DOUBT AND ANXIETY IN CONTINUOUS PROCESS INDUSTRIES (DANIELLOU F., DEJOURS C., WISNER F., 1987)

At the time of description of the dramatic situations of Bhopal, T.M.I. and Chernobyl, mention was made of the difficulties, for operators, of making interpretation and, therefore, decisions.

In the field of reasoning about the uncertain, Rasmussen and Rouse (1980) published a book called "Human detection and diagnosis of systems failures". In particular, the article by Bainbridge shows how the "internal model" (what Ochanine called the "operator image") is constituted. Anomalies are interpreted and decisions and taken on the basis of this internal model. It is obvious that this model has limits and that certain rare and complex combinations of system defects, like those at T.M.I., are beyond the integration capacities of the human brain, at least in the time limit imposed by the process. Unfortunately, we will probably be unable to construct decision-aid programs intended for operators who have to face such situations, without such programs constituting dangerous instruments in combinations of defects other than those for which they were designed.

It is not surprising to learn that the expressions used to describe the condition of these experienced operators during the incident were "bewildered", stunned, disorientated and confused. This is a clear illustration of the switch from an incomprehensible situation to a pseudo-breakdown of reason and psychopathology (Wisner, A., 1981).

It is important to describe not only the doubt of representation, the difficulties of decision and their causes, but also their relations with the resulting anxiety (Dejours, 1980; Daniellou, 1985; Dejours, Veil, Wisner, 1985). The study of the three accidents of Bhopal, T.M.I. and Chernobyl and the deterioration of the Pilgrim power plant show the increasing certainty of the next accident. We remember, for example, the steps taken by trade unions and the poster campaign in Bhopal. The increased level of anxiety has an initial beneficial effect since it makes operators more attentive. But, in particular, it has a formidable secondary effect when the accident itself takes place, since this never happens exactly the way it could have been imagined. The analogy between the causes of accidents in different countries could be underlined. The excessive authority which the Chernobyl test team had is only equalled by that which imposed the tragic launching of Challenger at Cape Kennedy. We know that, in this case, night frost, which is exceptional in Florida, had modified the resistance qualities of certain seals. The bursting of these seals, which was feared by the manufacturer, led to a hole being torn in a liquid propellant tank and the consecutive fire.

The previous analysis might be perceived as pessimistic. But complex and dangerous systems constitute a permanent threat to the lives of workers and populations, to the economy of the company and the country, to the future of an industrial branch and even to the future of humanity. The means necessary for research and for the production of prevention are still well below what is required, especially now that it is certain that the ritual blaming of scapegoats simply amounts to blaming the incompetent judges.

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