Nuclear Decommissioning: from Case-Studies to a Proposed Typology of Risk

Melchior Pelleterat de Borde, Christophe Martin, Franck Guarnieri

Nuclear Decommissioning: From Case-Studies to a Proposed Typology of Risk

M. Pelleterat de Borde, C. Martin & F. Guarnieri
Centre for research on Risks and Crises (CRC), Mines ParisTech, Sophia Antipolis, France

ABSTRACT: This paper presents a typology of risks which may be faced by operators in the transition to nuclear decommissioning. It is based on an analysis of the literature on nuclear decommissioning, both past and present, and a recent study of a nuclear power station. It first part outlines decommissioning definitions and current decommissioning strategies in broad terms. The second part focuses on decommissioning contexts in three different installations. Although the technological and environmental issues are the same, the impact of context from the point of view of staff and organisational risk is examined. Finally, the third section presents a typology of risks related to nuclear decommissioning operations.

1 INTRODUCTION

The use of atomic energy, whether for scientific research, medical applications or electricity generation has become commonplace in the modern world. Such practices regularly raise concerns about its relevance and its impact. These concerns resurface each time an event with complex economic, social and environmental consequences occurs. Examples include the incidents and accidents at Three Mile Island in 1979 (Perrow 1999), Chernobyl in 1986 and more recently at the Fukushima Dai-Ichi in March 2011. All three were also opportunities for a more general reflection on the operation of the installations concerned.

However, normal operations and the planned phases of the life cycle of nuclear facilities also provide an opportunity to learn about the technical, economic and organisational challenges these facilities face together with the associated risks and how to overcome them. The decommissioning of nuclear power plants is one of these sensitive situations. This is major challenge for nuclear power risk management, and as such, requires careful thought about how to categorise these risks.

This article is in three parts. The first defines nuclear decommissioning, specifies its principal characteristics and identifies its main international strategies. The second outlines the importance of the context for decommissioning and its associated risks. Finally, the last section presents a typology of risks divided into three main families.

2 UNDERSTANDING DECOMMISSIONING

Decommissioning is a long and complex process. Although it is the final phase of the life cycle of nuclear facilities, it is not homogenous. National and international supervisory bodies have identified timescales and strategies for decommissioning that have been implemented in countries where nuclear decommissioning is already a reality.

2.1 Definitions

It is first necessary to understand what decommissioning means and its place in the life cycle of nuclear facilities.

Nuclear decommissioning concerns all nuclear facilities regardless of size and function. It encompasses research facilities (reactors and colliders), medical facilities, military installations, industrial plants for electricity generation (nuclear power plants) and facilities that use nuclear energy for other industrial purposes. While these facilities are very different in their design and radioactive power, the issues of radiation, the environment and technology are similar. Likewise, risks related to the handling of radioactive materials and the importance of risk management in decommissioning are the same, demonstrated notably by accidents in the medical domain (IAEA 1988). However, in this article we focus on electricity power generation facilities, which have received more attention, both in the literature and in the political, social, scientific and media spheres.

There are four main phases in the life cycle of nuclear power plants: construction, production, temporary shutdowns and decommissioning. Decommissioning therefore forms part of the history of the installation; it inherits the same technical and organizational characteristics seen in the construction and production phases.

Decommissioning describes the overall process for the preparation, implementation and execution of the operations necessary for the “removal of some or all of the regulatory controls that apply to a nuclear site” (NEA/OECD 2002). It therefore concerns making facilities safe when they cease to be operational and changing their regulatory status. The facility must be made secure for the individuals working there, the general population and the environment (Bayliss & Langley 2003).

Dismantling is a more precisely defined activity that aims to physically destroy facilities: it concerns the work to be carried out. Decommissioning may therefore include the dismantling of a part of, or an entire building, but it can also be confined to the removal from the site of radioactive elements and the decontamination of the building for subsequent use. In this article, we focus on decommissioning in a global sense, which integrates upstream preparations and downstream activities surrounding the effective shutdown of production in nuclear facilities.

Although integrated into the overall life cycle of a nuclear power plant, decommissioning takes place within a specific timeframe and has particular characteristics.

2.2 Timeframe and characteristics

Nuclear decommissioning takes place with a particular timeframe that creates many fundamental challenges related to its management, and is defined by a particular set of characteristics.

The first point to note is that decommissioning takes place over a long or very long timeframe. Reactors such as Three Mile Island 2 in the United States, which was shut down following an incident in 1979 (US NRC 2013) or the decommissioning of Brennilis, a French nuclear power plant, which began 1985 (ASN 2013) have not yet reached the end of the process, and the Fukushima Dai-Ichi plant is currently being prepared for a minimum 40-year decommissioning process according to its operator, the Tokyo Electric Company (TEPCO 2013). This long timescale creates challenges in terms of cost management (NEA/OECD 2003), organisational management and supervision of operations (Martin & Guarnieri 2013).

Decommissioning is not homogeneous. Experiences are characterised by huge differences in the number of facilities that are in production, under construction, undergoing decommissioning or being dismantled. While the vast majority of commercial reactors are still in production, and operators have little experience of decommissioning (it is also the case for particle accelerators), research reactors and units that produce fuel or materials for the nuclear industry have more experience (IAEA 2004). Decommissioning is characterised by the highly exploratory nature of its techniques, organisational changes (Pelleterat de Borde et al. 2013), skills and staff management, and management of subcontractors. The actors involved in nuclear decommissioning regularly compare it to shutdown operations (Martin & Guarnieri 2013). The comparison, although fundamentally different in terms of timescale, is valid from the point of view of the heavy dependence on outsourcing and the potential over-exposure of workers to radiation. It could be said that decommissioning is a paradoxical phase in the life cycle of nuclear facilities. Although it is always strictly governed by regulations that guarantee operations are carried out safely, the timescale and constraints are very different to that of maintenance operations during the functionning period. This disparity creates situations that are complex for the facility’s actors to manage.

This section has shown that decommissioning, which is a complex process with multiple challenges, does not constitute a homogeneous field for research. However, international organisations, as we will see, have sought to limit decommissioning to one description. These stages and strategies attempt to standardise the process at the international level.

2.3 The international context

The international nuclear decommissioning landscape is characterised not only by the available technology, the age of facilities and their importance in different national contexts, but also by choices that are often a matter of national policy. In particular, they relate to requirements concerning acceptable conditions for unrestricted re-use. In terms of decommissioning options, the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) specify that, “there is no unique or preferred approach to Decommissioning and Dismantling of nuclear facilities” (NEA/OECD 2002). One of the main differences between countries concerns clearance levels for facilities and waste that, for example, do not exist in France unlike other nuclear countries. This difference has important implications for waste management and the reuse of nuclear facilities (French Ministry of Environmental Protection 2013; NEA/OECD 2006).

However, there are several internationally recognised phases or stages in nuclear decommissioning and three major strategies are recognised by the International Atomic Energy Agency (IAEA). Bayliss and Langley identify three distinct decommissioning stages (Bayliss & Langley 2003). These stages may be interspersed with periods of inactivity that leave time for radioactive decay. In the case of reactors, the first stage is to empty them of fuel and coolants and to remove sources of radiation. Equipment that is easily broken down is also removed and the facility is prepared for a monitoring period and future dismantling. The second stage is to decontaminate the facility by removing, as far as possible, sources of radiation and parts that can be easily deconstructed. The last stage aim is to obtain the declassification of the installation by removing the remaining radioactive elements in order for the site to obtain greenfield (un-restricted use, or a return to the pre-construction installation status) or brownfield status (with use or development restrictions due to former nuclear use).

At present, as the study by Bayliss and Langley (Bayliss & Langley 2003) shows, the IAEA defines an operational continuum consisting of several phases: the operational phase, the shut-down transition phase (Pelleterat de Borde and al. 2013), preparation for safe enclosure, the safe enclosure period and final dismantling. However, it does not seem useful to contrast these two approaches (stages or phases). The phases proposed by the international literature tend to be a specific modality of the final period of the facility's life cycle, namely phased dismantling (IAEA 2004).

The IAEA defines three decommissioning strategies, which are broken down by country according to national policy, the type of installation (e.g. radioactive decay does not apply to plutonium processing facilities) and regulation (IAEA 2004). Describing these activities in terms of different strategies is probably also an exaggeration: it is more the case that the first two strategies represent two options regarding the timeframe for decommissioning, while the latter does not strictly deal with decommissioning.

The first strategy is immediate dismantlement. It consists of immediately decommissioning the facility, without waiting for the radioactive decay of its contents. The goal is to reach, as quickly as possible, the end point defined by the rules; typically declassification. This strategy presupposes that there is an efficient nuclear waste processing chain: if not, timescales will be affected by the ability of the system to cope. In theory, the phases of dismantlement immediately succeed each other, without any intermediate lapses in time. Immediate dismantlement has been the preferred choice in, for example, France – despite the fact that the nuclear waste processing chain is not fully established. This leads to situations where temporary storage is used on decommissioned sites.

The second strategy is called deferred dismantlement, safe enclosure or safe storage. It aims to benefit from the time needed for radioactive decay to empty and secure the facility (stages 1 and 2). The IAEA argues that this strategy has several advantages, of which the principal are that workers are protected from radiation and there is an increased ability to raise funds for the future decommissioning work (stage 3). This strategy essentially aims to delay the transition from stage 2 to stage 3.

The third strategy is called entombment: the goal is to bring the facility (usually research facilities or powerful reactors) to a stable state that requires minimal monitoring. Equipment and radioactive materials are entombed in a solid structure not intended for deconstruction The IAEA describes it as follows: "this essentially means that the site becomes a near surface waste disposal site" (IAEA 2004).

These examples show that decommissioning strategies and the stages of deconstruction are more general guidelines that reproducible operational blueprints. They can orient understanding of risk management and indicate the priorities to be given to risks arising from decommissioning. However, the reality of decommissioning is very different, as the next part of this article will highlight.

3 THE IMPORTANCE OF CONTEXT

The difference between how decommissioning is expected to work, as described by the IAEA, and specific situations observed in the real world highlights the emergence of new risks and shows that the decommissioning context is extremely important.

3.1 Theory vs. practice: the impact of context

One of the key elements of nuclear decommissioning is the ability of operators to anticipate, prepare and plan both prior to, and during the decommissioning itself. These concepts are at the heart of the difficulties highlighted by the IAEA in the decommissioning process. Preparations made by operators influence the entire process, particularly with respect to risk management (exposure to radiation, organisational, human and economic risks) and skills. The transition between production and decommissioning is a sensitive phase of deconstruction process and can take up to two years (Bayliss & Langley 2003). However, this ideal scenario: preparation, implementation, and monitoring, with specific timeframes dedicated to each stage can be undermined by the international, political, social and economic context in which operations are carried out. Bayliss and Langley are extremely clear on this point, “Ideally, adequate notice should be given of the intention to shut a plant – up to 2 years is required to carry out the required planning work. In reality, the decision to shut down a plant is often precipitated by adverse commercial circumstances, which may leave less time to plan the transition”, (Bayliss & Langley 2003).

The current international decommissioning landscape appears to be more a matter of exploratory techniques and methods than industrial implementation. Despite the sweeping assertions of industry and international organisations for whom, “many nuclear facilities have already been successfully decommissioned and dismantled” decommissioning operations continue to be very heterogeneous and exploratory. In fact, as IAEA statistics show (IAEA 2004), decommissioning has so far mainly concerned small facilities, plutonium processing plants and research reactors. In 2003, the vast majority of commercial reactors were still in production (446 operating, 45 under construction, 107 shutdown undergoing decommissioning and 14 successfully decommissioned). This shows that the decommissioning of large facilities is still in the experimental phase, and technical and organisational solutions are mainly responses to specific contexts.

The decommissioning context is important not only in terms of technology (type of facility, size), but also in terms of the events that led to the decision to shut down the facility. Conditions are not exactly the same when decommissioning is anticipated far in advance (Pelleterat de Borde et al. 2013) and when it is the result of a political decision or an accident.

3.2 Three examples of unanticipated decommissioning

Unanticipated or unprepared decommissioning is an important factor to be taken into account when examining the risks created by this phase of the life cycle of nuclear facilities. Here we take three examples of decommissioning conducted in poorly-prepared situations, show how these contexts may compromise the smooth execution of operations and lead to the emergence, if not of new risks, at least to a change in their relative importance. These examples concern decommissioning conducted in degraded conditions: the first due to a political decision, the second due to a nuclear accident of regional significance, and the third due to war and a permanent loss of knowledge of the facilities.

SuperPhénix was a French industrial fast breeder reactor prototype. Construction ended in 1985 and it began production in 1986. Throughout its life, operations were interrupted by short or longer-term outages due to various technical and administrative problems. In 1997, the French government decided to permanently shut it down, despite the fact that it was in the midst of the ten-year maintenance period and ready to restart effective operations. This decision, taken in the context of a change of government and political negotiations, pushed the facility into a decommissioning phase that the plant’s actors had neither prepared for nor imagined. In the opinion of actors and observers, this unanticipated decommissioning of an operational facility led to professional trauma that had an influence on risk management. The speed of decommissioning, the objective to keep the experienced personnel of operational teams in this new phase of the plant’s life cycle and how to carry out the most difficult operations were identified by the facility’s own employees as challenges (Rodriguez et al. 2004).

Our second example concerns the decommissioning of the Fukushima Dai-Ichi nuclear plant in Japan. These boiling water reactors were commissioned between 1971 (Unit 1) and 1979 (Unit 6). Units 1–4 suffered serious damage as a result of events of March 2011 and the operator TEPCO decided, together with the Japanese government, to implement a comprehensive forty-year decommissioning programme (TEPCO 2013). However, the extent of the damage and the fusion of three of the four reactor cores (Units 1–3) radically transformed the decommissioning process, posing a series of challenges that have proved difficult to overcome. The multiplicity of concurrent problems is the main characteristic of the Fukushima decommissioning. The lack of a waste processing system for the treatment of spent fuel and cooling fluids, together with a severe lack of safe areas for the storage of irradiated materials add to the difficulty. Operators, who have to both manage the emergency and prepare for decommissioning, are in a particularly difficult situation, made worse by an unfavourable political and social climate.

Our third example demonstrates that decommissioning can take place over an extremely long period of time, during which risks can be prioritised as action principles. This was the case for the decommissioning of Iraq’s nuclear facilities (Bibi et al. 2013). Beginning in the

1950s, Iraqi facilities were constructed to support the development of the civilian and military nuclear industry. They underwent numerous bombings during military operations carried out by Israel (1981), the Iran-Iraq war (1980–1988), and the wars of 1990–1991 and 2003. These bombings led to extensive destruction and the almost complete withdrawal of Iraq from the international nuclear community. The 2003 war resulted in the looting of around a dozen facilities, which led the government to draw up an ambitious decommissioning programme in order to rapidly secure installations for workers, the environment and the civilian population. In this case, contextual difficulties were due to several factors: the loss or absence of documentation concerning nuclear sites (which meant that knowledge had to be rediscovered), a lack of qualified personnel, the absence of a waste processing system and storage areas, and lack of experience in the field.

3.3 The effect of unanticipated decommissioning on risks

The above examples show that context is a fundamental element in the identification and categorisation of the risks of nuclear decommissioning. The contextualisation of decommissioning not only leads to the emergence of new risks that may be minimised or forgotten in the ideal decommissioning scenario, but it may also lead to a better understanding of the relative importance of risk factors.

This question of anticipation and preparation for nuclear decommissioning has highlighted several fundamental points. The first concerns technical aspects of decommissioning related to the categorisation of zones and radiation mapping, which is a crucial stage in radiation risk management (Bayliss & Langley 2003). This is complicated by the changing nature of radiation contamination, particularly in plants that have been severely damaged, such as the Fukushima Dai-Ichi plant or the Iraqi nuclear facilities.

A second important point is the existence or establishment of an effective and comprehensive waste processing chain, which impacts the management of the decommissioning timescale. National and international regulations can have an impact on the performance of such networks. However, the issue of nuclear waste goes far beyond the simple question of transport and storage. In this context, decommissioning is particularly pertinent as the concept of waste management is under constant review.

The third particularly sensitive challenge relates to the economics and financial provisioning for decommissioning. This issue is particularly relevant to industrial and commercial facilities, where profitability is a fundamental issue, although it is also a concern for research facilities. The economic dimension of decommissioning impacts operations at many levels, of which the link between decommissioning and outsourcing is one example (Martin & Guarnieri 2013).

Two other challenges relate to the organisational and human dimension of facilities. These concern motivation, commitment to change and timescales (Pelleterat de Borde 2013) on the one hand, the facility's collective memory of technical and production history on the other. The managerial consequences of the transition from production are an important area identified by the IAEA in their discussion of decommissioning. Context has a significant impact on the motivation of the facility's actors throughout the process. The establishment and maintenance of a collective memory (in technical, organisational and human terms) requires particular attention when decommissioning takes place over an extended period of time or is delayed.

This examination of the decommissioning context shows that it is not possible to analyse it, or the risks that arise from it without taking into account the whole process, in technical, environmental and human terms, and from the financial and temporal angle. Decommissioning constitutes a multifaceted continuum of risk. If it is to be credible, a typology of risks must take into account the decommissioning context, the types of facilities and associated strategies. That is the subject of the last section of this article.

4 A TYPOLOGY OF RISK

Our risk typology is structured into three groups: technical and technological issues, the decommissioning project, and those related to human and organisational factors. These three risk categories are classified according to the extent to which they are understood and managed by the decommissioning industry.

4.1 Technological risks

The risks associated with reactor technology and decommissioning techniques are relatively well-known, and the implementation of counter-measures is usually well-managed. The most familiar risk (specific to nuclear decommissioning) concerns ionising radiation. Both equipment and materials can be radioactive, and the protection of workers is a priority for operators. While during production, radiation levels are seen as a cost-benefit balance under the ALARA (As Low As Reasonably Achievable) principle, this approach is not viable during decommissioning (Bayliss & Langley 2003). Any immediate benefit does not justify exposure to radiation, and the entire operation is subject to maximum exposure limits. Although the risk of radiation and contamination is relatively well-understood by operators, decommissioning constitutes a new challenge for radiation management.

The second risk is more classical and concerns general occupational health and safety, i.e. physical risks to individuals. These risks are deeply embedded in construction and decommissioning culture. They concern work at height, handling of suspended loads, cutting and removal of equipment. They are the same in the nuclear environment as in other industries, and can be handled in the same way by operators.

The third technical and technological risk concerns the type of facility and specific risks arising from its characteristics and functioning. It relates to chemical hazards that need to be removed or processed in order to reduce any potential interactions with decommissioning operations. In the case of powerful reactors, technology design is particularly important. For example, the handling of sodium in fast breeder reactors such as SuperPhénix incurs specific risks, which require processing techniques and the implementation of special protective measures.

Radiation hazards, health risks and risks related to the characteristics of the facility itself and the safety of activities describe the hazards faced by operators and workers in the decommissioning process. In this category, techniques are most developed and reproducible, and research is likely to provide rapid solutions. This is not the case for risk associated with the overall decommissioning project.

4.2 Project-related risks

The inclusion of the overall process of decommissioning as a risk category is justified by the argument that the decommissioning context should routinely be integrated into a risk typology. Decommissioning is a complex, multi-dimensional project, and each of its components – financial, administrative, waste management, environmental and impact on the public – form part of the overall risk environment.

The first set of risks in this category concern project funding. Decommissioning is a non-productive period and waste management requires extra efforts from which it is not always possible to create value in a conventional system. Securing dedicated funding for decommissioning is therefore a focal point for the smooth management of the project. At present, the real cost of decommissioning is uncertain due to the lack of a global decommissioning industry. Anticipated costs vary enormously, which makes provisioning both difficult and subjective (NEA/OECD 2003). Moreover, finance has implications at all levels in decommissioning management. It determines what resources are allocated to the safety and security of operations and it impacts the speed of decommissioning; a relevant concern from the point of view of the public and the environment. Every aspect of decommissioning is affected by economic and financial issues, which are absolutely crucial.

However, decommissioning is also defined by its timeframe, which impacts the estimated cost of operations. Timescales link the facility being decommissioned to the industrial environment (in which waste management is paramount) and a complex administrative architecture. In turn, these two elements (administration and waste management) partially drive the timeframe. The administrative dimension is fundamental. In many nations the regulatory environment is uncertain and standards can change rapidly, which poses a significant risk to the economic viability of operations. In addition, administrative procedures have their own timescale that can impact decommissioning, and lead to transitional periods where organisational structures become complicated (Pelleterat de Borde et al. 2013). In France, the decree that led to the decommissioning of the Brennilis nuclear power plant was subsequently annulled by a civil action. This is an example of how decommissioning is temporally dependent on administrative processes. This can have a huge impact on costs, and lead the operator to change their future priorities.

Finally, these examples show how an effective and comprehensive waste processing industry is one of the conditions for limiting risks to the population and the environment. Waste processing systems are still underdeveloped and experimental and there are multiple temporary storage areas. Waste is a social symbol of the risks of the nuclear industry and it has significant value for the civilian population. Waste management is linked to environmental risks that emerge or are exacerbated by decommissioning, which involves opening up facilities and the diffusion of materials that are to a greater or lesser extent radioactive. Techniques used by operators can be accompanied by waste discharge, which in theory is managed but may have an effect on the environment.

Risks associated with decommissioning projects are currently the subject of close examination. One example is the establishment of a Decommissioning Risk Management Project as part of the International Decommissioning Network at the IAEA (François 2013). The management of various aspects of decommissioning is the focal point for many industrialists in the sector.

However, in our view, this emphasis on administration, waste management and finance ignores a risk factor that is both the most important and the least well-managed: the organisational and human dimension.

4.3 Human and organisational risks

Human and organisational factors are without doubt an afterthought in decommissioning, despite the fact that they present their own risks. Even if the IAEA actually carries out, as it has said it will, a study on the management of collective memory, knowledge and the need for qualified personnel to handle the most sensitive phases of decommissioning, organisational effects remain relatively unexplored.

A review of books and reports on nuclear decommissioning (such as the excellent work undertaken by Bayliss and Langley) is particularly illuminating in this respect. The organisational and human dimension occupies little more than one paragraph: "shut down of a plant also involves a major organisational change, often with a major reduction in staff numbers. This will be accompanied by significant cultural changes as the nature of the job changes, with a much greater focus on project management approach. A smooth transition process therefore needs to: 1) consider measures to identify and preserve key skills and knowledge, and 2) mitigate the impact of the changes on staff morale" (Bayliss & Langley 2003). This is very similar to what the IAEA has highlighted in its reports. It is clear to international authorities that the maintenance of collective memory concerning the facility and the consolidation of skills are the most fundamental issues that must be addressed in order to deal with the risks mentioned above.

However, organisational risk in nuclear decommissioning cannot be reduced to collective memory and the competence of agents. The transformation of the organisation marks a substantial change in an ecosystem that has developed throughout the plant's operating period (Pelleterat de Borde et al. 2013). This transformation implies reaching a new structural equilibrium that can be a distortion of the organisational structures provided by management. The gap between the theoretical organisation and its reality is patently obvious, as in other complex industrial systems. Therefore, understanding the functioning of the organisation and its potential weaknesses is a fundamental issue in the decommissioning process and operators must acknowledge its importance for the overall safety of decommissioning.

The important of organisational transformation was one of the points highlighted by the OECD in a technical note (NEA/OECD 2004). However, their warning was focused on an idea which is difficult to subscribe to. It is particularly evident in the note's conclusion, "The regulator may reasonably expect the licensee to develop and implement a system for managing change which is comparable with the approach taken to managing plant and equipment change, and encourage self-assessment as part of that system". The idea here is that the nuclear operator is able (as with technical change) to understand, anticipate and address safety risks that accompany the organisational changes. However, current research has established that the operator does not know the organisational implications of the changes put in place, particularly with respect to system safety and reliability. This was highlighted by, among others, Mathilde Bourrier (2005). She argued that, "what managers mostly lack is knowledge of the implications of their organisational choices". The beliefs of managers and operators are still very often rooted in a linear relationship between the desired and the actual, as far as the organisation is concerned, however the question of the smooth operation (or not) of the organisation in terms of the goals set for it is not enough (Pelleterat de Borde et al. 2013). The real challenge for risk management is to achieve a genuine understanding of the effects of organisational change, which can only be seen through a detailed analysis of the social recomposition that takes place in an organisation undergoing transformation.

The transformation of the organisation and the gap between the desired and the actual organisation have a particular impact on the management of field operations that, as in the construction phase, are heavily outsourced (Martin & Guarnieri 2013). Management of concurrent activities (i.e. the planning and scheduling of operations) is a challenge that in turn influences the entire set of risk factors: exposure to radiation, occupational health and safety, financing and timescales. However, the management of operations is influenced by social acceptance of change and its indirect effects: distorted organisational structures, structural reorganisation that is not accompanied by corresponding changes in decision-making and communication loops, unmanaged responsibilities given to actors, and discrepancies between actual changes and those that were intended.

This shows that the organisational dimension of decommissioning is still the subject of unrealistic representations of the relationship between the formal and informal organisation. The creation of a shared decommissioning culture in the wider organisation, including the operator and its subcontractors is still fundamentally limited and links between organisational, human and technical issues are not fully taken into account. It is just as important to understand and formalise organisational and human risks, so that that they are as well-managed as technical or environmental risks.

5 CONCLUSION

The identification and the treatment of risks in nuclear decommissioning is not an easy task. Far from being a conveniently uniform process, decommissioning involves an extremely complex set of very different situations, which each have their own challenges.

Moreover, it is not a homogeneous field for research and the variety of facilities implies a hierarchy of risks. The economic, social, political and international context is another source of variability, which complicates the creation of a risk typology.

However, it is possible, as we have seen, to identify three major risk areas, namely: technical and technological risks, risks related to decommissioning project and risks to the organisation that is responsible for on-site operations. We have shown how organisational risks have the greatest impact, but receive the least attention in the literature. In this context, this article is a call for greater attention to be given to organisational issues in nuclear decommissioning.

REFERENCES

ASN. 2013. *Monts d'arrée EL4 D (Brennilis)*, website of the French Nuclear Safety Authority, http://www.asn.fr/index.php/L-ASN-en-region/Division-de-Caen/Installations-en-cours-de-demantelement/Monts-d-arree-EL4-D-Brennilis (accessed April 2013)

Bayliss, C and Langley, K. 2003. Nuclear Decommissioning, Waste Management and Environmental Site Remediation, Elsevier, Burlington, MA.

Bibi, A., Al-Musawi, F., Jassim, H., Abd Alhadi, Q. 2013. "Decommissioning Challenges of Destructed Nuclear Facilities and Sites in Iraq", *Decommissioning Challenges: An Industrial Reality and Prospects, 5th International Conference*, Avignon, April 7-11

Bourrier, M. 2005. "The Contribution of Organizational Design to Safety", *European Management Journal*, 23, 1, 98-104

François, P. 2013. "Safety Assessment for Decommissioning – An International Approach", *Decommissioning Challenges: An Industrial Reality and Prospects, 5th International Conference*, Avignon, April 7–11

French Ministry of Environmental Protection. 2013. Sûreté nucléaire et encadrement des INB, website of the French Ministry of Environmental Protection, http://www.developpement-durable.gouv.fr/Les-installations-nucleaires-de.html (accessed April 2013)

IAEA. 1988. The Radiological Accident in Goiania, Vienna, STI/PUB/815

IAEA. 2004. Status of the Decommissioning of Nuclear Facilities around the World

Martin, C and Guarnieri, F. 2013. "Decommissioning and Organizational Reliability: Involving Subcontractors in Collective Action", *Decommissioning Challenges: An Industrial Reality and Prospects, 5th International Conference*, Avignon, April 7-11

NEA/OECD. 2002. The Decommissioning and Dismantling of Nuclear Facilities, status, Approaches, Challenges

NEA/OECD. 2003. Decommissioning Nuclear Power Plants: Policies, Strategies and Costs

NEA/OECD. 2004. Managing and Regulating Organisational Change in Nuclear Installations, CSNI Technical Opinion Papers No. 5

NEA/OECD. 2006. Releasing the Sites of Nuclear Installations, A Status Report

Pelleterat de Borde, M. 2013. Contribution à la maîtrise du changement organisationnel et de son impact sur la sûreté : le cas de la transition d'une installation nucléaire du fonctionnement vers le démantèlement, Thèse de doctorat, Mines ParisTech, En cours (2013)

Pelleterat de Borde, M, Martin, C, Besnard, D and Guarnieri, F. 2013. "Decision to reorganise or reorganising decisions? A First-Hand Account of the Decommissioning of the Phénix Nuclear Power Plant", *Decommissioning Challenges: An Industrial Reality and Prospects, 5th International Conference*, Avignon, April 7-11

Perrow, C. 1999. Normal Accidents: Living with High Risk Technologies, New York, NJ, Basic Books

Rodriguez, G., Frith, R., Berte, M. 2004. "General Review of the Decommissioning of Liquid Metal Fast Reactors (LMFRs) in France", *Operational and decommissioning experience with fast reactors, Proceedings of a technical meeting held in Cadarache, France, 11–15 March 2002*, IAEA

TEPCO. 2013. Main Schedule of Mid-and-long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station Units 1–4, TEPCO, http://www.tepco.co.jp/en/nu/fukushima-np/roadmap/images/t120730_03-e.pdf (accessed April 2013)

US NRC. 2013. *Fact Sheet on Decommissioning Nuclear Power Plants*, website of the United States Nuclear Regulatory Commission, www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html (accessed April 2013)