

A contribution for dismantling of nuclear facilities: a functional pattern for dismantling operations and indicators design and management

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Abstract. Optimizing nuclear installation decommissioning and dismantling operations is an ongoing quest. Faced with the complexity of this activity, Model Based System Engineering promotes relevant principles and modeling techniques. It motivated the definition of a functional generic pattern model of the waste package production line and the decommissioning of the facility. It proposes a global and generic functional architecture of such a system aiming to reduce the level of the pollutant. This pattern is coupled with a process of logistics. Six functions are combined to define this functional pattern. The application of this pattern model to a case of waste recovery in a pit shows the relevance of the model-based system engineering approach, reducing the weight of the history in the development of scenarios by optimizing the control means for nuclear safety and product quality.

1 Introduction

Nuclear facility dismantling is an industrial activity whose products are *waste packages and cleaned-up structures* [1,2]. The wide diversity of pollutants and of the nuclear facilities themselves (reactors, research laboratories, spent fuel reprocessing factories...) has generally meant that the preparation of de-pollution scenarios depends on the type of facility involved [3,4]. As a result, there are no or very few systematic approaches for helping the definition of requested dismantling operations and flows (data, material, and energy) that are then exchanged between these operations [5]. This situation opens up numerous perspectives for nuclear facility dismantling engineering [6]. We consider particularly hereafter principles provided by the Model-Based System Engineering [7] approach. Indeed, it offers combined inputs from strong system concepts, from the use of modelling activities, modelling languages and tools as a support for exchanges between different trades, and from confident iteration by promoting model checking and validation then system evaluation by using these models. MBSE advantages have already been recognized in many other fields, including avionics, transport, health... In the nuclear field, it is a way we suggest generalising dismantling scenario definition, modelling and validation prior to examining standard equipment, and evaluating sources of savings, performances, and safety.

The proposition outlined here is based on two hypotheses:

- A so-called “dismantling system” is defined in Section I. It allows defining i.e. modelling and checking rigorously, sharing between all stakeholders and validating, then operationalizing and managing dismantling projects (i.e. set operations, resources, means, risks analysis, etc.).
- The management of such operations is based on a single indicator as proposed in Section 2.

This paper presents an innovative contribution to the nuclear dismantling field. It consists of defining and formalising then proposing to all stakeholders being involved in such projects what must be the more logical arrangement of such operations and with which main indicators must be managed all along the project. The set of operations represents the functional architecture of the de-pollution system that must be as possible generic, flexible and adaptable to various kinds of nuclear installations to be dismantled. It is then a question here of the equivalent of Design Patterns [8] for Nuclear Decommissioning and Dismantling operations. The result that emerged is applied to the retrieval and the conditioning of waste stored in a pit as presented in Section 3.

Last, and before concluding and setting some perspectives, Section 4, the so-called “system model” for dismantling systems has been the opportunity to question the role of the facility’s industrial history in the definition of functional dismantling scenarios. More specifically,

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it raises questions as to the alignment of the historical content with the requirements for dismantling operations. The proposed approach eliminates the necessary mastery of industrial history. It complements the work carried out considering Model Based Systems Engineering principles (MBSE) and Systems Engineering (SE) by focusing on a functional analysis [6], an analysis close to the business lines.

2 Problematic: nuclear facility dismantling

Dismantling a nuclear facility is a de-pollution operation [9]. The French Nuclear Safety Authority (ASN) supports such an approach [1] and its Guide [10] specifies the method to be used in reaching the decommissioning objective. The de-pollution activity must make strategic choices. For example, [9] describes the advantages of immediate dismantling, which favours profiting from existing knowledge about the facility, a position in line with the ASN doctrine.

Whatever the strategic choice is decided on, two types of requirements must be mainly considered in order to manage these operations. The first type concerns nuclear safety. The second type is imposed by budget limitations. A priori, these concerns can oppose each other [11] interpreting a safe operation is assumed to be costly. In France, dismantling is carried out within an extended ecosystem of enterprises [12], and is therefore seen and represented as a system of systems [13]. Indeed, each enterprise is and remains autonomous in terms of decision and strategy all along dismantling duration, being then considered as one of the often numerous and heterogeneous Stakeholders of the dismantling. This induces technical, human and economic interactions [14] among all the stakeholders, often sometimes complex [15].

The de-pollution of complex older facilities, with the risk of discontinuity in historical knowledge due to the strategic and organizational choices previously made, or yet again the seeming antagonism between the two types of requirements, does not favour establishing common ground among all the different stakeholders. Nevertheless, it is necessary to find an equilibrium in order to design and qualify the de-pollution operations, in confidence and in a harmonious way. This fact has motivated the definition of a set of “simplified requirements law” or “shared temporal observables”, to facilitate and make durable the requested cooperation among the stakeholders.

2.1 An evolution of the activity through time

The concentrations and the levels of pollutants in the facility are measured using radiation protection or gamma camera instruments (Fig. 1) [16]. These qualify the operational objective, i.e. the target for the de-pollution actions [17] proposes the concept of “surgical dismantling”. In this, the concentration points are identified, and then removed, optimizing the decontamination factor. Such operations efficiently reduce the impact on human health, and therefore meet the nuclear safety requirements.

The approach is then to consider that managing the level and the distribution of radioactivity in the facility meets industrial performance criteria in an *economic context which is as reasonable as possible, and safe*.

This option facilitates exchanges among the stakeholders because relevant shareable indicators have been identified. The indicators retained come from lessons learned [18], either during a facility operation phase or during its dismantling.

The health quality of the scene within the limits of the image on the right in Figure 1 is qualified based on three indicators: the contamination ($\dot{A}$: activity, Bq, image on the right), the irradiation ($\dot{D}$: dose rate in mGy/h, table in the center), and the concentration of fissile matter ($\dot{C}$: mass of fissile matter, g).

A facility examined with these indicators is a temporal series with each variable $\dot{A}$, $\dot{D}$, $\dot{C}$ indexed by a spatial ensemble S . The temporal series resembles mining prospection with an ensemble of measurements for each variable in: $S, S \subset \mathbb{R}^3$.

Each variable $\dot{A}$, $\dot{D}$, $\dot{C}$ is a real random process, for example: $A = \{A_s, s \in S\}$. A is a measurable function: $A: S \rightarrow \mathbb{R}$ with a real value. The location of the site $s \in S$ is generally associated with a piece of equipment or perhaps waste.

The variables $\dot{A}$, $\dot{D}$, $\dot{C}$ are dependent. The constraints, i.e. the dose rate, contamination, and concentration of the mass of fissile matter, are dependent on the activity: A (Bq). More specifically, they are a function of the activity. The de-pollution is therefore managed based on a state of variable A at a given moment t whose object has been modelled by a minimisation function f . The de-pollution function: f if $S \subset \mathbb{R}^3$ is therefore:

$$\begin{aligned} t &\rightarrow f(t) \\ f(t) &= \min(g(\dot{A}(t))) \end{aligned} \quad (1)$$

where, $\dot{A}$: activity of the source term in Becquerel (Bq).

The de-pollution becomes an operation for the reduction of the radioactivity level ($\dot{A}$, Bq) retained or contained in a facility (Fig. 2).

Several conditions are checked: $A_c < A_s$. Generally, the solution resembles: $A_c \ll A_0$. The variation of activity through time: $\Delta\dot{A}(t)$, depends on the radioactive half-life ($T_{1/2}$) and on the results of the depollution operation. These depollution results, or objectives, are indexed by the overall decontamination factor: $FD(t) = \frac{\Delta\dot{A}(t)}{A_0}$. The steps are simulated based on: $\dot{g}(\dot{A}(t))$, $A \in [A_0, A_c]$.

$$A_i \in [A_0 + k \cdot \sigma_{A_0}, A_c - k \cdot \sigma_{A_c}], \text{ where:}$$

A_0 : Total radiological activity (source term) evaluated during the inventory phase. This is the activity present before the dismantling operations begin.

A_c : Activity target for the depollution operation.

A_s : Cut-off value, final depollution requirement imposed by the legislator or the regulator.

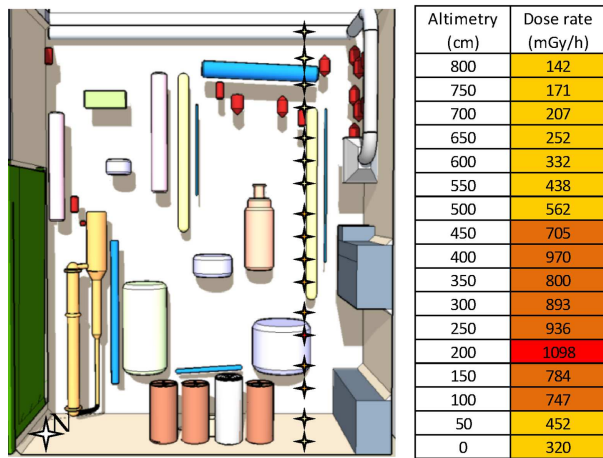
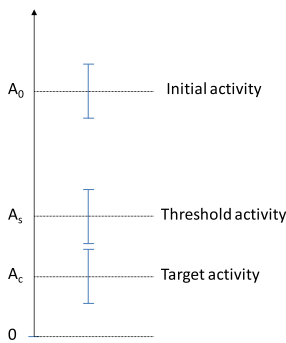


Fig. 1. Left and centre: dose rate measurement results following the Z axis. Right: composite image of the scene – overlap of a visible image and a gamma camera acquisition (blue through to red zones) – installation in the nuclear fuel cycle [18].



Decreased radioactivity is also the consequence of radioactive decay. Therefore, two possible strategies can be envisaged. The first consists of starting the de-pollution process after the radioactive decay of the radionuclides [19]. This implies a period of facility mothballing or a decay period. The second, in the case of radionuclides with a radioactive half-life longer than 30 years [9], radioactive decay has little or no influence on the decrease in the source term, and there would be an inevitable loss of the knowledge and know-how accumulated during the facility operation phase [20]. Depollution operations should then be undertaken as quickly as possible after the final shutdown of the facility.

The initialization of the minimization equation (1) by A_0 and managing the radionuclide quality is therefore a strategic aspect.

These elements are often accepted by all the stakeholders. They group stakeholder interests in the form of single shared, measurable indicators. Even more, they represent a “requirement function” for the industry [21]. The function therefore structures the system engineering approach based on an optimization of industrial performance and of nuclear safety.

These first structuring elements give rise to an operational view, in the form of a logistics chain for the Bec-

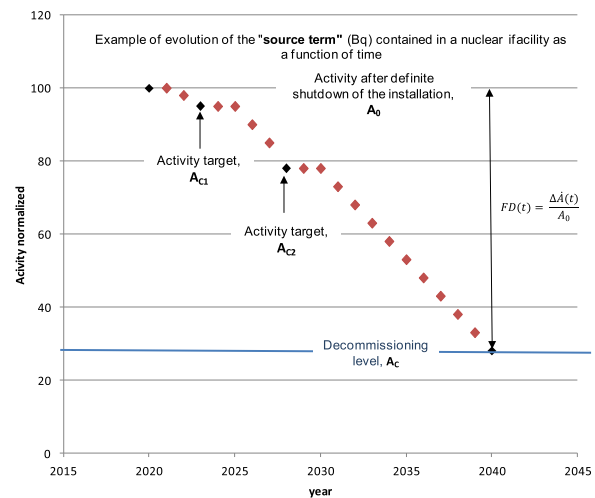


Fig. 2. Reducing the source term by depollution operations – radiological contamination case.

querel. It means emptying the “Becquerel stock” and sending waste packages to a disposal site, or “final customer”, and then delivering the decommissioning facility to a future owner.

2.2 An amount of data, information and knowledge to be shared and managed

First, a lot of Data, Information and Knowledge (DIK) [22] flows could be more or less available, coming from the facility’s engineering and construction phases, from operation and maintenance phases (historical DIK) as modelled simply in Figure 3. There is a requested continuity of the exchange modalities used during the facility dismantling operational phase. The facility owner imposes the DIK

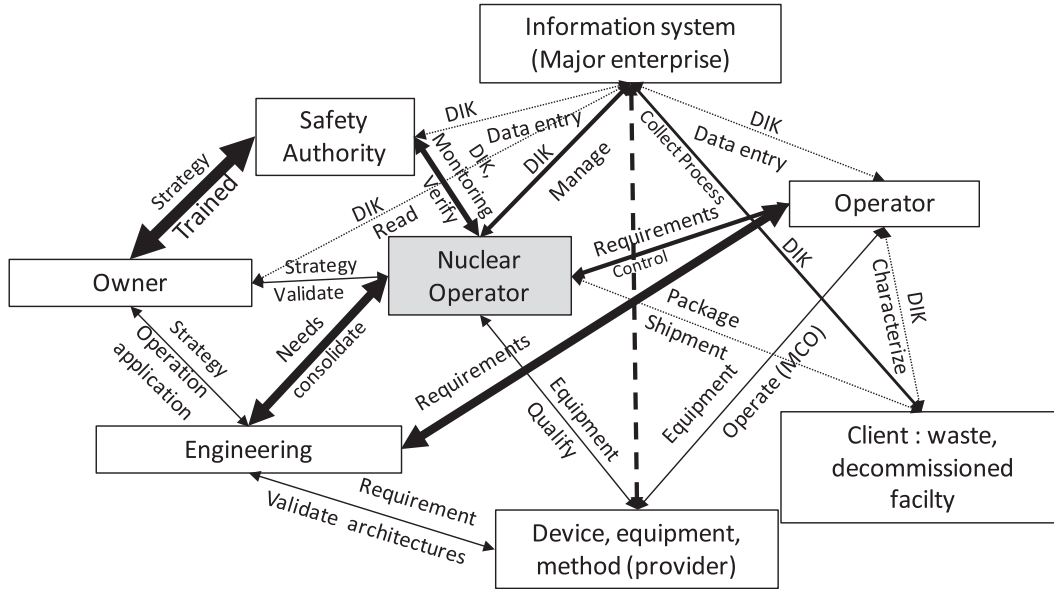


Fig. 3. A model of exchanges for depollution engineering centered on documents and on the nuclear facility operator (DIK: Data, Information, and Knowledge, MOC: Maintenance in Operational Conditions Op.: Operational).

management rules and essentially favours an organic view. This is centred on the facility manager during the operation phase, and then on the project manager during the dismantling phase. Their positions, roles, and responsibilities impose the quality and the volume of DIK exchanged or required. However, some of these DIK are however discarded a priori for studies of the dismantling phase. This absence of some crucial DIK during this phase impacts for instance the treatment line for the waste, then the decommissioning of the nuclear facility of interest. This problem is classically due to various kinds of interoperability problems when authoring project stakeholders to select, access, use and reformat, adapt, and share these historical DIK.

Second, stakeholders will have to create new DIK (proper DIK) in coherence and confidence all along the project but also make appear other flows that appear as considered in systemic sciences: material flows (e.g. waste package) and energy flows (e.g. electricity) between operations.

Considering historical DIK exchange, interoperability problems are studied both technically speaking (e.g. in terms of format, etc.) and conceptually speaking (e.g. of syntactic, semantic, or pragmatic interoperability). Some solutions are today proposed such as [23]. We must then consider all the flows (historical and proper DIK, Material, and Energy, Fig. 3) having to be modelled during dismantling project preparation (in project design time) and managed during the dismantling operation (in project run time).

3 Working hypotheses

Prior to describe the contribution of the work that is presented in the next, we must set two main hypotheses of the work.

3.1 A model of “de-pollution system” for MBSE principles

To face these problems, some systemic concepts and principles could help stakeholders for instance to put in light and model from an unambiguous manner the expected flows and their requested treatment, making them appear as the so-called functional architecture of the project. In this way, dismantling operations could be defined as functions that exchange flows from both DIK (historical and proper), Material or Energy type.

So, a working hypothesis has been set and positioned in a scientific framework. This framework is based on a model-based system engineering approach (MBSE) [24]. It favours an approach where the exchange of information among all stakeholders (engineers, contractors, authorities...) is no longer governed by documents written in natural language. The engineering is indeed organized around three main principles: the principle of system applied to the de-pollution system, the place and use of a set of models that are to be built and then exchanged by stakeholders, and finally engineering processes that are even standardized [25]. The main advantages of MBSE hereafter considered is to facilitate representation (modelling languages, tools and techniques), discussion (sharing a common vocabulary and rules by putting in light systemic principles), evaluation (by using models, more or less formal) and providing proofs and arguments for decision makers by using simulation techniques and analysis mechanisms (e.g., sensibility or dependence analysis).

We call the whole set of models a “de-pollution system model” on which exchanges among the stakeholders become possible and promising [25]. This model highlights particularly, and at least:

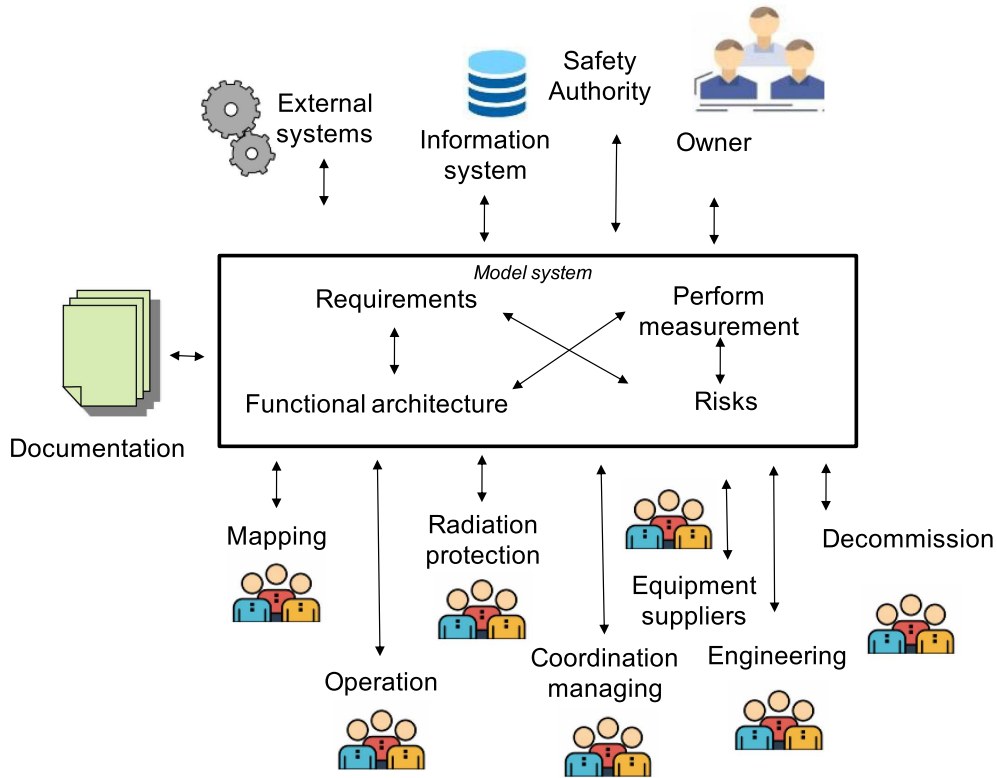


Fig. 4. A model for depollution system model.

- a requirements repository model that must be established and validated then shared involving all stakeholders and following Requirements Engineering principles;
- architectures models: a functional model that focuses on what the system must do and which flows are to be exchanged between functions, a logical model that focuses on with which components and links the system must perform its functions [26], and physical i.e. how the system must be then implemented in the reality by choosing all components from both technical, organizational, or human nature.

As an example, the co-design of the functional architecture of the dismantling system (Fig. 4) is facilitated by needing involvement from all the trades. In the same way, by reducing the dependence on historical DIK, the model becomes transposable (Fig. 4). It is not attached to a single facility [25]. The next focus is on the proposition of six generic functions allowing us to provide functional architecture modelling patterns. The equation for managing the Becquerel qualifies the performances and the risks. These results open the way to standardization of dismantling methods and means, thus contributing to an optimization of nuclear facility dismantling operations.

Last, it is of course mandatory to deploy and push all project stakeholders, whatever may be their roles and responsibilities, to use the proposed engineering framework, to map the polluted space, to define applicable solutions, to analyze risks, etc.

3.2 A first general model for activity reduction (Bq)

The first phase in structuring the dismantling system model is a logical sequence of tasks (Fig. 5). It addresses classical operations: (1) management of the Data, Information, and Knowledge [27], of Material and Energy flows, definition of the Becquerel stock and contaminant mapping or location of the “stocks”, (2) simulation of the de-pollution processes (dismantling) and reduction operations, then finally (3) conditioning and dispatch of the products (Fig. 5).

This is an iterative process, with given milestones, as de-pollution can be achieved sequentially and repetitively (Fig. 2). In this case, the intermediate activity levels targeted are defined, and labelled: $A_{c,i}$ (Fig. 2). The last configuration is characterized by a target activity level achieved: $A_c < A_s$, the contamination level to reach in order to consider the structure or the facility depolluted.

The intermediate level reached: $A_{c,1}$, $A_{c,2}$, $A_{c,n}$ for which $A_{c,n} > A_s$ indicates a notable step, for example a change in the working conditions. This can be the change from needing breathing equipment to protect the workers to being able to work without protection. It can also represent a change in the category of waste packages produced, from Intermediate level to Very Low Level, for example [28]. These different operational configurations meet the criteria of the same process, as they have the same objective: deliver a depolluted facility gaining both in confidence, performance, safety and security, whatever may be the initial contamination level.

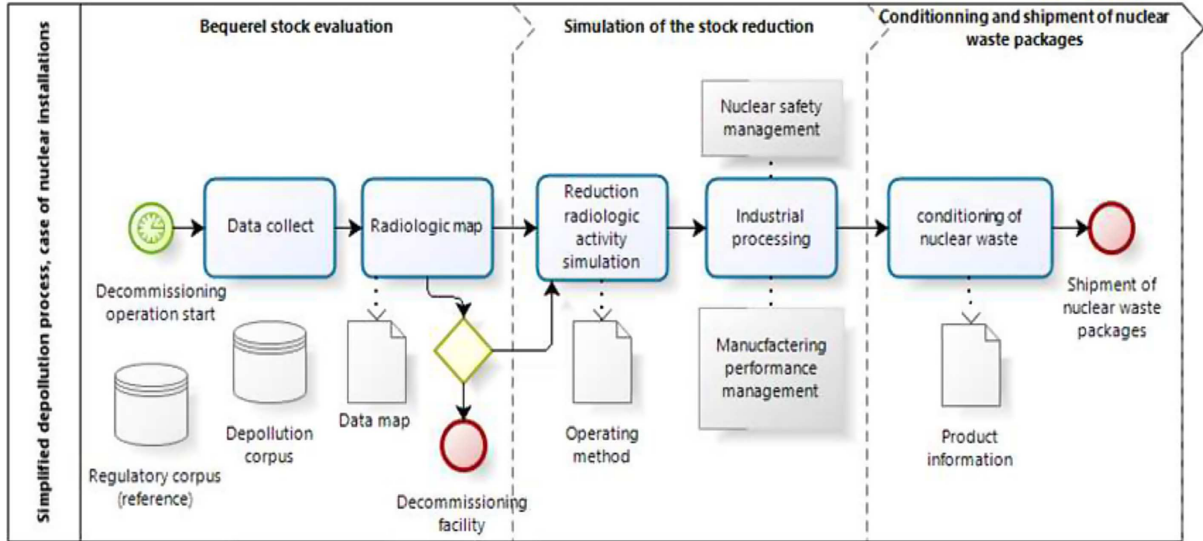


Fig. 5. Simplified process of activity (Bq) reduction in three steps – nuclear facility dismantling.

So it exists a general process named “*Becquerel logistics*” that highlights different steps and milestones to be respected. The objectives are initiated and maintained throughout the de-pollution operation, governed by specific regulatory conditions: those of waste zoning, radiation protection zoning, and waste categorization [28]. Operational constraints depend on the radiation protection zoning. Decommissioning is a change in the waste zoning [10]. The “*Becquerel logistics*” process has the advantage of clarifying task sequencing. A process is a necessary framework but does not give a high enough level of definition to structure the activities of the trades involved. To do this, system engineering extends the definition of the requirements into the proposed functional architecture pattern.

4 Contribution: a functional architecture pattern model for nuclear facility dismantling

Considering these hypotheses, and as detailed in the next, it seems important and innovative to note that, independently of the inherent complexity of de-pollution system, the requested operations and the general process make appear it exists a common and generic set of functions that could be organized, sequenced and synchronized from the same manner to each the de-pollution system objectives. So, we propose a functional generic architecture model based on a function inventory.

The flow of waste or of contaminated matrices (matter) is transformed via a succession of steps or functions. The result of a function is a concentration of the associated risk: for example, the removal of a pollutant by aspiration concentrates this pollutant in the collection point.

By concentrating on the hazardous product, the upstream functions impose ever-increasing constraints on the downstream functions through to the conditioning step.

The function is defined as an activity of transformation [29]. An input flow (Input) of matter, energy, or information is transformed into an output flow (Release). The function is characterized by a reference document of time, of space, and of form. It is constrained by the means of control. The activity is ensured by a resource flow [21], and the function is defined by its quality ($f(t)$). The general de-pollution function is based on the operational view, the regulatory objectives, and the reduction equation (1): radiological (Fig. 6).

By definition, the de-pollution system mission, i.e. its main function, does not propose a reading of the interface complexities. It does not enable a formalization of the resources or integrate too great a volume of constraints. In merging the details of the operational model (Fig. 5) of the general function (Fig. 6), a functional decomposition for which the interfaces are characterized and managed is envisaged. The intention is also to break down the details of the de-pollution system or “*Becquerel logistics*” until a generalizable set of functions can be obtained [26]. The arrangement of functions then forms an architecture from which engineering companies can simulate industrial performances and establish safety laws while respecting cost control.

The breakdown is based on the de-pollution process (Fig. 5). The different steps in the Becquerel logistics chain are approached functionally: managing the distribution of the pollutant within the facility, simulation then physical removal of the pollutant, followed by its conditioning and the transport of the product. This opposes performance law and operational behaviour, as they often seem antagonistic. The proposition means a safe, simple activity because of a dual analysis combining the risks and the performances. The elements of the functional breakdown focus on:

The site/the facility must not leave an industrial “memory” for the future, in the form of residual pollutant. At the end of the operations, “the pollutant warehouse” must be empty.

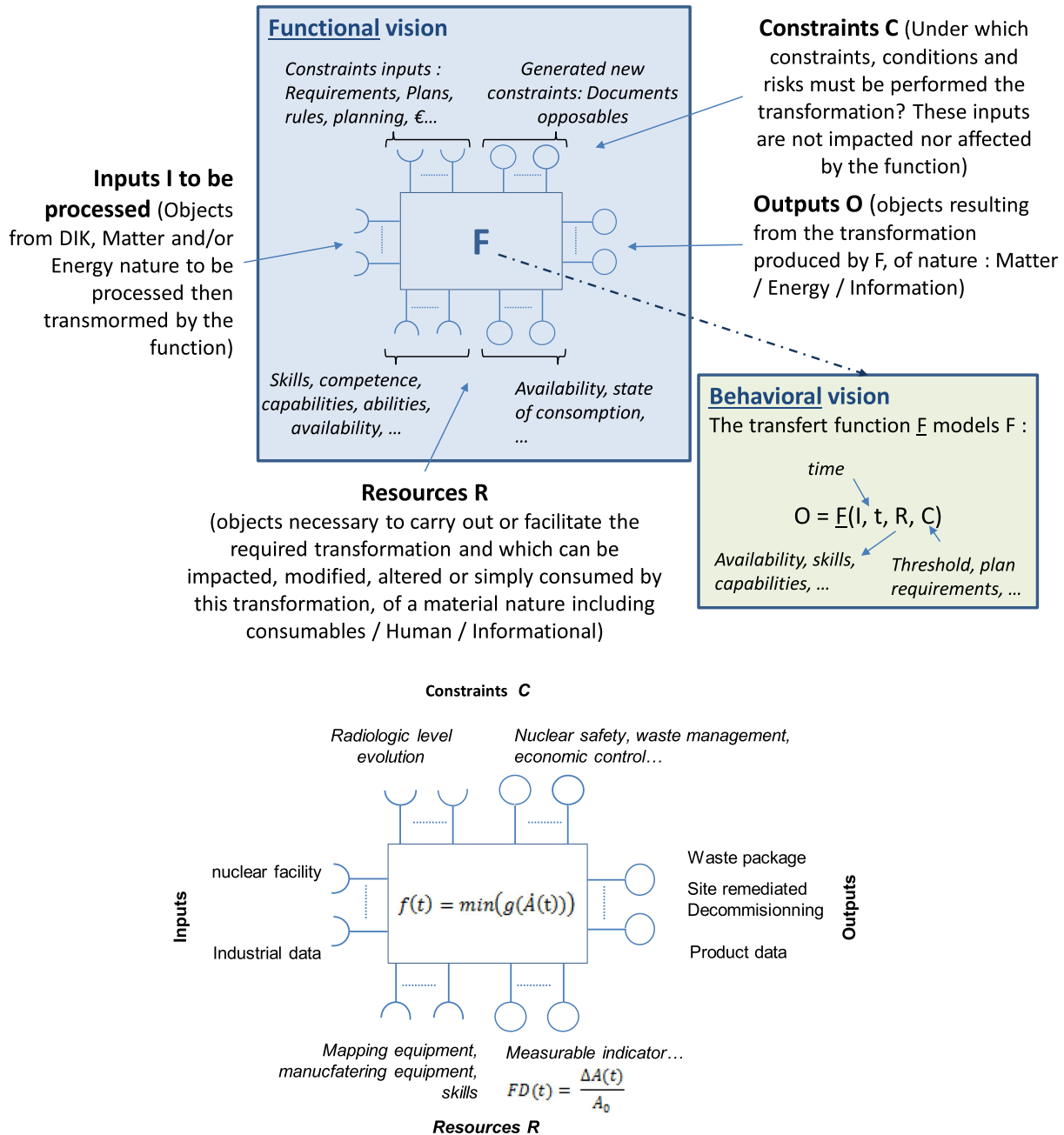


Fig. 6. Functional pattern (top) applied to Flows, constraints, monitoring, and resources of the general function $f(t)$ (bottom).

The waste packages are products compatible with the disposal facility requirements.

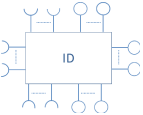
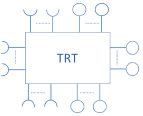
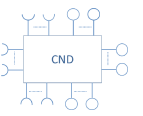
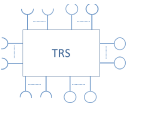
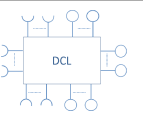
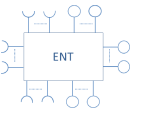
Package fabrication and site release are managed using checked, or safe and reproducible functions, with architecture based on the components of the logistics chain: Becquerel logistics.

The major issue is to have a vocabulary which is accessible and sufficiently precise to structure the analysis of the interfaces between the functions. A de-pollution activity is described by six functions (Tab. 1): identify (ID), treat (TRT), condition (CDT), store (ENT), decommission (DCL) and transport (TRS).

Throughout the line, the flow is a coupling of materials and information. At each step, transformations of material via energy are accompanied by DIK. The quality and the weight of the DIK dominate in the functional view vision. The DIK and “the Becquerel” move from the stock towards the finished product uninterruptedly.

An arrangement of the six functions corresponds to an industrial configuration. Source term accessibility is centred on the product and reduces the weight of the mapping. The functional architecture is independent of the quality of the facility.

Table 1. Inventory of the basic functions of the dismantling system.

Function definition	Symbol	Function characteristics
IDentify is a function of knowledge, information, and data collection, management, and supplementing. All these information items are attached to an object, a function, a place.		Flow quality: information, data, and knowledge. The resources (in): DIK, characterization techniques, information system. The resources (out): indicators interpreted to define the work conditions and the result of the operation (DF). The constraints (in): measurement uncertainties, contamination dynamics. The constraints (out): contamination distribution mapping and operational conditions.
The TReaT function is an operation for waste radiological and physical resizing. This aspect concentrates on the problems related to safety. It must be shown that the process is managed as concerns criticality safety, containment, and radiation protection (holdup).		Flow quality: contaminated matrix or waste. The resources (in): the means for cutting, for radiological characterization of the waste, the means for contamination containment. The resources (out): the means for monitoring the work environment. The constraints (in): the waste dimensions and masses, the radiological characteristics, the mass of fissile matter. The constraints (out): the contamination dispersion, the dose rates.
The Waste packaging or CoNDitioning function groups the resizing and radiological operations on the waste in order to supply the finished object: the process product, i.e. the waste package.		Flow quality: resized waste, containers. The resources (in): the containers. The resources (out): the DIK associated with the waste: physical-chemical and radiological. The constraints (in): the package dimensions, the radiological and physical-chemical cutoffs. The constraints (out): the health safety quality of the waste package.
The TRanSport function includes all movements of objects within the facility or storage locations, and on the public road network. [30]		Flow quality: waste packages. The resources (in): means of handling. The resources (out): definition of the transport means and modes. The constraints (in): Hazardous goods road transport authorisation Accord pour le transport des marchandises Dangereuses par la Route (classe 7). [30] The constraints (out): transportation of hazardous material.
The Decommission DCL function is the operation guaranteeing that the treated facility is in conformity with the rules set by the French Nuclear Safety Authority (ASN).		Flow quality: matter or civil engineering structure. The resources (in): the means for low-level mapping, a monitoring station at the site exit. The resources (out): a decommissioned building. The constraints (in): 0 Bq [10] or 300 µGy/year. The constraints (out): none.
The ENT , or Storage function consists in keeping the waste in safe, accessible conditions.		Flow quality: waste packages. The resources (in): the storage buildings and locations. The resources (out): storage plans. The constraints (in): the limits set for each facility. The constraints (out): access to storage zones.

At this stage, the de-pollution model system is defined based on reduced requirements and on a proposition for a modular functional architecture. An evaluation must next be made of the ranking of the DIK flow called “legacy” or the dimension of the weight of these DIK for the system.

4.1 A test application: treatment of waste stored in a pit

The arrangement of the six functions describing the system is an architecture, and this favours the definition of the functional interfaces. It reduces the distance between the trades involved, in order to manage the complexity of a de-pollution system better.

To decrease the complexity of the functional interfaces and evaluate the weight of the operation phase DIK in the

de-pollution model definition, a simple configuration was retained: *the retrieval of legacy waste containing all of the pollutants* from the part of the facility under consideration.

The case of legacy waste retrieval from storage is a configuration where the source term is limited (managed volume). Moreover, the logistics chain is often compact and located very near the waste concerned. It is a simple case for the application of de-pollution system modelling.

4.2 Application of an arrangement of the 6 functions for waste reconditioning

In this case, the waste is stored in a pit. The retrieval operation, i.e. taking the waste out, and then conditioning it in waste containers, is broken down into three steps.

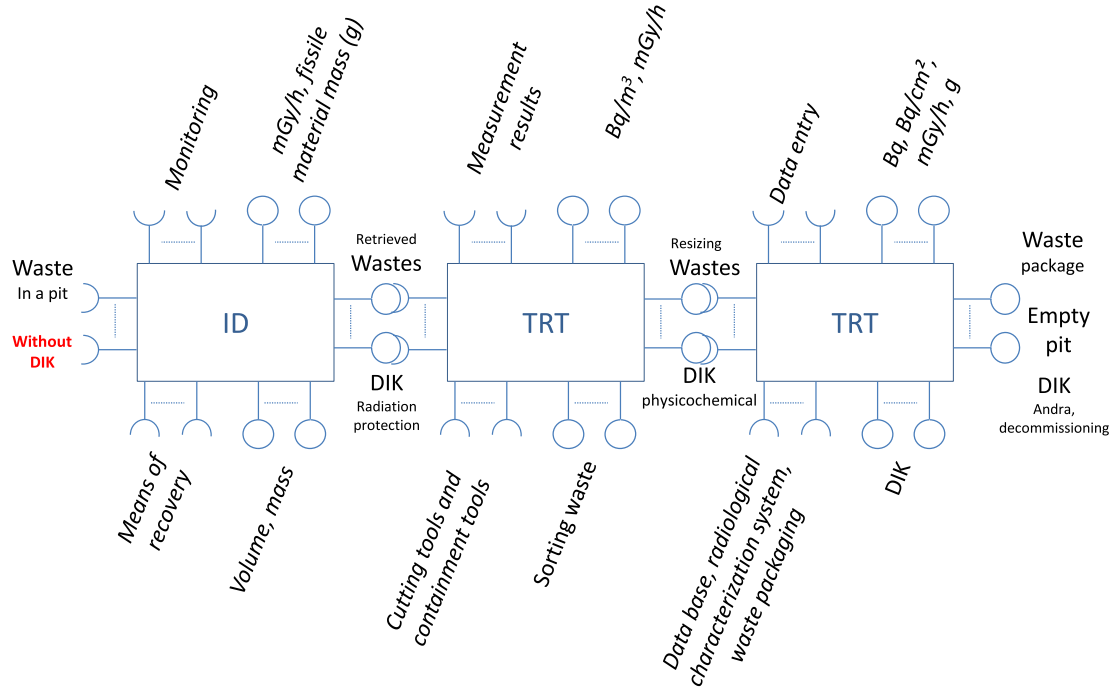


Fig. 7. Proposition of an architecture for the treatment and conditioning of pit waste, with the data flow.

Classically, it begins by identifying the waste, for example by collecting the following information: mass (kg), activity (Bq), and physical-chemical quality (elements). It goes on to a treatment which consists in removing part of the waste from the pit, and then carrying out a resizing of the pieces. The operation is finished when the material is put into a waste or conditioning container.

By respecting the logistics process and the general equation for pollutant minimization, the functional viability of this architecture is based on its ability to identify the waste in the pit, or more precisely, on the ability to define the terms of the function: $g(A, x, y, z)$. If the architecture can indeed propose a succession of actions that appear causal, it is cleared of physical constraints. So how to characterize an object located at the bottom of a pit? The tools available and the accessibility conditions generally do not enable this (Empty DIK, Fig. 7). The functional sticking point therefore comes from the notion of source term accessibility, stated to be the decisive parameter for the definition of a scenario. Without knowledge of the contaminant quality and its distribution in space, the de-pollution operation seems impossible to launch.

Propagation of poorly identified waste within the production line leads to a product of random quality. As in a classical logistics chain, the starting point is essential. Moreover, in the case of a de-pollution operation, the results of the IDentify function categorize the work conditions or safety management.

To ensure correct management of the product, i.e. the waste package, in spite of the poor source term accessibility, a functional alternative must be defined. To do so, new checkpoints are necessary in order to monitor the operating conditions by evaluating the dose rates (mGy/h) and

the volumetric level of contamination (Bq/m^3), and thus guarantee industrial performances by managing the radiological activity handled (Bq).

Checking waste material as it is retrieved from the pit a priori meets industrial performance criteria and a safety criterion focusing on the worker who handles the waste. When these checks are carried out during the different operations, they give information on the operating conditions but are not aligned with the industrial performance requirements. The radiological activity and the physical-chemical quality are not measured, even though they qualify the raw material going into the final package.

The alternative to the previous architecture (Fig. 7) is therefore a functional architecture where identification of the waste while in the pit is discarded. The waste is therefore removed under the terms of another function: transport. This means the retrieved waste is first identified outside the pit using *in situ* means for radiological characterization, then treated and conditioned (Fig. 8).

The radiological quality of the waste is managed after its retrieval from the pit and not from a pit mapping. The measurement of the magnitudes of interest associated with the production of waste packages is therefore carried out under conditions where these magnitudes are managed. The background noise and the waste volumes are reduced, and the physical-chemical quality can be assessed. The uncertainty associated with the activity measurement is, therefore, lower, a guarantee of gains in industrial performance and in safety.

This second architecture, where the initial identification of the pollutant is reduced to the limits of the contaminated space, must be used in such waste retrieval operations. The evaluation of the contamination level and its distribution within the zone considered no longer have any

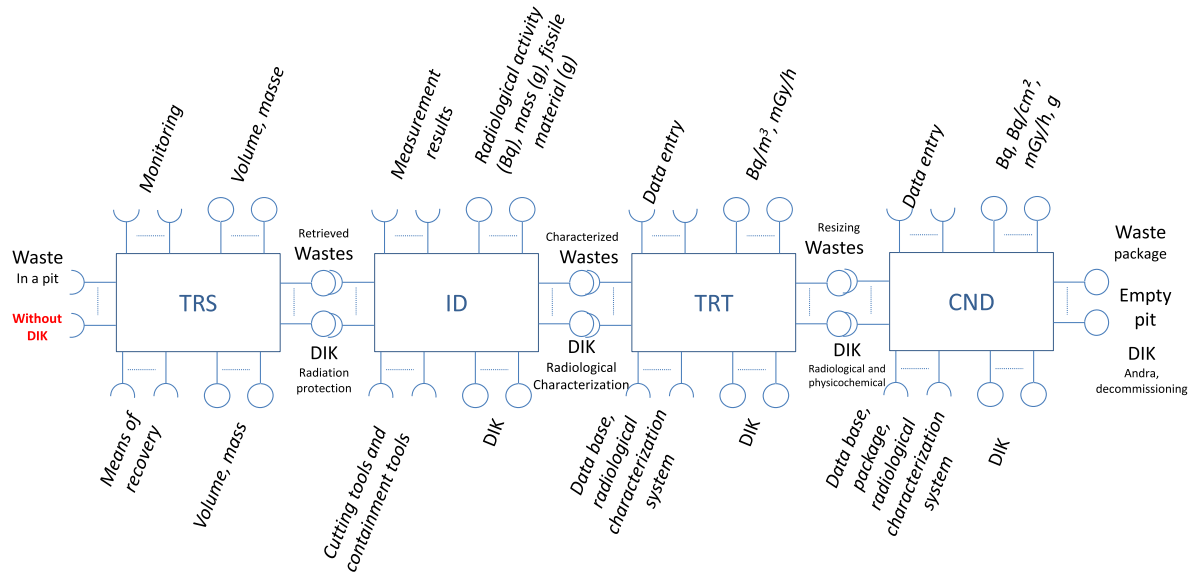


Fig. 8. Proposition of an architecture for the treatment and conditioning of waste from a pit, inspired by Lessons Learned.

interest. The weight of the industrial history is therefore lower. Only the elements or fractions of waste are mapped and then carried over in a process of treatment and conditioning. The process is organized taking into account the operational constraints and has the means for differential orientations depending on the waste category.

This architecture can be generalized, as the industrial history is not the controlling element for the source term. The operational de-pollution essentially depends on physical limits and so, as was the case during the operation phase, it depends on the waste zoning and radiation protection zoning. These parameters are deliberately neutral and are applied whatever the type of facility.

5 Comments and discussion on the current limits of the general dismantling model for nuclear facilities

The combination of two views – operational, then functional – undertaken to define a simplified model of a de-pollution system, contributes to the qualification and then the quantification of stakeholder exchanges.

Organization is not integrated in the approach and represents a first limitation for the proposition. It can be assumed that it is attenuated by the reduction in the number of performance indicators. The retained hypothesis, or minimization function reduces the number of indicators to simple Becquerel management. This indicator or pollution level is spatialized (function: $g(A)$), firstly for the pollution assessment or original pollution mapping, then for the de-pollution method planning.

It can be shown that the convergence point for the stakeholders is a mapping $g(A)$ and a depollution objective formalized by a decontamination factor: $FD(t) = \frac{\Delta A(t)}{A_0}$ or $\dot{g}(A)$. The notion of a weak interaction among the stakeholders can be advanced by weakening the orga-

nization's view (Fig. 9) focusing on a sharing of reduced constraints.

The elements taken from the operational view confirm that the mapping is the decisional support for the de-pollution industry. A map is a shareable decision element, but it can also be acted on through the decontamination factor. For each point on the map, it targets the hoped-for evaluation estimator or indicator. All the stakeholders can converge on this support, as if on the musical score of an orchestra conductor. The system of information and decision must therefore be structured on the basis of contamination maps. This fact is the model's second limitation.

Pollutant mapping is not always accessible. The initial activity: A_0 is nevertheless essential for the definition of the de-pollution system. It supports the definition of the operating conditions and industrial performance, as it dimensions the decontamination factor and the product quality.

Waste storage configuration is confronted with the impossibility of this mapping, as accurate mapping of buried waste pollution cannot be carried out. Thus, managing the limits imposed by “the storage facility” or zoning is the only available viable mapping element. The retrieval of legacy waste from storage was the configuration retained to augment the operational model with a functional view and overcome this new limit. It is representative of de-pollution operations, as pollutants are rarely accessible.

This functional limit is approached in the form of a simple question: thirsty hikers are beside a well. Can they trust the reassuring signs displayed, or demand complete checks of the entire well contents, or checks on the contents of the bucket from which they are going to drink the amount of water necessary to survive?

To be sure of the quality of the well water, the hikers must ask the local population who use the water, taking the risk of not having enough energy left to return to the well to drink. This approach is useful if the information

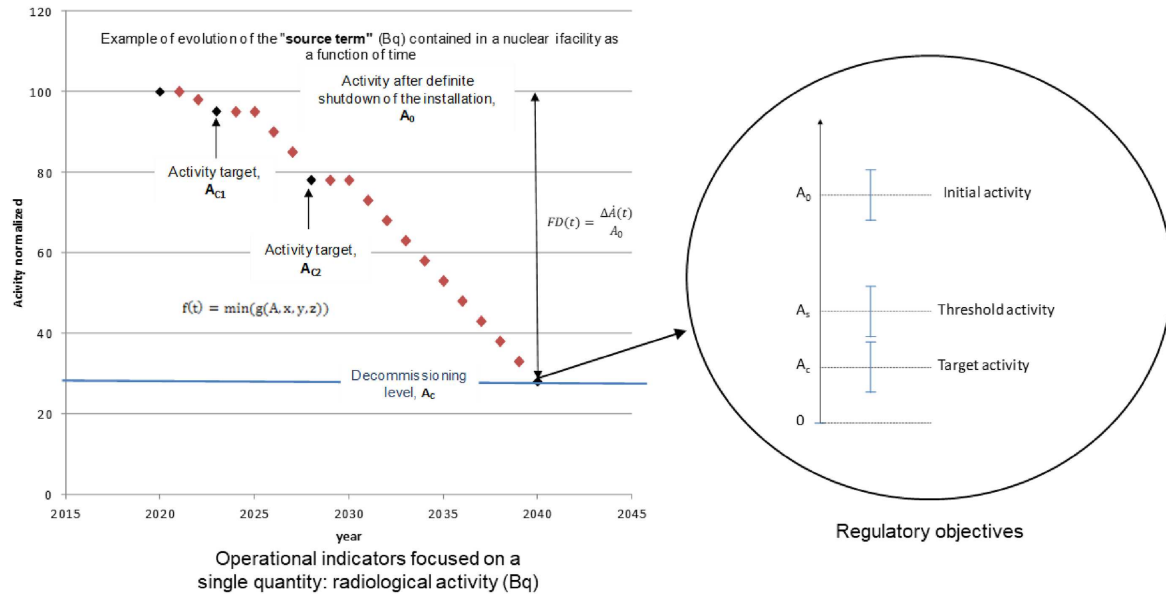


Fig. 9. A general function for site de-pollution described by a minimization equation of the pollutant content, focalization elements for the stakeholders.

can be found and is accurate. The history of the well water consumption is enough to know if it can be drunk, but gathering the information and interpreting it has a cost. What's more, it must be accurate and safe.

We would all agree that the safest way is to check – analyze – the well water before drinking it. This would not be reasonable in every case of water consumption but must be imposed for a truly safe approach, particularly in the case of suspect, possibly life-threatening products. This is the situation for operations where hazardous products removed from storage must be handled. It is unnecessary to check or to write the history of the entire storage facility, as it is enough to check the retrieved objects.

This principle is applied to the retrieval of waste from a storage pit. It parallels depolluting a contaminated well. The goal is to remove the pollutant so that the well can refill and used without restriction on its consumption. Two points follow on from the approach:

- The quality check operations on the products removed can be launched based on just the limits of the zone of interest, without mapping and without a historical record,
- Systematic checks on the bucket contents before consumption reduce the weight of history in managing the production of packages. The water is drunk if, and only if, the bucket contents meet health requirements.

The simplifications contributed by analogy with the evaluation of the well water health quality reduce the flow of DIK coming from the facility's construction and operation phases (historical DIK). They can be discarded a priori for studies of the dismantling phase. A new limit appears, that of the impact of the absence of this flow on preparing the functional architecture of the treatment line for the waste, then the decommissioning of the structures.

6 Conclusion

The dismantling of nuclear facilities is a young industry, still evolving towards maturity. In this context, operational and functional models can accelerate the generalization of safe, efficient means. The approach proposed here, and applied to a case study, is based on two elements: a source term minimization equation, and a logistics process (Becquerel logistics).

The pollutant is extracted, conditioned, and then sent on to a customer. This flow sheet satisfies the need to reduce the pollutant content of a facility. It meets both the necessary criteria: industrial performance and risk reduction. The minimization communicates clearly with and mobilizes all the stakeholders, and reduces the weight of trade ontology without ignoring it.

These perceptions open the way for the definition of functional architectures adapted to industrial configurations: retrieval of legacy waste, removal of solid components, or the clean-up of large surfaces. Each pattern or functional architecture (scenario) is thus the result of the organization of six elemental functions: identify, treat, condition, transport, store, and decommission.

The application of the functional model to the treatment of waste stored in a pit shows that the source term definition is reduced to the limits of the polluted space. The functional input (pattern) therefore serves to enhance industrial performance and safety while putting aside "pollutant history" and favouring instrumentation of the production line.

The combination of the six elemental functions of the Becquerel logistics chain must now deal with complex operations: cutting and removal of components, or clean-up operations. These applications will enable the functional vocabulary to be extended to and confirmed in industrial de-pollution operations. These studies will be carried out with the goal of extracting organic

architectures, followed by the identification of equipment that can be generalized to the entire de-pollution industry.

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Author contribution statement

Vincent Chapurlat brought the methodology analysis in system engineering.

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