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**The D&D of Nuclear Facilities: a Systemic Approach for Project Organization and Monitoring - 18099**

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**ABSTRACT**

The Decontamination and Decommissioning (D&D) of Licensed Nuclear facilities takes place under circumstances which make it a very complex field. On the one hand, more and more facilities of widely varying types are concerned, and many D&D projects are currently running or planned. A nuclear facility's life cycle is often very long and the building may be modified or impacted by incidents during its operation. These changes need to be known and taken into account for the D&D plans, in order to ensure safety at all times. In addition, the numerous stakeholders involved in a project express needs which impose many requirements. These encompass various points of view, and data from different detail levels must be managed to satisfactorily meet them. On the other hand, legacy data (including records, plans etc.) is a recurring issue for D&D projects. The quality and availability of relevant data regarding the different phases of the nuclear facility lifetime may be insufficient, for instance due to the lack of traceability practices in the past. The uncertainty level is not always specified and explained, old documents can be damaged and are not necessarily digitized, etc. It is therefore particularly important to define the relevant type of raw data to be collected and traced for D&D projects as early as possible.

In this context, CEA (Commissariat à l'Énergie Atomique et aux Énergies Alternatives) has been analyzing past D&D projects for many years. The goal is to facilitate reproducibility by generalizing best practices and promoting efficient organizational rules and technical solutions.

A method is currently being studied to help project managers to prepare specifications for future D&D operations and improve both the efficiency and the relevance of the decommissioning strategy throughout each project, depending on the expected quality of its end-state. This method first consists in formalizing and specifying the entire set of requirements to be taken into consideration, *e.g.* technical, operational, logistical, regulatory, financial, organizational, safety and security, human, ethical, or, naturally, environmental aspects. Second, based on these requirements, it will enable the project team to structure, check, and then to demonstrate the coherence and feasibility of the project from both the technological and organizational points of view. Lastly, the method will enable the evaluation of the various possible solutions for the management of dismantling products, for instance, regarding the waste outlets: direct disposal or interim storage. To conclude, the method should permit a constant re-evaluation of the D&D strategy depending on the possible evolution of the stakeholders' requirements, and thus it should optimize the monitoring of D&D projects.

**INTRODUCTION**

The purpose of the work described in this article is to increase the reproducibility and the automation of the procedures implemented during future Decontamination and Decommissioning (D&D) projects. The objectives included improving the performances of future dismantling operations in terms of scheduling, cost and performance, for the operational aspects as well as the management and piloting of such operations. At the same time, all the requirements imposed on D&D, formalized or not, must be respected, while targeting this purpose.

Today each D&D worksite project is considered as a special case, except from civil power reactors, even though there are several common points, which enable to provide feedback and standards. The work presented here therefore seeks to develop, provide appropriate tools, and validate *in situ* a method to

describe, analyze and help in the piloting of a D&D project. In order to move efficiently towards the application of this method, the support tool includes the development of modeling and analysis tools which will then be integrated around a single interoperable data base working with the information systems of the stakeholder companies involved in each of the projects.

The objectives of the method are to modify and improve current approaches to D&D project piloting:

- through the adoption of a systematic and holistic view and through a model-based approach (modeling all the dismantling from several points of view or “dimensions”). This enhances the overall taking into account of the parameters involved in a D&D project, particularly by facilitating both the understanding of the initial state and the traceability of the input data, a precise upstream specification of the final state targeted, and the description of all the stakeholders needs, and all the processes and interfaces involved during the project during the different stages of its life cycle;
- by assisting the decision-taking and giving a wider view for strategic management of projects, through particularly the whole set of requirements applicable to D&D projects;
- by supplying modeling patterns to assist each project design and carrying out, and guide the design and the creation of an information system which will be shared within the extended enterprise – i.e. all the project stakeholders – sharing and further ensuring the availability of all the data, information, and knowledge, making use for example of technologies such as BIM (Building Information Modeling). Hence the need to be associated with a single interoperable data base, simplifying the management of data, information, and knowledge.

The method to be implemented must therefore consider a certain number of inputs. It must take into account the needs (expectations, constraints, etc.) expressed by the stakeholders involved in a dismantling project, likely to be actively or passively impacted by whatever decision is taken. It must also consider all the data specific to the facility to be dismantled and to its environment, which could also have an impact. Finally, it is important to refine all the needs and constraints into a repository containing all the requirements applicable to a dismantling project. These requirements are of all types: *e.g.* technical, operational, logistical, regulatory, financial, organizational, safety and security, human, ethical, or environmental.

The method must also be able to suggest outputs in order to reach the objectives targeted. It will provide a set of models linked to a D&D project: *e.g.* process models synchronizing the operations to carry out, requirement repositories, or many diagrams which will describe the facility to be dismantled, its lifetime, past, configurations, etc. The method must also facilitate the various potentially complex simulations and analyses needed to verify and validate these models, and to establish and guarantees the traceability and the interoperability of the many components they contained.

Finally, in order to guarantee the method’s efficiency, it is primordial to consider the evolutionary dimension of a dismantling project, taking into account incidental and accidental situations. The models need to be sufficiently open to allow regular updating during a project, so that it remains as reliable as possible.

## **THE METHOD**

To reach this goal, formalization and theoretical work has had to be undertaken to provide the bases for this method. They must be coherent, comprehensive and reproducible in an industrial context. Firstly, the sticking points were identified. A sticking point is one of the causes of a problem detected, for instance in current practices or in worldwide project feedback, which has led to issues to reach the purpose of the method. Indeed D&D must implement different changes, both organizational and technical, in order to lead to increased reproducibility and process automation, taking into account the additional opportunity now offered by digital technology. The sticking points identified can be conceptual, organizational,

technical, economic and human. Overcoming a sticking point thus involves combining various skills within the D&D field in order to finally be able to build this method (*Fig. 1*).

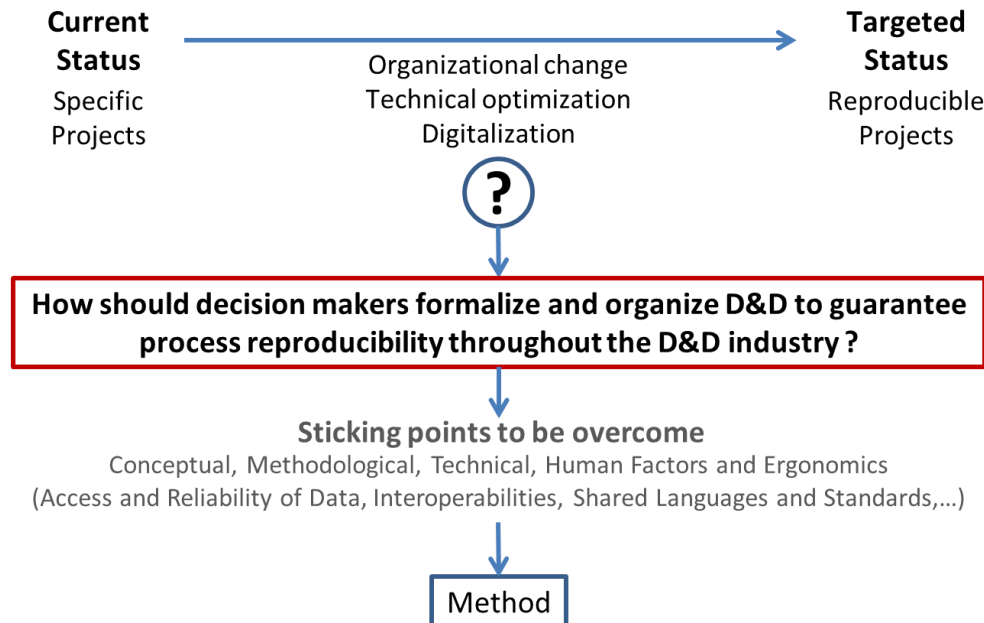


Fig. 1 – D&D, a significant changing field

Thus, a systemic and systems thinking approaches is studied as a support for the design and implementation of this method. These approaches, especially thanks to systems engineering and more specifically MBSE (Model-Based Systems Engineering), enable the building of a formalized representation of a so-called “*D&D system*”. Such a *D&D system* is defined as “*a set of elements of various and heterogeneous nature that interact in order to decommission a nuclear facility*”.

With these approaches, the method then permits the creation of a model of this *D&D System*, which implements a set of concepts through some coherent and consistent views, which must be considered both from the technical and organizational angles:

- functional view, to model required activities, processes, resources and capabilities;
- physical view, to model technical means, tools and techniques, and their interactions during D&D operations, as well as the particular skills and know-how to be put in practice;
- behavioral view, to model both the various scenarios describing the numerous future project evolutions, and the various configurations and functioning modes of the nuclear facility to be decommissioned;
- risk management view, to model various events that could occur and to evaluate their impact on the project, on the resources involved and so on;
- requirements management view, to model and check the entire set of requirements for the *D&D system*. In particular, it is mandatory here to give details concerning the requirements and the constraints related to each type of waste to be handled and taken into account.

First, all the concepts and relationships required to achieve and detail each of these views are gathered, then syntactically and semantically described in a meta-model [8]. This meta-model remains open to new concepts. It is modifiable and adaptable considering, for instance, the nuclear facility type. Moreover, it enables the specification of a set of ontological resources, and it has to ensure cross-knowledge

management for all the D&D stakeholders. In other words, a unified vocabulary must then emerge from this meta-model.

Domain Specific Modeling Languages (DSML) will then be defined based on these concepts for each previously described view. These DSML must be ergonomic and understandable by experts from various business fields who are not necessarily familiar with the modeling domain.

It is therefore important to also set up an approach containing some processes which enable to guide each stakeholder involved in a project to model parts of a specific *D&D System* (and consequently its associated facility, as detailed in the next part of this article) then to verify and validate scenarios by *e.g.* simulations. Particularly project managers will then be able to model *D&D systems* and share their models throughout the project (*Fig. 2*).

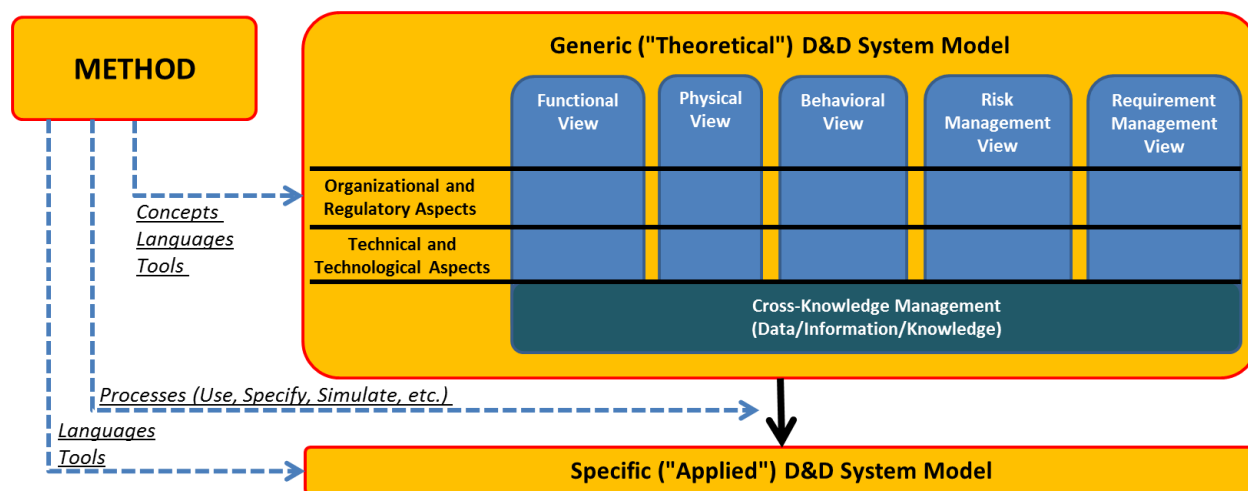


Fig. 2 – General presentation of the method

### THE APPLICATION CASES OF THE METHOD: THE NUCLEAR FACILITIES

In order to build the meta-model, the different concepts enabling the definition and formalization of the D&D field must first be examined. It was therefore firstly a question of formally specifying a certain number of parameters applicable to the *D&D System*: its application cases, its purpose, its missions, functions, structure, organization, context, boundaries, environment, etc.

The work presented hereafter applies to French regulations but the method then designed is open and may be applied in other regulatory frameworks.

D&D applies to all nuclear facilities, under the definition which was initially given in Europe by the OECD-ENEA (now OECD-NEA) at the Paris Convention on Third Party Liability in the Field of Nuclear Energy [1]. In France, there are three types of classification for these facilities: nuclear ICPE (Installation Classée pour la Protection de l'Environnement, or Facility Classified for Environmental Protection), INB (Installation Nucléaire de Base, or Basic Nuclear Facility) and INBS (Installation Nucléaire de Base Secrète, or Secret Basic Nuclear Facility).

The SoI (System of Interest: "*system whose life cycle is under consideration [...]*") [2]) for a dismantling project is usually an INB, which represents the majority of French nuclear facilities. The difference between an INBS and an INB only depends on whether the facility has had confidential activities or not. Otherwise, the two types are comparable and therefore the method designed by the CEA will also be able to be applied to the INBS with little modifications. For a nuclear ICPE, on the other hand, there is a far lower level of nuclear safety risk related to the type of radioactive matter which is handled and consequently fewer constraints are imposed on a dismantling project. The ICPE have therefore not been taken into account in designing the method. Later, an analysis of the differences between INB and ICPE

could be proposed, in order to assess what aspects could be re-used and to what extent the model could need to be simplified to be applied to an ICPE.

Furthermore, the INB have their own classifications (type *e.g.* nuclear reactor or radioactive waste storage facility, and category indicating the level of risks which it presents) defined by the French Nuclear Safety Authority (ASN) in decision 2015-DC-0523 [3].

A nuclear facility can be formalized as a system which will require classically the existence and interaction with a certain number of Enabling Systems (“*system that supports a system-of-interest during its life cycle stages but does not necessarily contribute directly to its function during operation*” [2]), which contribute to carrying out its missions during the different phases of its life cycle. Thus each nuclear facility will have its own system for the design and the construction, its own system for operation, and its own system for dismantling (Fig. 3). It is important to note that the system for operation is going to continue to act on the nuclear facility during its dismantling phase. Even though the nuclear facility is shut down, it continues to carry out some of its operational missions such as containment, through services rendered by the system for operation (nuclear ventilation, monitoring, etc.). As a result, a certain number of constraints imposed by these interactions will be translated into requirements for the system for dismantling.

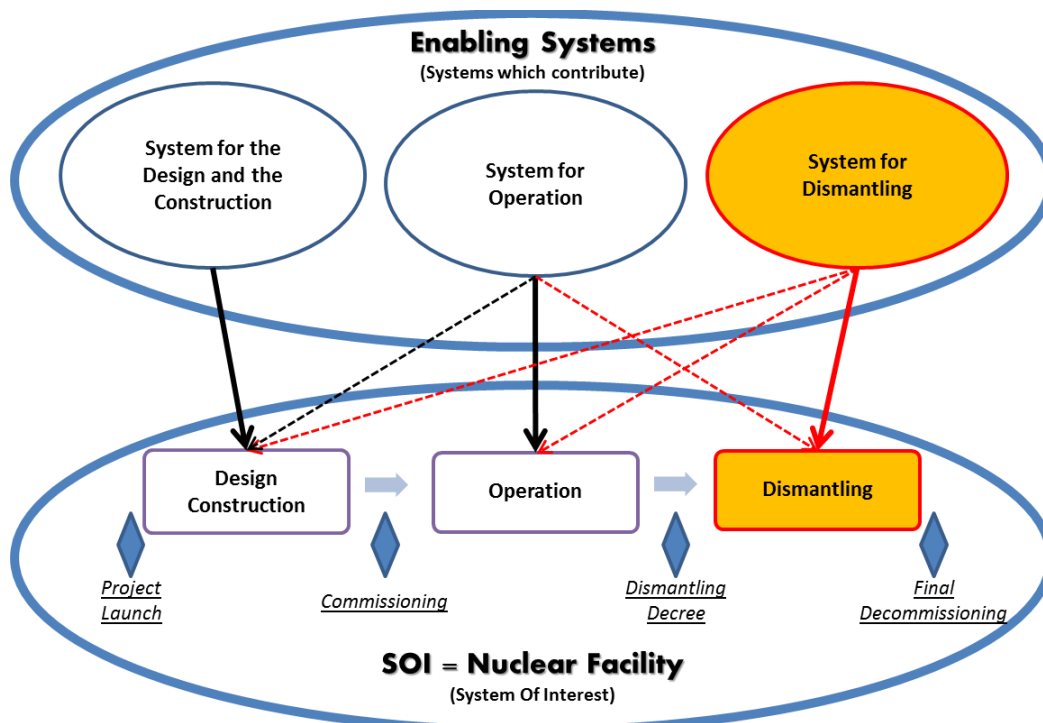


Fig. 3 – The enabling systems of a nuclear facility

### PRESENTATION OF THE D&D SYSTEM

In fact, one system for dismantling can be considered as several *D&D Systems* which could exist for the same nuclear facility, which correspond to several dismantling projects carried out successively at several decommissioning levels – predefined upstream in the project – and this could go through to the final decommissioning, leading to the complete remediation of the facility. Like any system, a *D&D System* has a purpose, *i.e.* its reason for existing, what it was designed for. Given that it is intimately linked to a given dismantling project targeting a pre-defined end state which may be different from the final decommissioning, its purpose has been defined as follows: “*Reach an end state for a nuclear facility*”

compatible with pre-defined future uses, while guaranteeing the compatibility of all produced waste with the existing waste routes”.

The method is therefore going to consist in creating an instance of a *D&D System* for each dismantling project from the meta-model (generic model), and then enriching it with its own special features (*Fig 4*).

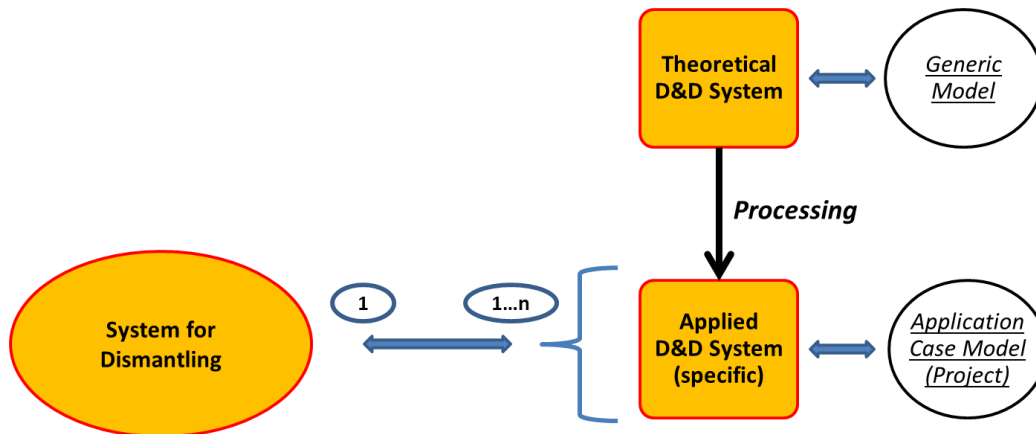


Fig. 4 – Formalization of the “*D&D System(s)*” for one Nuclear Facility

The *D&D System* must accomplish several missions, which correspond to the services rendered to reach its purpose. These have been defined as shown in TABLE I.

Finally, a *D&D System* must reach a certain number of objectives, which precise the quantified or qualified performances expected of it when it fulfills its missions, and which are of different types (economic, timing, quality, safety, etc.)

Type of Mission	Mission Description
Decisional	<ul style="list-style-type: none"> <li>• Draw up scenarios: characterize, simulate, decide and schedule</li> <li>• Pilot the nuclear facility dismantling operations</li> <li>• Launch and pilot the final shutdown and the post-operation clean out [6][7]</li> <li>• Organize waste management</li> <li>• Adapt the missions and operations to deal with contingencies and strategic changes</li> </ul>
Informational	<ul style="list-style-type: none"> <li>• Ensure the targeting, processing, sharing and security of the data, information, and knowledge related to a nuclear facility and its ongoing dismantling</li> <li>• Build and distribute the feedback from a dismantling project in order to guide and inspire those responsible for other projects</li> <li>• Schedule and manage the required training for all involved stakeholders</li> </ul>
Operational	<ul style="list-style-type: none"> <li>• Carry out the data acquisition operations and the studies</li> <li>• Carry out the operations for final shutdown, post-operation clean out [6][7] and actual dismantling of a nuclear facility</li> <li>• Prepare the dismantling plan and files to give to the competent authority</li> <li>• Characterize, sort, condition (dimensional re-sizing and appropriate radiological measures) and carry out the transfer to storage, repository or recycling facilities for all the waste (radioactive and conventional)</li> <li>• Prepare the request for the decommissioning of a nuclear facility</li> </ul>

TABLE I – Missions of a *D&D System*

A *D&D System* and its associated nuclear facility are tightly linked and then interdependent, for instance as concerns their respective lifetimes (e.g. for an *Fig. 5*). Just as each nuclear facility represents a special

case, the *D&D System* associated with it must be highly specific. Because of all the phenomena which may arise during a facility's lifetime, this *D&D System* must be able to anticipate right from the launching of a construction project [4], and be able to adapt dynamically case by case, ideally at any moment. In fact, it is this strong linking which means the *D&D System* and the nuclear facility give each other the role of an "*Enabling System*".

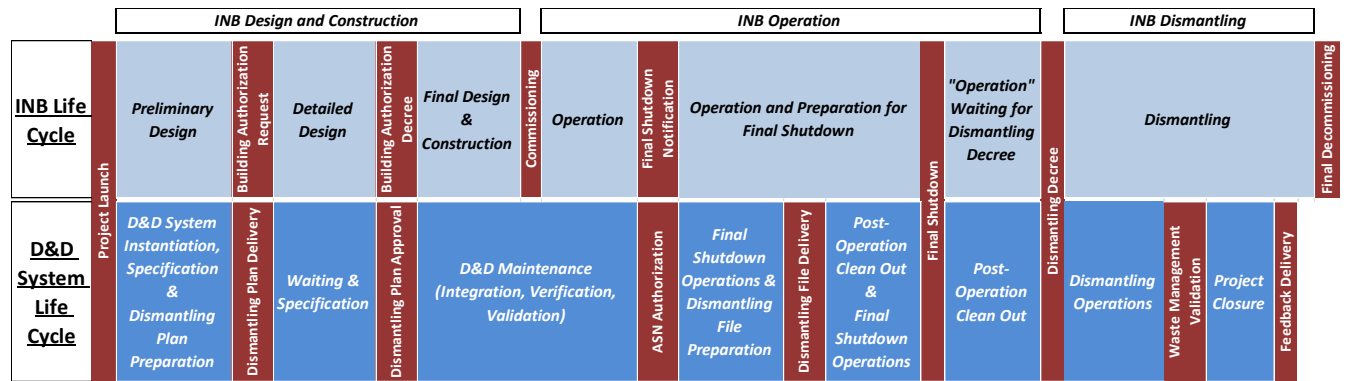


Fig. 5 – INB and *D&D System* Life Cycle

### INTEGRATION IN A GLOBAL D&D SYSTEM

Apart from the interactions taking place with the nuclear facility concerned, each *D&D System* also interacts with many other systems related to regulations, waste management, standardization and certification, etc. Each of its relationships means a certain number of services supplied and/or received – e.g. the ANDRA (Agence Nationale pour la gestion des Déchets Radioactifs – National agency for the management of radioactive waste) must "provide the specifications relating to the existing disposal sites" – which directly involves the requirements which impact the design of the *D&D System*. Because there are certain transversal requirements for all dismantling projects, such as the generic constraints for radioactive waste shipments or regulatory constraints (e.g. requests to obtain a dismantling decree must be spread over time in order to be able to be dealt with in the planned timeframe), it is necessary to coordinate all the *D&D Systems*. This gives rise to a *D&D Strategic System* (DDSS), whose purpose is to "ensure the transversal control of D&D projects and external relationships", and whose missions are to "coordinate, schedule and pilot the *D&D Systems*. Establish strategies with external stakeholders. Collect, organize, and supply feedback to the *D&D Systems*."

A super-system, the *D&D Global System* (DDGS), is therefore considered. This encompasses the entire field (Fig 6). Its mission consists in ensuring the continuous improvement of the D&D industry in order to guarantee its competitiveness and its sustainability. The DDGS is nevertheless reduced to the projects concerning a single operator (here, the CEA) for a number of reasons: independence of their operational management, strategic and organizational independence, etc. In fact, other *D&D Global System* can be considered for other operators – e.g. AREVA or EDF in France – and their model would be analogous, with the same final objective, the same missions, and the same interfaces.

Within this DDGS, the separation of the *D&D Systems* from the DDSS depend on strategic, tactical, and operational considerations involving more particularly the different services received and supplied from the systems at the interface. This consideration is based on a decisional hierarchy. Any strategic decision must be given priority on tactical, then on operational levels. A transversal decision concerning projects, which is often of a strategic nature, generally means giving a priority to each project decision. This is why the *D&D Systems*, in charge of managing specific dismantling projects, act on the tactical and operational levels. These levels are taken into account in describing the interactions within the super-system as well as with the interface systems.



To give an example, the Waste Management Industrial Program (Programme Industriel de Gestion des Déchets, PIGD), developed jointly by ANDRA and waste producers involved in the CIGEO deep geological repository project [5], constrains waste flows towards their destinations quantitatively and in scheduling, and acts transversally across projects. Elsewhere, project decision-makers and subcontractors also communicate their needs concerning management of the waste they produce. Nevertheless, the requirements related to the constraints imposed by the PIGD are considerably less flexible than those related to each project, and therefore must be taken into account as a first priority during the design of a *D&D System*.

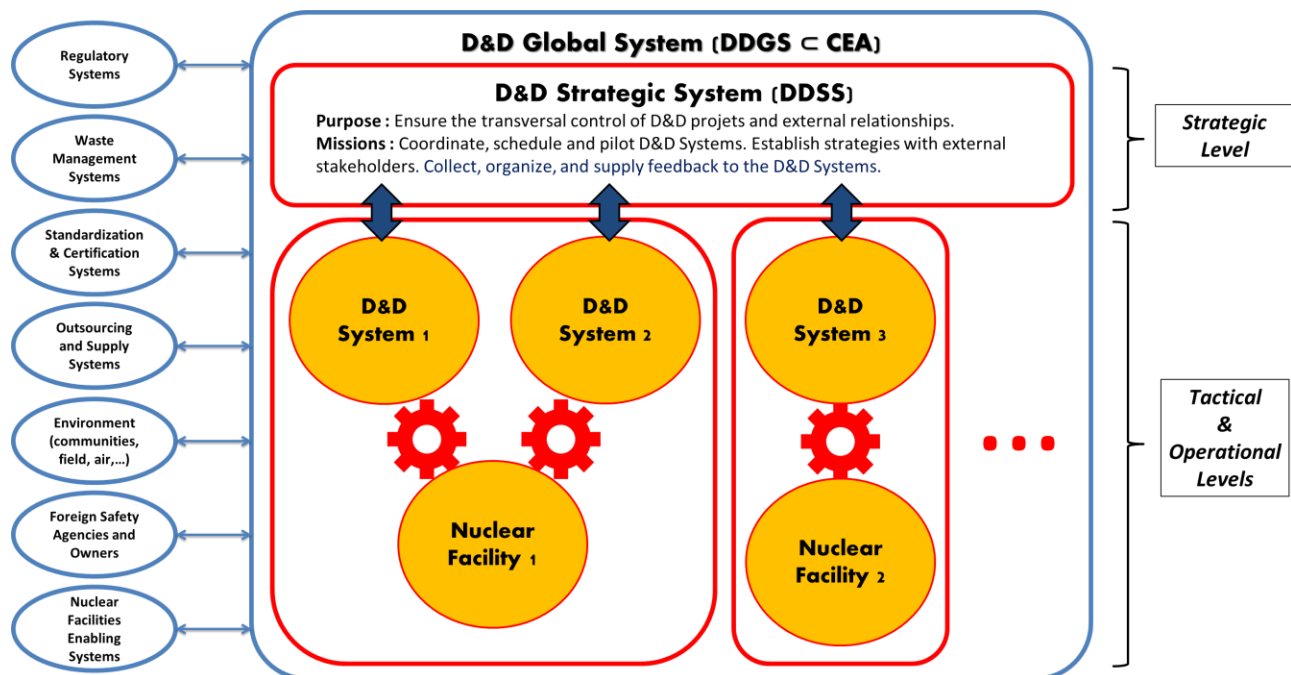


Fig. 6 – The D&D Global System and its relations

Carrying out this division enables the perimeter of the *D&D System* to be further formalized, and therefore enables more accurate specification of its missions, its constraints on the interfaces, etc. In order to obtain all the services received and supplied by a *D&D System*, it is necessary to consider and model all its operational contexts (e.g. operations during final shutdown imply different stakeholders, activities, interactions at the interface, etc. than during actual dismantling) throughout its lifetime, during which it will interact differently with a certain number of systems at the interface.

## PERSPECTIVES

Thanks to the design work which has been carried out and briefly described in this article, representing the result of dismantling analysis and formalization, the meta-model given (Fig. 2) is gradually being built. It is receiving feedback from completed dismantling projects, in order to be enriched by specific knowledge related to different dismantled facilities. This contributes further information to the consideration of the issues related to the special features of each facility, and thus enables to build the "enrichment" approach which will detail more specifically the applied *D&D systems'* models.

As the operating phase may be very long, and major technical constraints are imposed by the technological challenges of nuclear facilities during their construction, it can be difficult to anticipate dismantling-related issues in the early stages. By targeting the data of interest to collect especially thanks to the set of requirements applicable to a *D&D System*, the method will enable very early specification of the necessary input data, well before the actual dismantling operations. Traceability of this data must be

ensured. This will permit very precise specifications to be prepared right from the design phase of a nuclear facility, during which a dismantling plan must be written.

## **CONCLUSION**

The D&D of nuclear facilities is currently evolving rapidly, and the increasing number of such facilities reaching the end of their lifetime has a high impact on the overall future of the nuclear field. Many challenges are arising today, among which we find the unitary reduction of costs, the management of dismantling waste, and the high safety stakes which are concerned. The situation imposes a need to move away from the idea of specific individual projects by working instead with an all-encompassing reproducible industrial vision, though without denying the differences which of course exist between each nuclear facility. To achieve this, a reduced automatic upstream design phase using complete sets of appropriate input data, targeted depending on the applicable requirements and sourced in a single data base composed of a global reference of D&D elements must be considered. The method currently under development will consist of building the relationships which exist between the requirements applicable to a dismantling project – both generic and specific – and the data, information, knowledge, resources and procedures necessary and available in this data base. The set of applicable requirements must also guarantee interoperability within the extended enterprise of D&D projects, by considering all the roles, skills, and trades involved, and their relationships.

Moreover, having a method which permits the tracing and visualization of the interdependence links between each requirement and the functions, components, behaviors, operational modes, etc. and all the associated parameters, will facilitate adapting to each new situation, whether it be controlled automatically or not. For instance, in the case of a modification, it could be possible to add or delete an aspect of a requirement (*e.g.* should there be a modification to the constraints concerning a waste route, a standard, etc.), and automatically retrace all the related impacts on the model. This will facilitate such impacts being taken into account and, if necessary, the specifications for action plans to implement will be more easily prepared.

Finally, a model applied to a dismantling project and the knowledge of all level of flexibility for all the requirements applicable can aid in decision-making regarding the choice of the most appropriate dismantling scenario, based on the different feedback. It can also help, to a lesser extent, in taking decisions as to the future dismantling strategies to implement, including questions related to the sorting, conditioning and management of waste.

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