Managing knowledge to improve industrial safety

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Abstract: The capacity to manage risks and maintain industrial safety is largely based on the capacity of various actors to acquire, maintain and share knowledge on a large variety of subjects. The actors are, of course, the plant operator but also the employees, the competent authorities, the external maintenance teams or internal or external experts in charge of risk assessment and design of risk management. The knowledge ranges from the regulatory framework to the details of a machine or a process but also includes the general knowledge about the industrial safety, the hazardous phenomena, or the properties of the substances. Part of this knowledge is also largely tacit. It lies in the brain of the scientific experts or the employees who are able to make the connection between apparently disconnected pieces of knowledge. Detecting, extracting, maintaining and communicating this knowledge are typical knowledge management activities.
The authors have been developing for several years knowledge access tools dedicated to the communication of generic knowledge on the industrial safety. The structure and content of this system is described in the present paper. New developments are now in progress to improve the capacity to retrieve and exploit this knowledge as well as to facilitate the management of specific knowledge. These developments are based on an ontology of industrial safety.
The basic principles for developing and using ontologies are recalled. The process for building such an ontology in the industrial safety domain is then described as well as its use for indexing and searching documents in an industrial safety web platform. Other applications of this ontology are also briefly presented.

Keywords: Safety management, knowledge management, ontology, Internet

1. INTRODUCTION

The issue of the application of knowledge management to industrial safety is not new. The need for a safety related knowledge management strategy was already stressed in 1996 by F. Lees [1] who wrote "knowledge of its processes and plants is one of the prime assets of a company, but the management of this asset often appears to be relatively neglected". Yet, it seems that the link between knowledge management and industrial safety has not been intensively investigated with by researchers in the last decade except for the implementation and exploitation of a learning from accidents system. In the meantime however, knowledge management has become an issue in many companies. It is therefore more than time to study the matter and propose solutions for the companies to manage their safety critical knowledge. An more generally, as safety is a collective concern, it is an asset for the entire society that the knowledge required to reduce the risk caused by the industry be properly managed.
After a short introduction about what knowledge management is, this paper presents a system for the management of generic knowledge through a web resource plate-form. Then it describes a more advanced and complementary approach using an ontology as the main support for the building of a safety related knowledge base. The use of this ontology is briefly described.

2. INTRODUCTION TO KNOWLEDGE MANAGEMENT

Knowledge Management (KM) refers to a range of practices used by organisations to identify, create, represent, and distribute knowledge for reuse, awareness and learning across the organisation. This very broad definition illustrates the large scope of knowledge management in organisations. In this paper, we focus on the need to better manage knowledge in organisations where risks are present and try to illustrate by practical applications how knowledge management techniques can be used to improve industrial safety.

2.1. Managing tacit and explicit knowledge

The knowledge can be described and categorized according a variety of classifications. One of the most famous was introduced by Nonaka [2] and makes the distinction between explicit knowledge and tacit knowledge. Explicit knowledge is the knowledge that is conscious and can be documented. Tacit knowledge is the knowledge that resides in the people's mind in a more or less formalised form, most of the time unconsciously. Nonaka identifies the various operations that can be undertaken on knowledge :

- Transforming the tacit knowledge into explicit knowledge is often called formalisation or externalisation.
- Making explicit knowledge accessible to people who may benefit from it is diffusion.
- Making the explicit knowledge turn into tacit knowledge of actors who will then be able to use it is internalisation.

A complete knowledge management system should be able to perform all these tasks. It should also be able to deal with generic and specific knowledge.

2.2. Managing generic versus specific knowledge

Beside the traditional tacit versus explicit classification of knowledge the distinction between generic and specific knowledge is essential. Generic knowledge corresponds to the general concepts. Specific corresponds to the instances of these concepts in a given context. Competence is the ability to use generic knowledge in a specific context. Many situations illustrate this need to possess generic knowledge that will be used to extract and interpret specific information or knowledge. Among them, risk analysis is the most emblematic. On the other hand, learning from experience, and especially from past accidents obeys to the opposite process. It is specific knowledge that is used to produce generic information that will be used in other context to interpret specific data.
However, there is a large variety of knowledge management system structures and processes answering to a large variety of needs. Designing a KM system requires following a series of steps that will be described in the next paragraphs.

3. SPECIFYING AND IMPLEMENTING A KNOWLEDGE MANAGEMENT SYSTEM

3.1. Specification process

A first approach of the design of a knowledge management system is user-centred. It focuses on the future users of the system, their needs and the way they will use the system. The users are not only the beneficiary of the formalised knowledge but also the actors owning a tacit or explicit knowledge that will be used as input to the system. The following questions are thus in the heart of the design process:

- Who will be the users?
- Which are the various user types?
- What are their characteristics and behaviours?
- What are their goals and tasks?
- In which situations and contexts will they operate the system?
- What types of knowledge is going to be processed by the system?
- What are the tools and organisation already existing?
- What is the life cycle of knowledge in the organisation, how is it validated, when and how does it become obsolete?

3.2 Users and other actors involved in the knowledge management process

The users of a safety related Knowledge Management system could be all the actors involved in the industrial safety management at the various stages of an industrial plant : design, building, operation, maintenance, shutdown, decommissioning. Those actors are, authorities, process experts, risk experts, plant designers, plant builders, plant operators, plant workers, plant management staff, contractors. Their needs are different but they all interact with common knowledge elements and should be able to share common representations, to be aware of risks associated with given substances or equipment and to take sound decisions within the organisation. The authors have introduced the concept of Safety Critical Knowledge (SCK) to describe the type of knowledge involved in safety management of industrial plants [3].

As far as industrial safety is concerned, various actors have a role to play in the setting of a knowledge management system to answer the needs of the industry. Actors with a public mission such as research centres, health and safety institutes, universities, but also some consulting companies or industry research or service centres, are expected to provide generic knowledge. Plant operators and consulting companies use the generic knowledge combined with the plant specific knowledge to manage the risks and the associated knowledge. The ideal knowledge management system could therefore be described as the combination of a generic knowledge management system operated by actors with a public or collective mission and a specific knowledge management system that would be managed for the plant operator by himself or sub-contractors.

3.3 Categories of knowledge to be managed

The structure of a very general Knowledge management process dedicated to safety is described in figure 1. The process involves the acquisition or creation of knowledge, its organization in appropriate structures or systems and the management of these systems, the diffusion of the knowledge to suitable users and their application of knowledge. The systems described in the present paper focus on the organization and diffusion phases. Their initial purpose is to organize and make available the knowledge necessary to carry out the risk assessment of industrial plants.

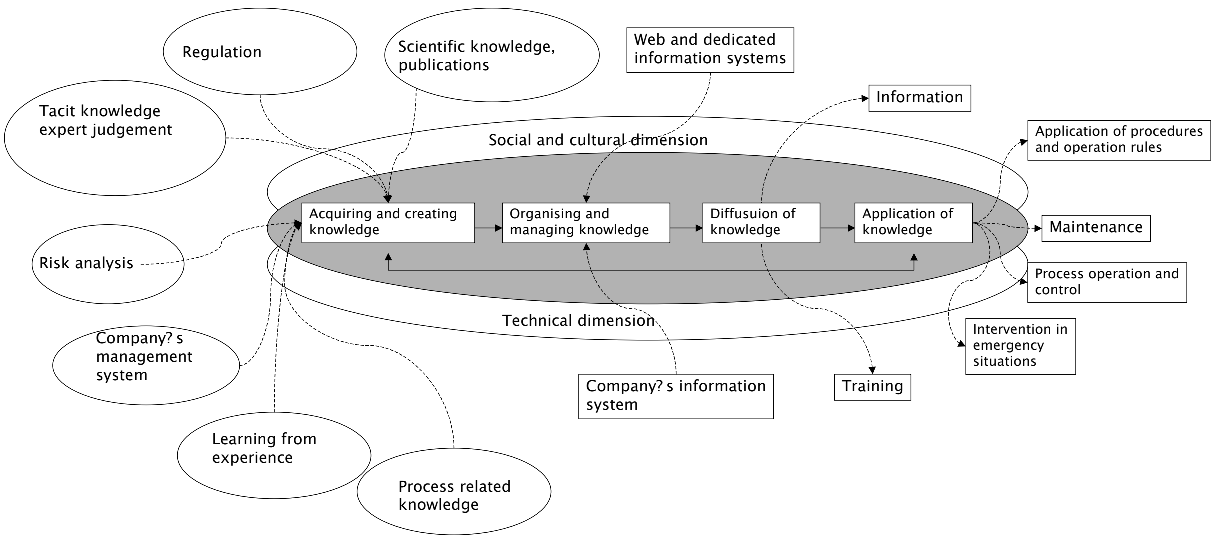

Figure 1 : Structure of a knowledge management process and variety of knowledge concerned by the process.

3.4 Risk assessment : a knowledge intensive task

Risk analysis, and more generally risk assessment, is a knowledge formalisation process in the sense that it consists in extracting tacit knowledge from the participants of a risk analysis work group and turning it into explicit knowledge. Yet to do so, risk analysis also requires that the participants have quite an extensive explicit knowledge both at a specific and generic level. Figure 1 describes the various types of knowledge involved in the risk analysis process. Projects such as ARAMIS [4] have also produced large amounts of risk analysis specific knowledge. A first issue is how to make this necessary knowledge available to the actors. This is partly the goal of a tool like PRIMARISK described below.
As described in figure 1, the risk expert uses a large variety of models and data associated to the various steps of risk assessment processes. To make these models, tools and data available to the risk assessment community, INERIS is presently developing the resource platform PRIMARISK® [5]. It is available on INERIS web site since January 2007. The next paragraphs describe the main features of this web platform and present its basic structure in relation with the needs of potential users.

3.6 Definition of the target users

PRIMARISK was designed as a tool to facilitate mutual understanding between the competent authorities in charge of the application of the SEVESO directive, the industry, plant operators and safety departments and the risk experts, national institutes such as INERIS and consulting companies. Each of these users expects to find validated information and tools that will enable him to perform risk analysis and risk management tasks, but above all, that will be accepted and recognised by the other parties. For this reason, a large part of the knowledge contained in PRIMARISK has been debated within national working groups that were set up by the authorities in 2004 and is the result of a consensus.

3.7 Content of PRIMARISK

The first content is the description of the risk assessment process itself. Whereas the objectives and principles of industrial major accident risk assessment are relatively well defined by the regulation [Arrêté PCIG], the method to achieve these objectives is not fully described.
INERIS, as technical support to the ministry of environment was in charge of designing a risk assessment method, which, even if it's use is not mandatory, constitutes a recognised national reference. This method, partly influenced by the results of the ARAMIS project [4], is fully described in a report available on INERIS web site [6] and is structured according to the following sequence :

- Description of the plant;
- Identification of the hazardous pieces of equipment;
- Selection of the relevant equipment for analysis;
- Risk analysis;
- Identification of the safety barriers;
- Assessment of the consequences of accidents;
- Definition of the safety control and requirements for the safety management system.

Each of these steps mobilises a specific knowledge. The description of the process is explicit but the understanding of which models, tools and data to use is more of a tacit type. The expertise lies in the ability to use the right model for a given hazardous situation. It lies also in the capacity to understand the results of the process. In PRIMARISK®, each steps is first described in terms of objectives. The relevant legislative texts are given together with other reference text, when they exist. Then the tasks are listed. Each of them is described and linked with useful resources and knowledge elements that will ease the risk assessment. The format of expected results is described.

The resources can be of three main types :

- Local resources : PRIMARISK® lists the elements of information that the person in charge of the risk assessment has to obtain from the plant operator such as the maps or process instrumentation diagrams.

- General resources : these are the resources available elsewhere that the user should consult to obtain useful information. Most of these resources are available online from INERIS or other web sites. Among these are databases, documentation, etc.
- Specific resources available directly from PRIMARISK®: These are tools and databases that were developed specially for being made accessible through PRIMARISK®. For example, PRIMARSIK supports a series of computer models for the online calculation of effect distances of hazardous phenomena such as BLEVE, Boil-Over and pool fire. Other models are being developed and should constitute progressively a global tool kit for major industrial risk assessment.

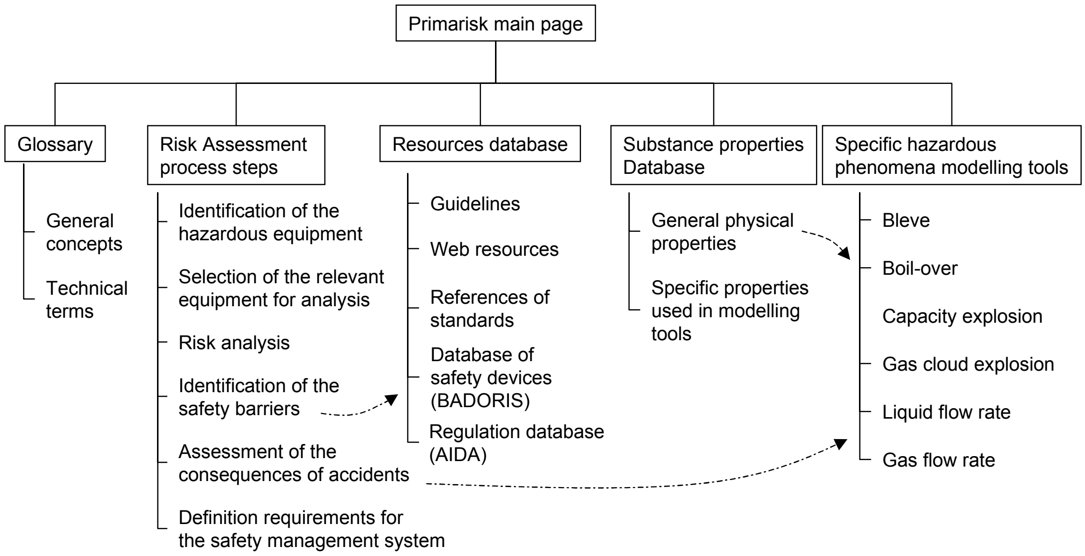

Figure 2 : general structure of the knowledge resource plate-form PRIMARISK®

Figure 2 shows the general structure of PRIMARISK®. The core system was implemented on a MySQL® database and proposes many internal and external links with classical web pages and more specific online software. The system also contains a glossary of more than 300 terms, which are put in relation with the useful documents, resources and tools.
PRIMARISK® is updated on a regular basis and constitutes a generic knowledge management and capitalization tool both for INERIS scientists and the French industrial risk assessment community.

3.8 From centralised to distributed generic knowledge management systems
PRIMARISK® is an example of generic knowledge management tool where experts from a single institution, here INERIS, can formalise and make their knowledge available in a more elaborated format than the usual reports or guides. Its richness lies in the relations established between a variety of resources on a base of semantic content of these resources and of their position in a risk assessment and management process. In the future, it would be valuable that such a tool be fed with expertise from a larger variety of actors from other scientific institutions or administrative or industrial bodies. This would increase the capacity of those actors to communicate and understand each other. The same is true when considering actors from various countries. Experience has shown that risk assessment and management although generally following the same basic principles, were still significantly different in the various European countries. Providing a unified European reference resource repository, filled by a network of European expertise institutions, would be a useful step towards a more harmonised and integrated approach of risk management in Europe. For such a resource to exist it will be necessary to propose a common vocabulary and a common way to structure information. This is the one of the potential objectives of the development of ontologies described in the second part of this paper.

4 DEFINITION OF AN ONTOLOGY OF INDUSTRIAL SAFETY

Ontologies are efficient structures used to formalise the knowledge of a specific domain. An ontology contains a set of concepts of the studied domain organised in a hierarchy of classes and sub-classes along with other relations between them. In practical terms, developing an ontology includes defining classes of concepts, arranging them into a taxonomic (subclass–superclass) hierarchy, defining properties and their facets (constraints). A knowledge base can then be created by defining individual instances of these classes, filling in specific property value information and additional property restrictions.

Developing ontologies has many advantages mentioned by N. F. Noy and D. L. McGuinnes [7]:

- Share a common understanding of the structure of information among people or software agents.
- Enable reuse of domain knowledge.
- Make domain assumptions explicit.
- Separate domain knowledge from the operational knowledge.
- Analyse domain knowledge.

4.1 Process for building an ontology of industrial safety

As described above, ontologies are powerful tools to formalise and reuse the knowledge of a specific domain. This is the reason why the authors have undertaken the development of an ontology of industrial safety. The initial purpose of this ontology was to improve the structuring, indexing and search of knowledge in PRIMARISK. But its aim is broader. It should eventually constitute a reference on which a large variety of actors could base their knowledge management and their communication. In fact, an ontology can constitute the main structure of a knowledge base that contains much more than traditional databases because of the capacity to create an infinity of relations between the concepts and their instances.

To build the ontology of industrial safety, tools were developed to extract terms from the documents produced by INERIS scientists. Experts were then asked to organise this knowledge into classes and subclasses, and to define the properties of classes and their relations. Building the ontology was initiated using the Protégé 3.3 ontology editor and other tools developed specifically [8]. The process is described in figure 3. A first version of the ontology was built and used as a test the elaboration of an information retrieval system. The evolution of this ontology is now continuing as a central knowledge formalisation process.

Describing the structure of an ontology is not an easy task. Our aim was first that the ontology be a good support for indexing documents in a repository. It should then contain all the concepts of the domains described in the resources and documents in the repository. The objective is now to further formalize the domain knowledge through the definition of the properties and relations between concepts in the ontology.

4.2 Hierarchy of concepts

The ontology is therefore first a hierarchy of concepts among which are upper level general concepts and lower level applied concepts. General concepts are, for example risk, hazard, accident. More concrete concepts are, for example equipment, safety devices, documents. For the moment; approximately 500 concepts are defined in the ontology. Figure 1 illustrates the structure of the ontology with a small extract of its present content with terms relevant to the risk analysis of a LPG storage. The structure of the ontology reflects the structure of the concepts involved in the risk assessment process.

4.3 Defining properties of concepts

Once the hierarchy of concepts is defined, the ontology allows to define properties to these concepts. The most simple type of property is the attribution of a numerical or string value to a slot. Physical properties of substances are good examples of such properties. Strings or other types of variables can be used to define the properties, which can be organised in hierarchy.

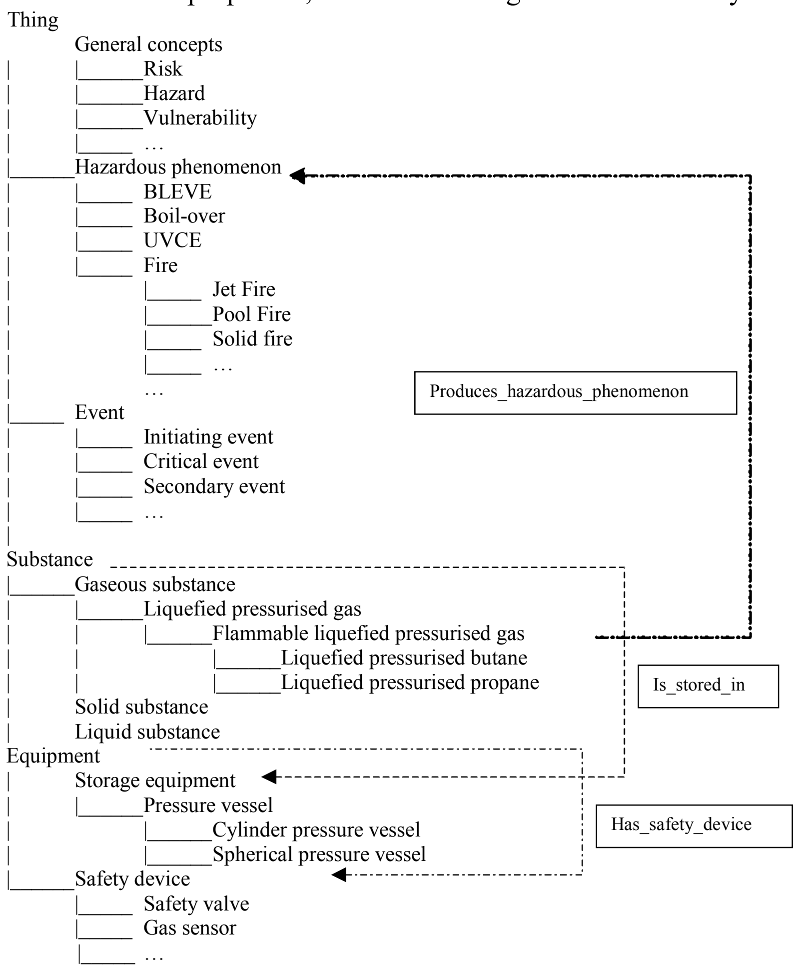

Figure 3 : extract of the ontology of industrial safety showing hierarchy of concepts and relations between concepts

4.4 Defining semantic relations in the ontology

At this stage the structure of the ontology is mostly a hierarchical structure where the terms are related to each other by a so called subsumption relation or is_a relation. The next step of developing the ontology is to define the other semantic relations between terms. Those will be exploited, for example, to navigate in the ontology. They are the expression of the expert knowledge.

For example, the ontology contains the information that propane is a flammable gas. That flammable liquefied pressurised gases can produce the hazardous phenomenon BLEVE. This is expressed by a relation produces_hazardous_phenomenon between the concepts flammable liquefied pressurised gas and BLEVE. Other relations can be defined, such as is_stored_in which is used to described the fact that liquefied pressurised gases are stored in pressure vessels. A relation has_safety_device specifies the types of safety devices which should be present on a given storage equipment.

Eventually, a complete net of relations can be established which reflects the knowledge on a substance or a technology. The user of a system based on the ontology can easily navigate between the concepts and access related knowledge. But the system also allows the description of a specific situation by creating instances of the concepts. For example, when studying a specific plant, it is possible to create an instance of a given equipment to which it is then possible to relate instances of specific safety devices categories and instances of initiating events and critical events. By doing so, it becomes possible to express the complete results of a risk analysis in the ontology, turning it into a powerful tool for the management of the knowledge produced during the analysis.

4.5 Current use of the ontology

A simple ontology-based information retrieval system was developed to improve the search capabilities in PRIMARISK. From a first input of the user, this tool proposes the list of concepts containing at least one of the entered words. The user chooses the concept that suits most his query. Then, a list of related close terms is proposed. A close term is defined as any term having a direct relationship with the initial term. This relation can be an is_a relation but also any other type of relation such as the produces_hazardous_phenomenon relation described in figure 3.
For example, a user entering the keyword "ATEX explosion" will be proposed to refine his query by choosing among "gas explosion" and "dust explosion" but also "overpressure effect" and "thermal effect". This system allows at the same time for a better formulation of the query by the user and offers possibilities of refinement or enrichment of the results. Indeed the user has the choice to limit the search to the specific term of the ontology that best describes his search or to enlarge the results to all the documents linked to this term by a specific relation (close terms).

4.6 New developments

New applications of the ontology are now under development. The first one concerns the identification of suitable safety devices for a given equipment containing a given hazardous substance in a given state. Safety devices are associated to safety functions and to the events potentialy causes of an accident scenario. All these concepts were defined in the ARAMIS project. The ontology provides a suitable structure to capitalize the extensive inventory work that was done in this project. Additional applications are under study to improve the selection of safety devices to ensure its compatibility to specific environmental constraints (temperature of use, humidity, presence of dust…).

5 CONCLUSION

The management of industrial safety requires the use of a large variety of knowledge by many different actors. This knowledge needs to be managed both at a generic level for the entire community and at a specific level in the industrial plants themself. To answer some of these needs, INERIS has set up a knowledge management tool PRIMARISK, which offers a structure to capitalize the knowledge produced by INERIS in its public support mission and make it available to a large variety of users.
The authors have also initiated the development of an ontology of industrial safety which will become a basis for knowledge formalisation and capitalization. The ontology is composed of a hierarchy of the main concepts involved in industrial safety to which are associated properties and relations in a very flexible way. It is presently used to improve the search of information in PRIMARISK but other applications are under development to provide a more general Safety Critical Knowledge management system.

References

[1] F. Lees *"Loss prevention in the process industry",* Butterworth-Heinemann, 1996,Oxford, UK

[2] I.Nonaka, *Dynamic theory of Organizational Knowledge Creation*. Organizational Science, vol. 5, n° 1, pp. 14-37,(1994)

[3] B. Debray, A. Abou-Assali, I. Pradaud, J. Vaudelin, D. Lenne, Knowledge management for industrial safety, generic resource platform combined with an ontology based approach, article accepté pour le symposium Loss Prevention 2007, 22-24 mai 2007, Edimburgh

[4] O.Salvi, B.Debray, *"A global view on ARAMIS, a risk assessment methodology for industries in the framework of the SEVESO II directive"*, J. of Hazardous Materials, vol. 130, n° 3, pp. 187-199. (2006)

[5] B.Debray, C.Joly, M.Merad, O.Salvi*, "Knowledge management and major industrial hazards" : an integrated approach*., Proceedings of the 28th ESReDA seminar, 2005, Karlstad.

[6] C.Joly, "Etude de dangers d'une installation classée", INERIS, 2006, Verneuil-en-Halatte, France

[7] N. F.Noy and D. L.McGuinnes, "*Ontology Development 101: A Guide to Creating Your First Ontology*." Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics, Technical Report SMI-2001-0880, 2001.

[8] Abou Assali, A., Lenne, D., and Debray, B. "*Ontologies for Industrial Risk Analysis*". In proceedings of the IEEE International Conference on Information & Communication Technologies: from Theory to Applications (ICTTA'08), Damascus, Syria. (2008).