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A Taxonomy for the Decommissioning of Nuclear Facilities

European Commission

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A TAXONOMY FOR THE DECOMMISSIONING OF NUCLEAR FACILITIES

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A TAXONOMY FOR THE DECOMMISSIONING OF NUCLEAR FACILITIES

PREPARED BY THE
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INTERNATIONAL ATOMIC ENERGY AGENCY,
IN COLLABORATION WITH THE
NUCLEAR ENERGY AGENCY OF THE ORGANISATION
FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

INTERNATIONAL ATOMIC ENERGY AGENCY
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For further information on this publication, please contact:

Section on Decommissioning and Environmental Remediation
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

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FOREWORD

Over the past decade there have been significant advances in the ability of computer systems to collect and organize knowledge. Modern semantic technologies make possible the association of information from many different sources. This development results from the increasing ability of software systems to deduce the meaning of concepts by evaluating the attributes characterizing those concepts and the relationships between them. These advances make possible the interconnection of different decommissioning knowledge systems, thereby creating a much more extensive decommissioning knowledge management system. Moreover, as more and more nuclear facilities are successfully decommissioned, the decommissioning knowledge base is rapidly expanding. However, the lack of a commonly agreed taxonomy for organizing this knowledge, combined with the company specific approaches taken by many organizations working in this domain, have made it challenging to exploit synergies.

In 2021, the IAEA, the OECD Nuclear Energy Agency (NEA) and the European Commission's Joint Research Centre launched a collaborative exercise to facilitate the organization of knowledge on the decommissioning of nuclear facilities and to promote the interoperability of such knowledge organization systems, beginning with the creation of a common taxonomy for nuclear decommissioning. The resulting taxonomy is structured in such a way that it can be embedded in Simple Knowledge Organization System (SKOS) based systems. SKOS is the semantic web standard recommended by the World Wide Web Consortium for representing any type of structured controlled vocabulary. The widespread adoption of the proposed taxonomy is expected to facilitate improved access to knowledge about the decommissioning of nuclear facilities.

The 2021 initiative also encourages organizations to use the taxonomy to build ontology structures for managing knowledge that will further enhance interoperability. In support of this, the initiative has considered the benefits and issues of building ontologies so that organizations can more appropriately decide how to use the proposed taxonomy. However, ontologies are developed for specific needs, so the initiative does not seek to propose a common ontology, but rather to inform users so they make appropriate choices to improve their decommissioning knowledge management in a way that can promote improved interoperability.

This publication presents the outcomes of the collaborative work on the development of a taxonomy for decommissioning of nuclear facilities. It was prepared jointly by the IAEA and the European Commission's Joint Research Centre, in collaboration with the NEA. The IAEA is grateful to A. Piagentini (Joint Research Centre) for his extensive contribution to this publication. The IAEA officers responsible for this publication were E. Kancsar and O. Vakula of the Division of Planning, Information and Knowledge Management, and M. Yagi and P. O'Sullivan of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION 1

1.1. BACKGROUND 1
1.2. OBJECTIVE 1
1.3. SCOPE 2
1.4. STRUCTURE 2

2. DECOMMISSIONING TAXONOMY 3

2.1. INTRODUCTION 3
2.2. DECOMMISSIONING TAXONOMY STRUCTURE 4
2.2.1. Decommissioning 4
2.2.2. Preparation for decommissioning 5
2.2.3. Post operation 5
2.2.4. Dismantling 6
2.2.5. Demolition 6
2.2.6. Cleanup 7
2.2.7. Termination of authorization 7
2.2.8. Facility management 7
2.2.9. Characterization 8
2.3. PROCESS TO DEVELOP THE PROPOSED DECOMMISSIONING TAXONOMY 8

3. BUILDING ONTOLOGIES 9

3.1. INTRODUCTION TO ONTOLOGIES 9
3.2. ONTOLOGICAL RELATIONS 11
3.3. DEVELOPMENT OF ONTOLOGIES USING SEMANTIC TECHNOLOGIES11
3.3.1. The Potential of Semantic Technologies 11
3.3.2. Approaches to Building Ontologies 12
3.3.3. Complexity of an Ontology 12
3.4. EXAMPLES OF PRACTICAL APPLICATION OF AN ONTOLOGY 13
3.4.1. Knowledge Management 13
3.4.2. Support to Training 13
3.4.3. Process Modelling 13
3.4.4. Machine Reasoning 14

4. OUTLOOK 14

4.1. BENEFITS OF A STANDARD DECOMMISSIONING TAXONOMY 14
4.2. PROMOTING INTEROPERABILITY OF KNOWLEDGE SYSTEMS 14
4.3. FURTHER IMPLEMENTATION OPPORTUNITIES AT INTERNATIONAL LEVEL 15
4.3.1. Promoting Adoption of the Standard Taxonomy 15
4.3.2. IAEA 15
4.3.3. OECD-NEA 16
4.3.4. EC-JRC 16

5. CONCLUSIONS 17

APPENDIX I CASE STUDIES 19

APPENDIX II PROJECT MANAGEMENT TERMINOLOGY 27

REFERENCES....29
DEFINITIONS....31
ABBREVIATIONS....39
CONTRIBUTORS TO DRAFTING AND REVIEW....41

1. INTRODUCTION

1.1. BACKGROUND

Taxonomies provide a hierarchical classification of things or concepts [1]. The most prevalent example of a taxonomy is that for biology, classifying living things such as plants, animals, etc. but taxonomies are used for many purposes. Taxonomies are not necessarily fixed, they can evolve with time as understanding of the domain grows e.g., the taxonomy for biology has been developing since the 18^{th} century.

In knowledge management, ontology refers to the structured representation of a knowledge domain. In the context of this publication, an ontology refers to a semantic representation of a specific system or domain of reality. Domain ontologies capture classes of concepts and entities existing within a specific knowledge domain and indicate the relationships between them. Thus, ontologies identify and describe points of interaction between different taxonomies to create a multi-dimensional network of knowledge. Ontologies are widely used in the field of natural sciences where they were originally developed, but their use is spreading rapidly into other knowledge domains.

Taxonomies and ontologies existed before computer-based systems were available. But the increasing use of information technology allows knowledge systems based on these concepts to be created more efficiently using large collections of documents and information. Furthermore, the creation of internationally recognized semantic web standards, such as the Simple Knowledge Organization System (SKOS), allows information to be widely accessed and shared in machine- and human-readable formats. Several open-source and proprietary semantic web tools based on the SKOS standard are currently available.

Many organizations involved in decommissioning have established systems to capture information and knowledge, to ensure that participants in future decommissioning projects (project managers, designers, operators, regulators, etc.) can benefit from the experience gained. Often, the ontologies of these systems are implicit, i.e., built into the connections and functionalities of the systems and not explicitly described. The formulation of an explicit ontology fosters a common understanding of the knowledge area, which enables those separated systems to be connected. This has the advantage of both expanding the knowledge base and also making that base accessible to more people. Adoption of commonly defined concepts, such as a common SKOS based taxonomy, is an important pre-requisite to enabling such interconnectivity to occur.

1.2. OBJECTIVE

This publication aims to facilitate greater sharing of knowledge for the decommissioning of nuclear facilities by proposing a common SKOS based taxonomy for decommissioning knowledge management. Timely adoption of the taxonomy will support the capture of knowledge from the ongoing implementation of decommissioning activities involving nuclear power plants, research reactors and fuel cycle facilities.

Adoption of a common taxonomy for decommissioning knowledge management should also facilitate the interlinking of relevant knowledge management systems developed by different organizations, thereby producing a more comprehensive decommissioning knowledge management system. Users of such an interlinked framework are much more likely to find relevant, valuable information for decommissioning. IAEA Safety Standard GSR Part 2 [3] requires that the knowledge and the information of an organization be managed as a resource.

The publication also seeks to promote wider use of ontological tools, using recognized international standards, to better facilitate interoperability. Nonetheless, it is a matter for individual organizations to determine whether, and how, to adopt any such proposals.

1.3. SCOPE

This initiative is concerned with the decommissioning of authorized nuclear installations of all types, including nuclear power plants, research reactors and fuel cycle facilities. Facilities used in uranium mining and milling are excluded from consideration.

This publication is focused on proposing a taxonomy intended to provide a common foundation for structuring decommissioning knowledge. It is also intended that this proposed taxonomy serves as a foundation for building future decommissioning ontologies, whether as a collaborative effort or within specific organizations.

Thus, the project comprises four related elements:

- An agreed set of key terms for major decommissioning activities with associated definitions for each term.
- An agreed core taxonomy for the set of terms, presented in a hierarchical structure (phase, activity, etc.).
- A set of terms and associated (decommissioning specific) descriptions for knowledge domains intimately related to, but not necessarily part of, decommissioning.
- An overview of considerations pertinent to, and additional benefits to be gained from, the development of ontologies for decommissioning.

1.4. STRUCTURE

This publication has the following structure:

- Section 1 Introduction
  The section describes the purpose and specific objectives of the project.
- Section 2 Decommissioning Taxonomy
  This section describes the decom missioning taxonomy and underlying concepts developed by this initiative.
- Section 3 Building Ontologies
  This section provides a basic description of how taxonomies can be connected by building ontologies, including examples of associated benefits.
- Section 4 Outlook
  This section describes a rationale for implementing the taxonomy and discusses the basic requirements to facilitate interoperability of different knowledge organization systems for decommissioning.
- Section 5 Conclusions
  This section describes the main conclusions of this initiative.
- Appendix I Case Studies
  The appendix provided more information on each of the case studies in the main report, including details of how these informed the development of the taxonomy.
- Appendix II Programme Management Terminology
  This appendix describes the approach adopted to terminology applicable to the associated primary domain of programme management.
- Definitions
  This section provides background information on the relevant terms, associated descriptions, and the derivations of those descriptions.

2. DECOMMISSIONING TAXONOMY

2.1. INTRODUCTION

Decommissioning involves the dismantling of a disused nuclear facility and management of the resulting materials and the site itself, in such a way that these present no current or future hazard to people or the environment. This allows all or some of the regulatory controls to be removed. Decommissioning may be implemented immediately following permanent shutdown of the facility or may be deferred – with an intervening period during which the facility is maintained in a safe interim state; typically to allow decrease of radioactivity levels to diminish through natural decay. Many factors bear on the decision about which strategy to follow and how to implement that strategy, including: national legal requirements; regulatory framework; availability of funding and waste management systems; training and competence of the workforce; and supplier availability. The socio-economic impacts of these decisions are generally also an important consideration and, accordingly, the views of local affected communities are considered.

The completion of decommissioning is normally marked by the partial or total release of the site from regulatory control, which may occur once the relevant authorities are satisfied that the agreed end state of the site has been achieved. Following site release, it may be used for new purposes, either within or outside the nuclear field. As with other nuclear activities, decommissioning is undertaken in accordance with strict regulatory requirements, generally overseen by nuclear and environmental regulators.

While decommissioning comprises a set of complex and interrelated activities, the concept of decommissioning (in the context of a taxonomy) can be represented by a set of key concepts. These concepts, and the associated sub-concepts described later in this section, are proposed based on work carried out by a group of international decommissioning experts. Fig. 1 illustrates these key concepts. In addition, the proposals have been compared and contrasted with other decommissioning knowledge management structures (see Section 2.3 below) to both inform and improve the concept terms and definitions and to test implementation of the taxonomy. Appendix I describes a number of case studies which informed the development of the decommissioning taxonomy described below.

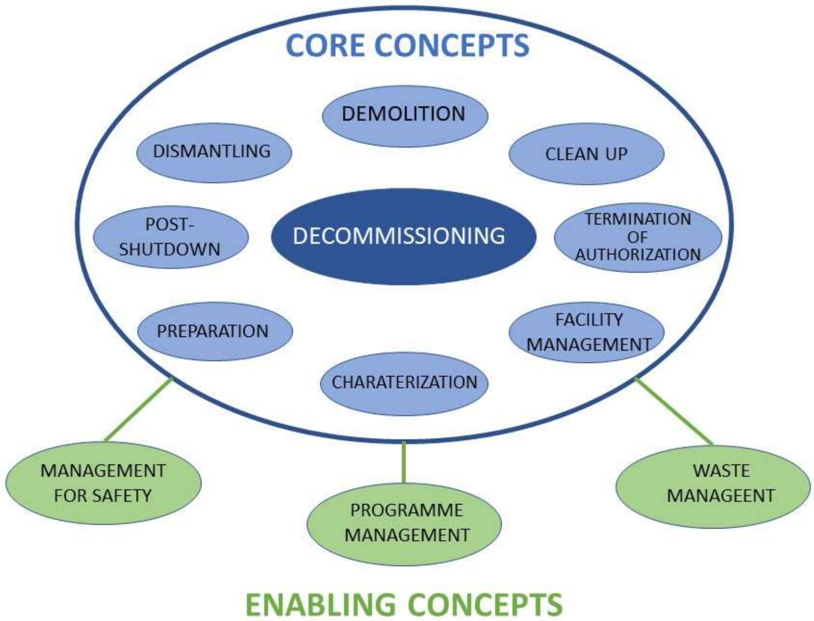

FIG. 1. Representation of core and enabling concepts

The decommissioning of all types of nuclear facilities typically follows a sequence described by the following concepts:

– Preparation for decommissioning.
– Post-shutdown activities.
– Dismantling.
– Demolition.
– Cleanup.
– Termination of authorization.

These concepts do not necessarily represent discrete stages in the overall decommissioning process, i.e., there is likely to be overlap between them. For example, preparation for decommissioning and post shutdown may take place in parallel. Also, for large facilities, different parts of the facility may be undertaking activities within differing concepts at any one time. Nor do the activities represent by these concepts necessarily have to follow each other immediately.

There are also some important concepts that capture activities that take place throughout the decommissioning process including:

– Characterization.
– Facility management.

All the above are 'core' decommissioning concepts and are described in further detail in section 2.2.

In addition to the 'core' concepts there are also important 'enabling' concepts, which, although closely related to activities that are fundamental to the implementation of decommissioning, represent knowledge domains of wider scope than decommissioning. For the purposes of this initiative three such associated domains were considered as being of greatest relevance: management for safety, waste management and programme management. Relevant terms, associated descriptions, and derivations of those descriptions are described below (see Definitions).

No descriptions or definitions are proposed in this report for the enabling domain of programme management. Appendix II includes a discussion of the importance of this domain to decommissioning and discusses options to address this at a later stage, ranging from developing a set of decommissioning specific programme management descriptions as with safety and waste management, or linking to other general definitions used in the domain of programme management.

The concepts provided in this publication have generally been derived from internationally accepted sources except where this conflicts with the widely accepted use of the term within the decommissioning domain, then a decommissioning specific definition of the concept is proposed. This does not intend to counter the generic definition of the term; it merely reflects and proposes a standard for the concept the term represents that is in line with the widespread use within the decommissioning domain.

2.2. DECOMMISSIONING TAXONOMY STRUCTURE

This section describes the proposed decommissioning taxonomy structure, including the terms and definitions associated with the core decommissioning concepts. Some concepts have been further divided into sub-concepts where the increased granularity enhances the knowledge management structure. Further details on where the definitions have been drawn from can be found in Definitions, below.

2.2.1. Decommissioning

The general explanation of decommissioning is provided in section 2.1. above, and so is not repeated here. For the purposes of this taxonomy:

“decommissioning” means the set of administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. This does not apply for that part of a disposal facility in which radioactive waste is emplaced.

2.2.2. Preparation for decommissioning

Successful decommissioning requires some activities to be planned and executed many years in advance of decommissioning, with detailed preparatory activities normally beginning within a few years of the anticipated permanent shutdown of the facility. Indeed, the initial decommissioning plan for a facility is prepared, at least in outline, as part of the regulatory approval process to construct the facility. This should identify how the facility is to be left at the end of its lifetime and include all the major steps required to decommission the facility to achieve this goal. The planning concept includes key preparation activities such as: establishing anticipated decommissioning costs and their associated uncertainties (i.e., financing); designing and constructing the facility to facilitate decommissioning (part of planning); creating or expanding waste management routes (an example of establishing support logistics); and initiating support activities in a timely fashion (such as providing appropriate systems to manage decommissioning).

For the purposes of this taxonomy:

“preparation for decommissioning” means all activities required for authorization of decommissioning.

The following definitions are adopted for relevant sub-concepts:

“financing” means all activities required to ensure adequate financial resources are available when necessary for safe decommissioning.

“decommissioning planning” means the preparation and maintenance (throughout the facility lifetime) of a plan and supporting documents –- to show how decommissioning can safely achieve the defined end state, in accordance with regulatory requirements.

“management system” means a set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner.

“logistics reconfiguration” means the modification of logistics facilities and services to enable decommissioning activities.

2.2.3. Post operation

Activities captured by this concept are typically performed to place the facility in a state that is ready for dismantling or a stable quiescent state awaiting dismantling. The activities are those that are specifically focused on taking the facility to a state of permanent shutdown i.e., they go further than the activities performed during a normal shutdown. The activities would typically include the removal and management of all remaining spent nuclear fuel and providing for the safe management of radioactive waste and residues from the operational period. Within the concept of post-operation, some limited preparatory actions for decommissioning may be performed if allowed within the scope of the operational license. Such activities might include e.g., closed loop decontamination of the primary circuit of a nuclear power reactor.

For the purposes of this taxonomy:

“post operation” means all activities relating to the permanent cessation of operation of a nuclear facility.

The following definitions are adopted for relevant sub-concepts:

> "spent fuel removal" means the removal of spent fuel from a reactor core and transfer of fuel to spent fuel storage.
>
> "post shutdown activities" means activities undertaken following permanent shutdown of a nuclear facility to reduce hazards and prepare the facility for immediate or deferred dismantling.

2.2.4. Dismantling

The dismantling concept comprises the core set of activities typically associated with decommissioning the radioactive (activated or contaminated) structures, systems and components (SSC) of the facility. The aim is to reduce the radioactive inventory to a level where operational radiological risks do not require active management or any special provisions. This differs from activities associated with Cleanup (see 2.2.6.), which involve management of any residual environmental risks.

For the purposes of this taxonomy:

> "dismantling" means the taking apart, disassembling and tearing down of the structures, systems and components of a facility (within a radiologically controlled area) for the purposes of decommissioning.

The following definitions are adopted for relevant sub-concepts:

> "facility reconfiguration" means the modification of structures, systems, components and access routes within the facility to support decommissioning activities, including where necessary the provision of safe enclosure(s).
>
> "cutting" means the act of separating or dividing structures, systems, components or waste using force or energy to divide the material.
>
> "decontamination" means the complete or partial removal of contamination by a deliberate physical, chemical or biological process.
>
> "containment" means methods or physical structures designed to prevent or control the release and the dispersion of radioactive substances.
>
> "remote operations" means the ability to perform activities that are physically distant from an operator.
>
> "material management" means the setting up of routes for and subsequent removal of structures, systems, components and material in the facility.

2.2.5. Demolition

Demolition typically uses non-nuclear specific techniques and applies only to buildings where radiological risk management measures are typically not required, e.g., where dismantling processes have already removed the radioactive risk or ancillary buildings where no radioactive material has been used or processed. In both cases, the part of the facility to be demolished should be deemed outside any radiologically controlled area. Nevertheless, while demolition may not require radiological risk management, there are often conventional safety or chemotoxic risks that need to be carefully managed.

For the purposes of this taxonomy:

“demolition” means the taking apart, disassembling and tearing down of the structures, systems and components of a facility (outside of a radiologically controlled area) for the purposes of decommissioning.

2.2.6. Cleanup

If, during the operational lifetime of the facility, any soil or groundwater in the vicinity of the nuclear facility has become contaminated to levels which are deemed to be of significance, this contamination will need to be cleaned up. Also, there may still be building foundations and other facility material requiring removal, which were not a priority during demolition. Both the contamination and residual material will need to be dealt with in accordance with the requirement to reach the defined end state for the facility.

For the purposes of this taxonomy:

“cleanup” means the removal of contaminated soil and other materials from an area within the authorized boundary of a facility, typically performed under the authorization for decommissioning for the purpose of reaching the defined end state.

2.2.7. Termination of authorization

To enable the termination of the decommissioning authorization, the approved nuclear decommissioning end state criteria for the facility has to be verified and demonstrably achieved. If the end state cannot be verified, further cleanup activities may be required. The termination of authorization (decommissioning) may be different from termination of authorized responsibility, which is a broader term signifying the release of the operator from any further regulatory responsibilities in relation to the authorized facility, e.g., responsibilities associated with environmental impact. The process of termination of authorization (decommissioning), should nevertheless include arrangements to assure that any residual conditions are adequately managed.

For the purposes of this taxonomy:

“termination of authorization” means the termination of the nuclear decommissioning authorization or license for the facility, either unconditionally or with stipulated conditions on the future use of the facility site.

The following definitions are adopted for relevant sub-concepts:

“Facility radiation survey” means the final radiological characterization survey of the facility and site following the completion of decommissioning to assure the end state for the facility has been achieved.

“Post decommissioning arrangements” means establishing arrangements to assure that any remaining authorized responsibilities are adequately discharged.

2.2.8. Facility management

Facility management comprises inspection and maintenance activities used to verify and assure the performance of structures, systems and components. The aim of such activities is to prevent any significant increase in risk from the facility either during decommissioning, between decommissioning stages, or while the facility is in a dormant state. Facility management will usually comprise a degree of physical protection commensurate with the risk and the state of the facility.

For the purposes of this taxonomy:

> “facility management” means all activities to verify and assure the performance of facility structures, systems and components of a nuclear facility, to assure the safety and security of the facility and to coordinate decommissioning activities across a facility.

The following definitions are adopted for relevant sub-concepts:

> “maintenance” means the organized activity, both administrative and technical, of keeping structures, systems and components in good operating condition, including both preventive and corrective (or repair) aspects.
>
> “inspection” means the examination, observation, surveillance, measurement or tests undertaken to assess structures, systems and components and materials, as well as operational activities, technical processes, organizational processes, procedures and personnel competence.
>
> “site security” the prevention and detection of, and response to, criminal or intentional unauthorized acts involving nuclear material, other radioactive material, associated facilities or associated activities.

2.2.9. Characterization

Appropriate characterization is fundamental to successful decommissioning. The concept of characterization is, in essence, an exercise to gather information about the condition of the facility (e.g., the physical, radiological and chemical properties of the SSC) and thus define the basis for the decommissioning activity. Deciding what information is required should be driven by need i.e., the specification for each characterization activity should transparently link to the decision or action the results are to be used for, and thus be clear about what degree of accuracy and what precision is required. Characterization may be carried out multiple times during the decommissioning of a facility and for differing reasons, e.g., for planning, for verification, etc.

For the purposes of this taxonomy:

> “characterization” means the determination of the physical, chemical and radiological nature of something for the purpose of informing activities and decisions.

The following definitions are adopted for relevant sub-concepts:

> “facility characterization” means the determination of the physical, chemical and radiological nature of the structures, systems and components for the purpose of informing activities and decisions.
>
> “site characterization” means the determination of the physical nature of a site, and of any potential chemical and radiological contamination for the purpose of informing activities and decisions.
>
> “waste characterization” means the determination of the physical, mechanical, chemical, radiological and biological properties of radioactive waste to establish the need for further adjustment, treatment or conditioning, or its suitability for further handling, processing, storage or disposal.

2.3. PROCESS TO DEVELOP THE PROPOSED DECOMMISSIONING TAXONOMY

The decommissioning taxonomy presented in this report was developed by combining the experience of a panel of international experts. The draft taxonomy was then tested through three different case studies. Each study created a useful output, but the primary purpose was to improve the proposed taxonomy. Each of the studies had slightly differing aims as described below:

- International Nuclear Information System (INIS) of IAEA.
    - to use the databank of reports incorporating domains beyond decommissioning to verify and validate the relevance of terms against a broad information source.
- International Structure for Decommissioning Costing (ISDC) by NEA, IAEA and EC.
    - to use an existing recognized information structure in the decommissioning domain to validate and improve the initial taxonomy.
- EC Horizon 2020 project PLEIADES.
    - to test the ability to automatically link to an open-source ontology for decommissioning being developed for the purpose of standardizing decommissioning project digital tools.

The case studies illustrate the opportunities available from developing and then linking a standardized decommissioning taxonomy to other taxonomies or ontologies. The intent of the examples presented in the appendix is to illustrate the potential benefits gained and effort required, demonstrating how the proposed decommissioning taxonomy facilitates interoperability as well as identifying the requirements to facilitate building a wider ontological framework.

The decommissioning taxonomy was built using *PoolParty*, one of several semantic software platforms available for building knowledge management systems and applications.

3. BUILDING ONTOLOGIES

3.1. INTRODUCTION TO ONTOLOGIES

The decommissioning domain taxonomy is a useful tool in knowledge management because it captures and structures concepts for the key activities and methods for performing decommissioning and, for the expert user, it can prompt recollection of the deeper understanding based on their experience and individual knowledge base. A taxonomy can only imply this understanding as the links to other related concepts both within and outside of the taxonomy are embedded within the expertise of the user, whereas an ontology can expressly capture these links by drawing additional connections within a taxonomy and connecting and layering multiple taxonomies. Such an ontology would represent a network of decommissioning knowledge by overtly connecting the concepts in the decommissioning domain taxonomy and other closely related taxonomies.

Ontologies can be derived by two different approaches: by computational analysis of existing documentation, making explicit the links between concepts (bottom-up) or by domain experts capturing the implicit connections in their individual knowledge base gained by experience (top-down). In the first case, the semantic link (or correlation) is made by the machine and the connecting property is always the same – ‘is connected to’. In this case, causality needs to be validated by expert judgement in order to make explicit specific properties (such as ‘is part of’, ‘uses’ or ‘is applied for’). In the second case, a panel of domain experts start with one or a few concepts and determine the connecting specific properties to make explicit their collective implicit knowledge.

Fig. 2 below provides a visualization of a computed ontology and an example of an ontological relation. This relation connects concepts from two different taxonomies (e.g., ‘operator,’ a decommissioning actor, and ‘cutting’, a decommissioning activity). An example of a top-down approach is shown in Appendix I.3.

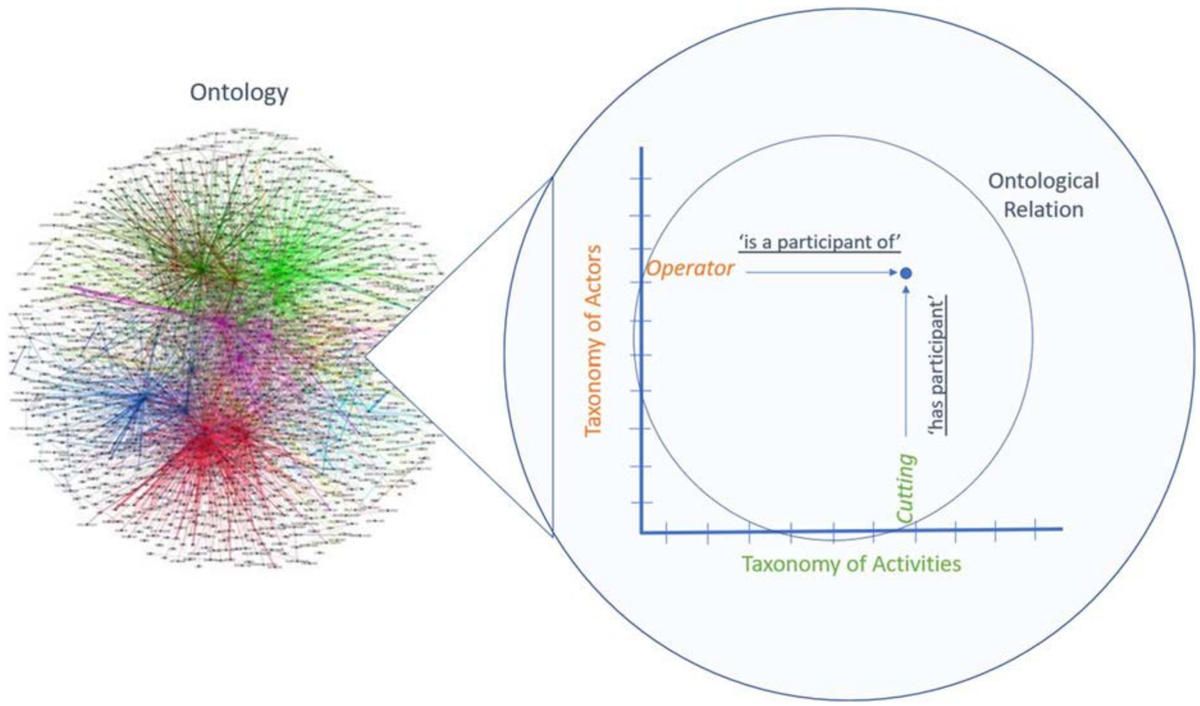

FIG 2. Visualization of an ontology and an example of an ontological relation

To further illustrate this idea taxonomies can be understood as concepts in a hierarchical structure, with one concept being 'is a part of' or 'is a type of' another concept in the taxonomy structure. In the case of the decommissioning domain taxonomy, decommissioning is subdivided into concepts representing activities. However, important knowledge about how an activity is carried out, by who and for what purpose, can only be captured with ontological relations. For example, domain experts know that to decommission a ventilation system, the component ductwork needs to be dismantled, often by cutting. However, cutting is an activity within the phase of dismantling in the decommissioning taxonomy. The object to which cutting is applied, i.e., ducting, can be thought of as a component in the ventilation structure i.e., part of a whole 'facility' taxonomy, unique to that particular facility, which describes the structures, systems and components of a facility. Fig. 3 below demonstrates how 'cutting' and 'duct' might be shown within their respective taxonomies and how the connection between 'cutting' and 'duct' might be expressed via an ontological relationship.

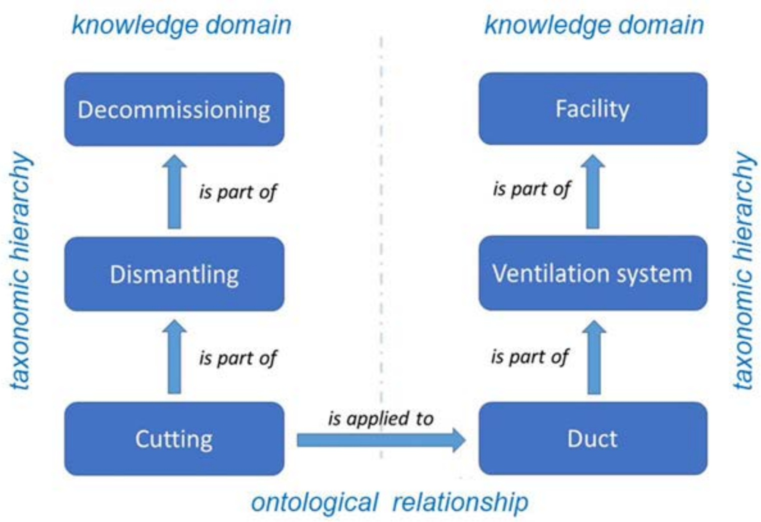

FIG. 3. Simple example of linking terms in different taxonomies using an ontological relation

3.2. ONTOLOGICAL RELATIONS

The example above is a simple one and demonstrates an obvious connection between ‘cutting’ and ‘duct’. However, an ontology seeks to reveal important, and often more complex relations between concepts, thereby making explicit context-specific, implicit knowledge, or knowledge that comes from experience and is not often codified. To understand how ontological relations enable this, the simple example below (Fig. 4) illustrates a simple ontology extending the relationship of ‘cutting’ to other concepts. The diagram is not complete and has been created merely for the purpose of highlighting how ontological links work. The diagram uses a number of core concepts (and sub-concepts) from the decommissioning taxonomy and introduces possible new concepts such as ‘organization’.

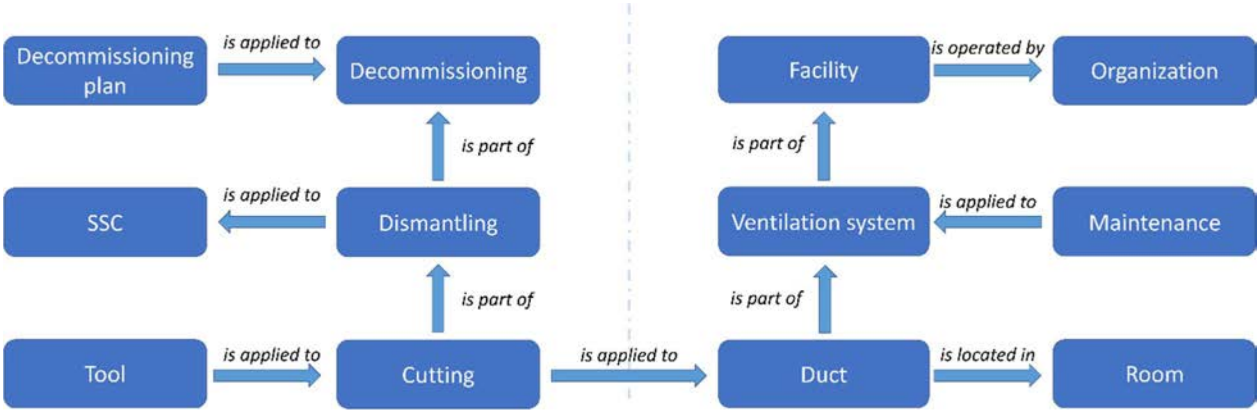

FIG.4. Illustrative example of ontological relations to represent more complicated processes (this is an extension of concepts illustrated in Fig 3.)

Fig. 4 above shows both taxonomical (‘is part of’) and ontological relations with various properties. Because of the extended network of these relations, it is possible for a system to identify that an organization performs cutting i.e., ‘cutting’ is applied to ‘duct’ which is part of the ‘ventilation system’ which is part of the ‘facility’ which is operated by the ‘organization’.

The knowledge that an ‘organization’ applies ‘cutting’ is widely understood but is often implicit and therefore would not be machine understandable with simple taxonomy. Ontological relations can capture implicit knowledge and make it accessible even though there is no direct linkage. For example, in Fig. 4 above, there is no direct link between ‘organization’ and ‘cutting’. Nevertheless, the extensive network of relations in the ontology enables browsing or searching for information to make explicit that ‘cutting’ is one of the activities an ‘organization’ applies in order to ‘decommission’ a ‘facility’. Therefore, by making explicit and then coding these ontological relations, it is possible to represent quite complex processes without coding every direct relation.

3.3. DEVELOPMENT OF ONTOLOGIES USING SEMANTIC TECHNOLOGIES

As most currently generated information is stored and manipulated digitally, and many business processes use computers, it is beneficial to engineer ontologies in and for the same environment. Both the creation and use of extensive ontologies have become simpler with the advent of more powerful IT tools.

3.3.1. The Potential of Semantic Technologies

An ontology could exist merely as a visual representation and reference for an organization’s knowledge. The potential value of an ontology is much greater when it is developed in a human- and machine-readable format on a computer, especially as most currently generated information these days is stored digitally, and everyday business processes take place via computer. Established standards for machine-readable, semantic web taxonomy and ontology modelling exist along with software that facilitate this task. Many of the proprietary and open-source knowledge management software tools offer features to help build ontologies using these standards. The tools offer users the advantages of:

- Quickly linking multiple taxonomies (in a supported, standard format) to each other.
- Accessing multiple collections of documents for the purposes of semi-automated analysis, extraction and validation of concepts.
- Guiding creation of taxonomies and ontologies according to semantic web standards.
- Providing taxonomies and ontologies in shareable formats.

Where the information is not already stored in digital form there is an additional value judgement to make before deciding whether or not to create a machine-readable ontology. The effort to digitize the information may, or may not, outweigh any benefits to be gained.

3.3.2. Approaches to Building Ontologies

A combination of both a 'top-down' and 'bottom-up' approach to ontology building ensures more comprehensive knowledge capture than one approach alone. The top-down approach involves tasking experts with identifying the important concepts, classes and relations for a taxonomy and ontology. A bottom-up approach consists of using semantic technologies to analyze existing documents and materials to identify semantic proximity of concepts (i.e., the frequency with which terms are associated with each other within the corpus of information), revealing additional concepts and indicating potential relations of import. Though discovery of semantic proximity does not yield a precise ontological relation, it might point to a subtle connection between two terms that experts do not often encounter or that they understand only implicitly. Software now exists that can support the bottom-up approach, making ontologies more robust whilst saving valuable expert resources and time. Such a bottom-up approach also supports durability by automatically maintaining ontologies.

A combined approach yields the more robust results using multiple sources of knowledge: the expert that is familiar with the current knowledge paradigm and can share knowledge from unique, personal experience; and the corpus of knowledge that potentially holds multiple generations of codified, formal knowledge. The top-down and bottom-up approaches can be used to validate each other. While bottom-up approaches promote completeness of ontologies, top-down approaches promote correctness.

3.3.3. Complexity of an Ontology

The complexity of an ontology depends on both purpose for which the ontology is to be used and the domain being represented. Non-complex ontologies may be constructed using the Resource Description Framework (RDF) standard, the framework on which SKOS was built. However, more complex ontologies, for example those that might include axioms as rules for attributing relations in the ontology, might be better constructed by adding a layer of descriptions using the Ontology Web Language (OWL) standard. SKOS taxonomies and OWL ontologies can be used together. The advantage of developing more complex semantic web ontologies is that they better support automated information retrieval and automation of other applications. A semantic web ontology can be developed with different levels of complexity; an ontology could provide a simple relational model, or an ontology could offer a relational model with domain rules (e.g., cardinalities or value constraints) and axioms.

Domain rules and axioms provide an extra layer of understanding by qualifying how a relation can be attributed or by using relations to describe the logical structure of the ontology itself rather than the specific domain knowledge. An example of a domain rule in an ontology might be the relation 'has participant', where the value of 'participant' is specified only as either an organization or person.

While the power of semantic tools has simplified the development of ontologies, the effort required should not be underestimated. Building a successful decommissioning ontology requires a clear understanding of the intended use for the ontology. It is also important to consider the degree of interaction desired with other ontological networks i.e., it is desirable for the decommissioning ontology to interface with a larger ontological domain such as generic nuclear domain. Building the ontology will require dedicated expert resources from knowledge management disciplines and from the domain experts of the appropriate knowledge areas (e.g., decommissioning, waste management, programme management, etc.). Before undertaking ontology development work or projects, an organization needs to consider the intended use and available resources, both in terms of investment of people (experts) and the costs of additional IT infrastructure.

3.4. EXAMPLES OF PRACTICAL APPLICATION OF AN ONTOLOGY

An ontology could support applications such as knowledge management and retrieval, training of early career professionals, implementation of new decommissioning projects, streamlining process management and development of machine learning and AI algorithms. The following examples briefly describe scenarios of ontology applications relevant to nuclear decommissioning.

3.4.1. Knowledge Management

The taxonomy proposed in this report provides a structure to assist the process of accessing information. This process is improved through use of an ontology, which in addition identifies the relations between terms, providing the ability to retrieve information using the relationships. For example, a taxonomy might help organize documents by project type (a category), which necessitates knowing the project type to carry out a search. However, an ontology allows users to search projects on a basis of other information, such as the technical approach, the type or part of the facility being decommissioned, key participants.

One of the key benefits of building ontological relations in semantic software is that it enables complex searches that can expose new information in significantly large knowledge domains. Ontological searches also can discover information that is closely related, but not necessarily an exact match for the search. Both features are particularly powerful for learning purposes, since they have the potential to generate new insights that would otherwise remain obscured. Ontologies can also help break down knowledge barriers between different groups of experts, especially helpful in large organizations where expertise has often become compartmentalized. An ontology-based search can span these various expert groups, thus making it far more effective and efficient for any employee to access the relevant information.

3.4.2. Support to Training

The taxonomy for decommissioning can already support training by organizing knowledge into recognizable categories and indicating important concepts for decommissioning. An ontology would enable a faster learning curve for employees by making explicit the associations between concepts that they are not yet able to infer themselves. In other words, the ontology explains the 'why' and 'how' key taxonomy concepts are related. This allows personnel to seek out information on their own in a more robust way.

An ontology-based knowledge management system can deal with frequently asked questions so that training time can be spent on more value adding interactions. However, this cannot replace entirely the benefit of conversations or demonstrations, and hence is not a substitute for the relationship between a mentor and mentee.

3.4.3. Process Modelling

Whilst a taxonomy might be developed to represent the different activities of a particular process (each activity being a different concept in taxonomical terms), ontological relations are then the basis for process modelling. They establish relations between activities and can also establish relationships between activities and entities (e.g., people or facility components). This can help a business optimize the overall process by understanding how the individual parts interact with each other. An ontology that establishes the rules of a process could be used, for example, to develop the interfaces that connect separate applications e.g., coding acceptance criteria for transferring information from one part of an organization to another. If a common, internationally based standard is then adopted such as SKOS, then the activities have the potential to interface not just within the organization but across organizations, such as with suppliers or regulators.

3.4.4. Machine Reasoning

The application of machine reasoning is becoming increasingly common to assist decision making and directly control actions. Whilst not yet common in the field of nuclear decommissioning, there are many potential applications that would benefit from machine reasoning such as: automated cut planning and execution to optimise material segregation and packing efficiency; determining the logic for activities to minimize dose uptake; or data management to record and track relevant information.

The use of machine reasoning benefits from an ontological basis. Using only a taxonomy yields incomplete results since a taxonomy lacks the relationships that an ontology offers. Therefore, in a similar fashion to the training of employees (see 3.4.2. above), an ontology makes explicit decommissioning knowledge in a way that helps build and use algorithms for machine learning.

4. OUTLOOK

4.1. BENEFITS OF A STANDARD DECOMMISSIONING TAXONOMY

The overall intent of the taxonomy proposed in this publication is to promote knowledge management and sharing to facilitate decommissioning. This taxonomy provides structure for decommissioning knowledge. It will help experts codify knowledge in a way that makes the knowledge explicit, for example, context and application that is derived from experience. A taxonomy is also a prerequisite to building a comprehensive ontology for organizing decommissioning knowledge.

Properly structured and accessible decommissioning knowledge is a valuable resource, from which some organizations in the decommissioning supply chain may wish to realize commercial value. In such a case, there is also a strong benefit in structuring the knowledge in a manner that is standardized so that the value is more evident, and the knowledge is more readily accessible.

4.2. PROMOTING INTEROPERABILITY OF KNOWLEDGE SYSTEMS

Interoperability describes the extent to which systems and devices can exchange data and interpret that shared data. For two systems to be interoperable, they have to be able to exchange data and subsequently present that data such that it can be understood by a user.

The key benefits of interoperability are:

- It expands the knowledge base accessible to the user.
- It allows users' work applications access to the knowledge management domain.
- It enables systems to send and receive information directly.
- It promotes a virtuous cycle of encouraging data uniformity which in turn makes interoperability easier.

This initiative demonstrated the first step in interoperability by the direct export of the SKOS structured decommissioning taxonomy from a proprietary software tool to an open-source platform being used to develop the ontology of the PLEIADES project. Although developed under very different contexts, this exercise showed the feasibility of combining the PLEIADES ontology and the decommissioning taxonomy across platforms. Full interoperability could be achieved using this structural connection.

This could in turn lead to establishing a data connection between the PLEIADES Application Programming Interface (API) and, for example, the INIS repository using the decommissioning taxonomy as the linking structure. This would allow a user operating within the PLEIADES ontology to directly access the wealth of information stored in INIS.

4.3. FURTHER IMPLEMENTATION OPPORTUNITIES AT INTERNATIONAL LEVEL

4.3.1. Promoting Adoption of the Standard Taxonomy

The three sponsoring organizations all aim to promote the sharing of knowledge in the domain of decommissioning, as in other nuclear sector domains. Several mechanisms are used to achieve this objective, including:

- Preparation of reports which aim to describe current good practice applicable to the activity in question.
- Organization of technical meetings, workshops and conferences at which practices in participating organizations are described and discussed.
- Use of electronic media to capture, analyze and promulgate information on relevant current practice.

The outputs from the above activities are widely circulated and used by the professional decommissioning community, e.g., such that those accessing the material can understand the range of approaches being used internationally. Depending on the need, such material may also contribute to benchmarking exercises, where users wish to compare their own experiences with those from other programs.

The intent of the sponsoring organizations is that the taxonomy outlined in this publication be implemented in future outputs from the various activities described above, including in systems which capture and organize decommissioning knowledge. Although it will necessarily be at the discretion of Member State organizations whether to use the taxonomy or not, it is hoped that it will be increasingly adopted in the decommissioning domain, thus facilitating easier access to knowledge likely to be helpful to implementation of their decommissioning programmes. Additionally, adding the decommissioning taxonomy to the INIS thesaurus will provide an immediate benefit in terms of improved searching of the historical wealth of information stores in INIS for decommissioning knowledge.

The development of a joint publication on decommissioning taxonomy signals an intent to encourage the standardization of terminology used in the domain of decommissioning; this is considered to be an important pre-requisite for improved knowledge sharing. The extent to which this occurs in practice will ultimately be determined by whether the proposed standard technology is adopted in knowledge systems maintained by Member State organizations. The sponsoring organizations intend to use their working groups and networks of professionals to publicize the developed taxonomy and to explain the benefits from its use.

4.3.2. IAEA

In addition to the regular publication of technical reports which address a wide range of issues pertinent to the planning and implementation of decommissioning projects, IAEA also maintains relevant knowledge organization systems which are located on electronic media platforms. These include a knowledge organization system – Nuclear Wiki – located on a MediaWiki platform and several online databases which contain operational and decommissioning information relevant to different generic types of nuclear facility: PRIS (nuclear reactors); RRDB (research reactors) and iNFCIS (fuel cycle facilities).

The Nuclear Wiki is currently being maintained as a resource for use by the professional nuclear community. In addition to other topics, it contains articles related to several information domains associated with waste management and decommissioning, including management for safety. The articles contained in the decommissioning domain address several information categories, including applications (main activities); methods; technologies; objects and finally case studies, describing Member State experiences in undertaking a particular activity. Information presented in the articles has associated metadata, i.e., information categories described in the articles are associated explicitly with a previously assumed taxonomy and ontology.

The IAEA intent is that decommissioning-relevant information in the Nuclear Wiki will be adjusted so that it is associated with metadata that is compatible with the standard decommissioning taxonomy presented in this report. The core concepts will directly influence the decommissioning metadata while the proposed enabling concepts will enable the decommissioning domain to link to the safety and waste domains without prejudicing the global definitions for those other domains. This process will entail some additional efforts as the currently existing articles were oftentimes written without having benefit of a standard decommissioning taxonomy as presented in this publication.

4.3.3. OECD-NEA

As part of its remit in facilitating co-operation and promoting excellence among countries with an advanced nuclear programme, the OECD-NEA played an active role in developing the taxonomy. In addition, the proposed taxonomy has been reviewed by several NEA bodies:

- Standing Technical Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM).
- Expert Group on Knowledge Management for Radioactive Waste Management Programmes and Decommissioning (EGKM).
- Expert Group on a Data and Information Strategy for the Safety Case (EGSSC).

In the context of NEA work, the intention is to use the decommissioning taxonomy for maintaining and cross-referencing documents, as well as structuring internal databases, at least throughout the CDLM and its subsidiary bodies. Further use by other NEA Standing Technical Committees and Sub-Bodies will be encouraged as appropriate.

4.3.4. EC-JRC

The European Parliament and European Council have noted the importance for European Union (EU) members to ensure that the expertise arising from ongoing decommissioning programmes is gathered, retained and disseminated to support the future industrial decommissioning projects in the EU. The EC-JRC was designated to lead the development of this specific decommissioning knowledge management system.

The overall vision is to create a ‘community of knowledge’ on nuclear decommissioning in the EU, allowing relevant knowledge to be ascertained from existing decommissioning programmes, its dissemination to all interested parties, including operators, industrial actors, safety authorities and education and training organizations. A dedicated team has been created within the JRC, with responsibility to oversee the development of knowledge products and stimulate the interaction with the interested parties in the field of decommissioning.

Against the above background, a standard taxonomy serves as a basis for the collecting, storing and disseminating knowledge. The envisaged platform for the dissemination of knowledge will benefit from the implementation of the taxonomy by enabling dissemination of information, knowledge and best practices – in standardized formats - to different groups of users and will facilitate integration with existing knowledge initiatives and databases in the decommissioning domain.

It is envisaged that interested parties could benefit in a variety of fields, such as on governance aspects, project management practices and maturity levels of potentially applicable research and development (R&D) technologies. Areas of sharing and potential cooperation may include:

- Education and training: the promotion and dissemination of knowledge and information on the various existing education and training opportunities.
- Supporting R&D: to find pragmatic methodologies that shorten decommissioning programs and reduce costs.
- Standardization of methodologies and technologies: the learning process from current and future decommissioning activities should allow for improved productivity and reduce costs and delays.

5. CONCLUSIONS

From the perspective of international organizations supporting decommissioning activities, it is important to establish standard approaches to the structuring of the rapidly growing body of decommissioning knowledge. Implementation of such a structure would facilitate knowledge management at the organizational level and knowledge sharing between organizations. The SKOS compatible taxonomy for decommissioning provides the necessary structure and a basis for the definition of concepts.

The main potential benefits of using a shared standard decommissioning taxonomy are:

- Enabling the creation of a structured inventory of knowledge that grows with accumulated experience.
- Assisting the development of knowledge management systems enabling effective retrieval of information to support decision making for decommissioning.
- Evaluating the effectiveness of knowledge management systems and identifying potential gaps.
- Facilitating workforce training and development.

Adoption of the taxonomy by an individual organization will be influenced by local factors and is therefore a matter for that organization to decide based on its specific situation. Nevertheless, widespread adoption of the proposed taxonomy will facilitate access to decommissioning knowledge. The three sponsoring organizations aim to apply the proposed taxonomy in their own publications, electronic media resources and knowledge systems.

Recent significant advances in information technology make possible the creation of extensive ontologies with correspondingly advanced search capabilities. These technologies rely on internationally recognized standards to allow interoperability of knowledge management systems. This publication discusses features pertinent to the development of ontologies for the decommissioning domain and encourages the creation of ontologies where there is value in doing so.

APPENDIX I CASE STUDIES

I.1. INTERNATIONAL NUCLEAR INFORMATION SYSTEM

I.1.1. Background

The International Nuclear Information System (INIS) Repository of the IAEA contains bibliographic references and full-text documents, including scientific and technical reports, conference proceedings, patents, and theses.

INIS also maintains a multilingual thesaurus in Arabic, Chinese, English, French, German, Japanese, Russian and Spanish, providing translations of thousands of technical terms that help with navigating and searching the Repository. The terminology is intended for use in subject descriptions for input or retrieval of information in INIS, as well as in other information management systems.

The INIS Thesaurus serves as a major tool for indexing and describing nuclear information and knowledge in a structured form. It contains several concepts that are used to describe the knowledge domain of decommissioning, but since the INIS Thesaurus covers the whole knowledge domain of nuclear science and technology it does not currently contain the same level of detail as the decommissioning taxonomy developed in this publication. Fig. 5 below shows a screenshot capturing the current detail.

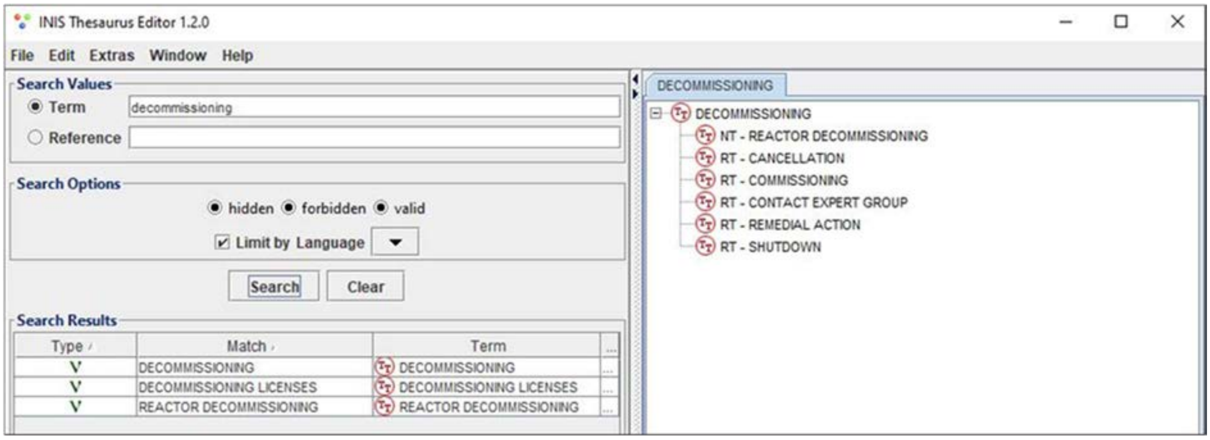

Fig. 5. The word block structure of the concept 'Decommissioning' currently in the INIS Thesaurus.

Thus, the decommissioning taxonomy can serve to enrich the INIS taxonomy in the specific area of decommissioning and lead to improved searching of the entire INIS Repository for decommissioning related content.

I.1.2. Approach and results

The analysis of this case study involved 707 PDF documents extracted from the INIS Repository that were considered to have some relevance to decommissioning. These documents were uploaded to the PoolParty software tool and a corpus analysis with the decommissioning taxonomy was performed. A total of 78 (out of 80) terms of the proposed concepts were found in the pool of documents.

Further inspection of the terms was then carried out to see if the concepts represented by the terms did indeed match i.e., to validate the initial results from the software tool. For most terms the match was valid. However, for some terms the concepts were markedly different even though the term wording was very similar or even identical. Table 1 below highlights four of those terms.

TABLE 1. SIMILAR TERMS REPRESENTING DIFFERENT CONCEPTS.

Decommissioning Taxonomy	INIS Thesaurus
Treatment	Treatment (Therapy)
Preparation	preparation (Chemical)
Storage	Storage (Spent fuel)
site characterization	Site characterization

The concept of ‘treatment’ (an enabling concept from the waste domain) was often associated with medical practice rather than waste management. The term ‘treatment’ is more often used in the sense of making chemical solutions than in the sense of preparing for something. Even where the term might have been expected to have a quite narrow application such as ‘site characterization’ the concepts varied with use in the thesaurus. It could be linked to determining locations for waste disposal or to ascertain the radiological condition of a nuclear site. This exercise clearly demonstrated that expert validation of terms is necessary.

I.1.3. Findings

The validation of the decommissioning taxonomy showed that 80% (i.e., 24 out of 30 concepts) of the newly created vocabulary was found within a broad frequency of occurrence range between 2358 and 21 in the full text of the documents (see Table 2 below).

TABLE 2. CONCEPTS EXTRACTED FROM THE POOL OF INIS DOCUMENTS AFTER CALCULATION OF THE CORPUS ANALYSIS IN POOLPARTY

Extracted Concepts	Frequency	Relevance	Most Frequent Label	Broader Concepts
dismantling	2358	336.64	dismantle	
final radioactivity survey	30	177.48	final radioactivity survey	termination of authorization
decontamination	1228	124.56	decontamination	dismantling
post operational activities	233	88.07	POCO	post-shutdown
management system	955	69.85	management system	preparation
characterization	4649	67.07	characterisation	decommissioning
containment	1702	65.45	containment	dismantling
cleanup	2228	48.19	remediation	decommissioning
site characterization	146	43.63	site characterization	characterization
cutting	755	37.5	cut	dismantling
demolition	729	35.58	demolition	decommissioning
decommissioning	26638	21.49	decommission	
post-shutdown	2296	19.31	shutdown	decommissioning
maintenance	1997	16.56	maintenance	facility management

TABLE 2. CONCEPTS EXTRACTED FROM THE POOL OF INIS DOCUMENTS AFTER CALCULATION OF THE CORPUS ANALYSIS IN POOLPARTY (cont.)

Extracted Concepts	Frequency	Relevance	Most Frequent Label	Broader Concepts
site security	24	14.32	site security	facility management
surveillance	607	13.01	surveillance	facility management
waste characterization	131	10.87	waste characterisation	characterization
facility characterization	55	10.81	facility characterisation	facility characterisation
preparation	1684	10.44	preparation	decommissioning
spent fuel removal	302	9.05	defuel	post-shutdown
remote operation	120	8.12	remote control	dismantling
termination of authorization	65	7.05	delicensing	decommissioning
financing	1012	6.41	finance	preparation
environmental monitoring	124	0.48	environmental monitor	
decommissioning planning	1163	0.14	decommissioning plan	preparation
facility management	34	0.12	plant management	decommissioning
material routing	21	0.1	material handle	dismantling
facility reconfiguration		0		
logistics reconfiguration		0		

In summary, the notable findings were:

- Four terms, as shown in Table 1, were found with low hit rates (relevance <1) and two terms with zero hit rates (relevance 0). However, these terms represent key concepts in decommissioning and as such, even though the hit rate was low, it was deemed they be retained to focus attention on the concepts when capturing knowledge.
- The exercise and software proved useful when searching for synonyms. It was both easy and quick to search the body of documents for alternate terms, which were included as appropriate in the taxonomy.
- The software was used to generate automated suggestions for linking terms. However, the actual matching of terms still had to be carried out or validated manually to assure that the terms did indeed represent the same concept, with the same definition and identical scope.
- Once the decommissioning taxonomy is added to the INIS Thesaurus, the combined vocabulary can be used to search content in the INIS Repository for decommissioning knowledge. This can also be used for indexing documents through a semi-automated (reference documents) indexing project used by INIS.

I.2. INTERNATIONAL STRUCTURE FOR DECOMMISSIONING COSTING

I.2.1. Background

The International Structure for Decommissioning Costing (ISDC) [2] is a joint initiative by the OECD-NEA, the IAEA and the EC to bring standardization to the format, content and practice of estimating decommissioning costs. The aim of the report is to both improve the quality of decommissioning cost estimating and to create a common structure for the purposes of comparison and learning.

For developing the decommissioning taxonomy, the costing structure (rather than the costing guidance) of the ISDC was used. This structure is stable, although the costing guidance for decommissioning is continually evolving [6]. Therefore, the ISDC cost structure is a useful reference to both inform the decommissioning taxonomy and to enable the decommissioning taxonomy to link to cost information. The ISDC cost structure (see Fig. 6 below) represents cross-industry approach to cost estimation, so linking the decommissioning taxonomy to the ISDC demonstrates some ability to link taxonomies across multiple industrial domains.

I.2.2. Approach

A small team of decommissioning experts, supported by a knowledge management expert, attempted to map the decommissioning and cross-cutting concepts to the Level 1, Level 2 and Level 3 activities in the ISDC (see Fig. 6 below). Both the taxonomy concepts and the ISDC activities were coded in PoolParty so that the software could be used to create the links. The steps followed were:

1) For each taxonomy concept, attempt to find the equivalent concept in the ISDC cost structure and create a link where possible.
2) Check the totality of the ISDC structure for terms that might be important for decommissioning but may have been missed from the taxonomy.
3) Test the terms chosen for use in actual documents, and for synonyms, by searching a sample of 707 documents extracted from INIS.
4) Update the decommissioning terms and definitions based on the findings.

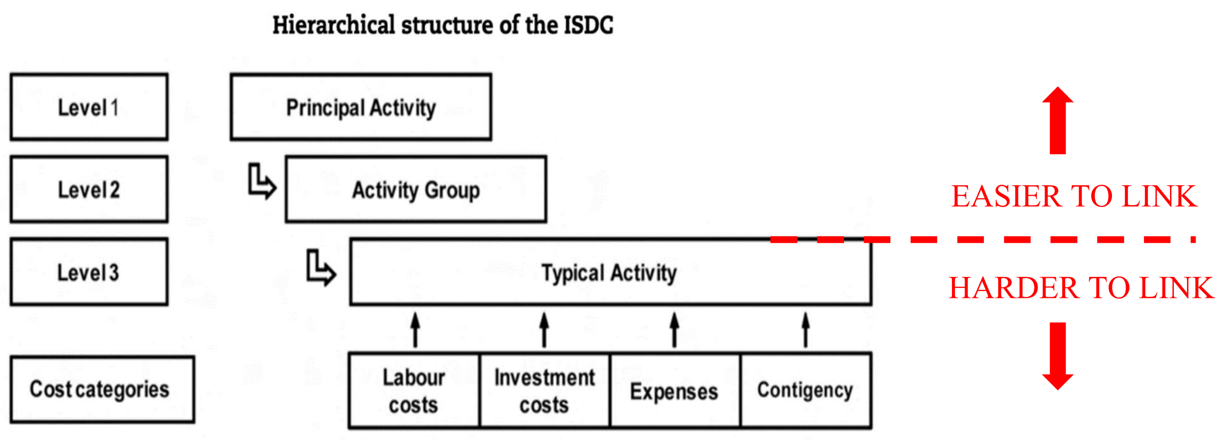

FIG.6. Representation of ISDC cost structure (source ISDC, NEA Report No.7088)

I.2.3. Results

The following points summarize the key results:

– The mapping exercise had to be carried out manually throughout. This was because the ISDC references use a hierarchical numbering system (e.g., #.#.#) as a key part of the activity label.

This allows the same 'generic' wording to be used in different parts of the cost structure, thus simplifying the activity labels, whilst maintaining unique activity identifiers. This is typical of cost structures and work breakdown structures in projects. However, this numbering is not compatible with PoolParty automatic linking tools.

- While many exact and partial correlations existed between the terms in the decommissioning taxonomy and the ISDC structure, the definition (and thus scope) of many of the ISDC activities differed from the taxonomical definitions and structure of the decommissioning and cross cutting domain taxonomies. A few of the differences represented wholly different interpretations of the meaning for the term, but more often the decommissioning taxonomy term was a subset or superset of the ISDC term(s). This required multiple links i.e., a decommissioning term mapped to multiple ISDC terms or vice versa. This is to be expected, the ISDC was developed as a structure for costing within the environment of a defined project, a very different purpose when compared with a taxonomy that seeks to structure an entire knowledge domain. Fig. 7 below illustrates the various types of matches found between the decommissioning taxonomy and the ISDC, clearly illustrating the need for multiple connections to certain concepts.

Local Concept	Mapping Property	Remote Concept
licensing	skos:narrowMatch skos:broadMatch	01.0501 License application and license approvals
safety regulation	skos:relatedMatch	08.0400 Health and safety
safety regulation	skos:relatedMatch	08.0900 Health and safety by contractors (if needed)
safety regulation	skos:relatedMatch	01.0303 Safety, security and emergency planning for site operations
preparation	skos:exactMatch	01 Pre-decommissioning actions
decontamination	skos:narrowMatch skos:broadMatch	04.0304 Decontamination of remaining systems
decontamination	skos:narrowMatch skos:broadMatch	04.0703 Decontamination of areas in buildings
maintenance	skos:closeMatch	06.0201 Inspection and maintenance of buildings and systems
environmental monitoring	skos:exactMatch	06.0403 Environmental protection and radiation environmental monitoring

FIG.7. Screenshot of the software used to match the terms between the decommissioning taxonomy and ISDC

- It was generally found to be easier to link terms at a higher level. Comparatively few links were made to the ISDC level 3.

- Some terms from the ISDC could not be mapped into the decommissioning taxonomy. These terms represented key decommissioning activities, and thus highlighted gaps in the decommissioning taxonomy that had to be addressed.

I.2.4. Findings

The mapping exercise proved to be valuable. It demonstrated that it is possible to link the decommissioning and the ISDC taxonomies. These are in the same industrial sector but were developed for different purposes. The ISDC is increasingly used as a format to present cost information (e.g., see Costs of Decommissioning Nuclear Power Plants, 2016, NEA No. 7201) and to being able to connect these knowledge domains is useful.

The exercise also generated some key learning, both generically and to help improve and update the decommissioning taxonomy. In summary:

- It was generally found that at higher levels the concepts were easier to match, but that at increasing granularity there was a differing interpretation of how the concept should be structured, leading to greater variation between concept scopes at lower levels. As a result, it was decided to define only the top-level enabling concepts. This retained the functionality and assured more robust concept matching.

- Some concepts in the decommissioning taxonomy and the ISDC used the same terms but covered markedly different scope. Therefore, matching of concepts between these taxonomies could not be carried out in a wholly automated fashion. Automatic term matching can provide a start (see finding below), but expert judgement is needed to verify the match is a valid one, even where the terms are the same. Conversely, using only automatic matching may miss some links if the terms are different but represent the same concept. Expert judgement can find these and then help make a match. The risk of missing these links is reduced if one of the taxonomies has a robust set of synonyms for each concept, so the automated searching can find any alternate terms used. The ISDC was used in this way to provide additional synonyms for the decommissioning taxonomy.

- Using non-standard characters in concepts can hinder automated search features. The numerical indexing in the ISDC terms meant that an initial automatic matching was not possible, requiring manual editing at the outset. This affected the efficiency of the exercise but did not reduce the effectiveness of the results. The terms of the decommissioning taxonomy use only standard characters and are as concise as practicable.

- The exercise allowed some key missing concepts to be identified and added to the decommissioning taxonomy.

I.3. HORIZON 2020 PLEIADES PROJECT

There are various tools available to plan, follow and analyse decommissioning projects using 3-D information and apply Building Information Management (BIM). The EU-funded PLEIADES project aims to provide an interface or platform to allow these tools to be connected.

The consortium partners in PLEIADES each have applications using BIM or knowledge management systems for decommissioning. The difficulty is that each software package, and the underlying databases, have been developed independently. This is to be expected since each organization is subject to different regulatory systems, has different roles (industry, research and regulatory organizations), has different aims and also different use cases for the application of their software.

To derive a common interface, it was necessary to align the partners on a common understanding of a decommissioning project. In order not to bias the approach by pre-existing approaches, the group held a series of expert workshops with cross-industry participation to develop a top-down decommissioning ontology (see. Fig. 8). The effort required to derive the ontology was significant.

There were regular exchanges between PLEIADES consortium and the taxonomy initiative described in this publication. These exchanges sought to align the concepts within the PLEIADES ontology and those of the decommissioning taxonomy. This alignment enabled the PLEIADES interface to understand the concepts in the decommissioning taxonomy.

A benefit of integrating the taxonomy into the PLEIADES ontology lies in the future use of the interface. The interface will provide a common Application Programming Interface (API) for the individual applications. This API can either directly connect to knowledge management systems that are using the taxonomy, or individual software solutions can import and use the taxonomy provided. This allows the software to retrieve additional information from external repositories that may help the end user find relevant techniques and comparable situations for certain tasks (e.g., the segmentation of a steam generator).

The application of a SKOS structure also allows more variability in the terms used (applying narrower and broader concepts) and the ontology ensures a common understanding of fundamental dependencies within decommissioning projects. Thus, this approach can be expected to retrieve better results from a range of information sources, including information that would not be found by simple keyword search.

I.4. SUMMARY OF CASE STUDY LEARNING

There are some generic points that can improve the effectiveness and efficiency by which taxonomies and ontologies can be created.

- Standardizing the terms and definitions can make the initial connectivity almost totally automated for systems based on the SKOS standard. Nevertheless, some expert review is still essential to verify that the alignment between terms is valid.

- Avoiding any form of special characters in the term is important to allow software to perform efficiently.

- When new concepts are introduced a taxonomy (and by extension any ontological relations) needs to be reviewed. Introducing e.g., new technologies can result in new concepts and terms coming to the fore. Therefore, it is important to realize that all taxonomies and ontologies require regular maintenance.

- The use of SKOS standard automatically embraces the ability to connect between different languages with synonyms, although assuring the correct translation of a term would still require approval by the publishing entity.

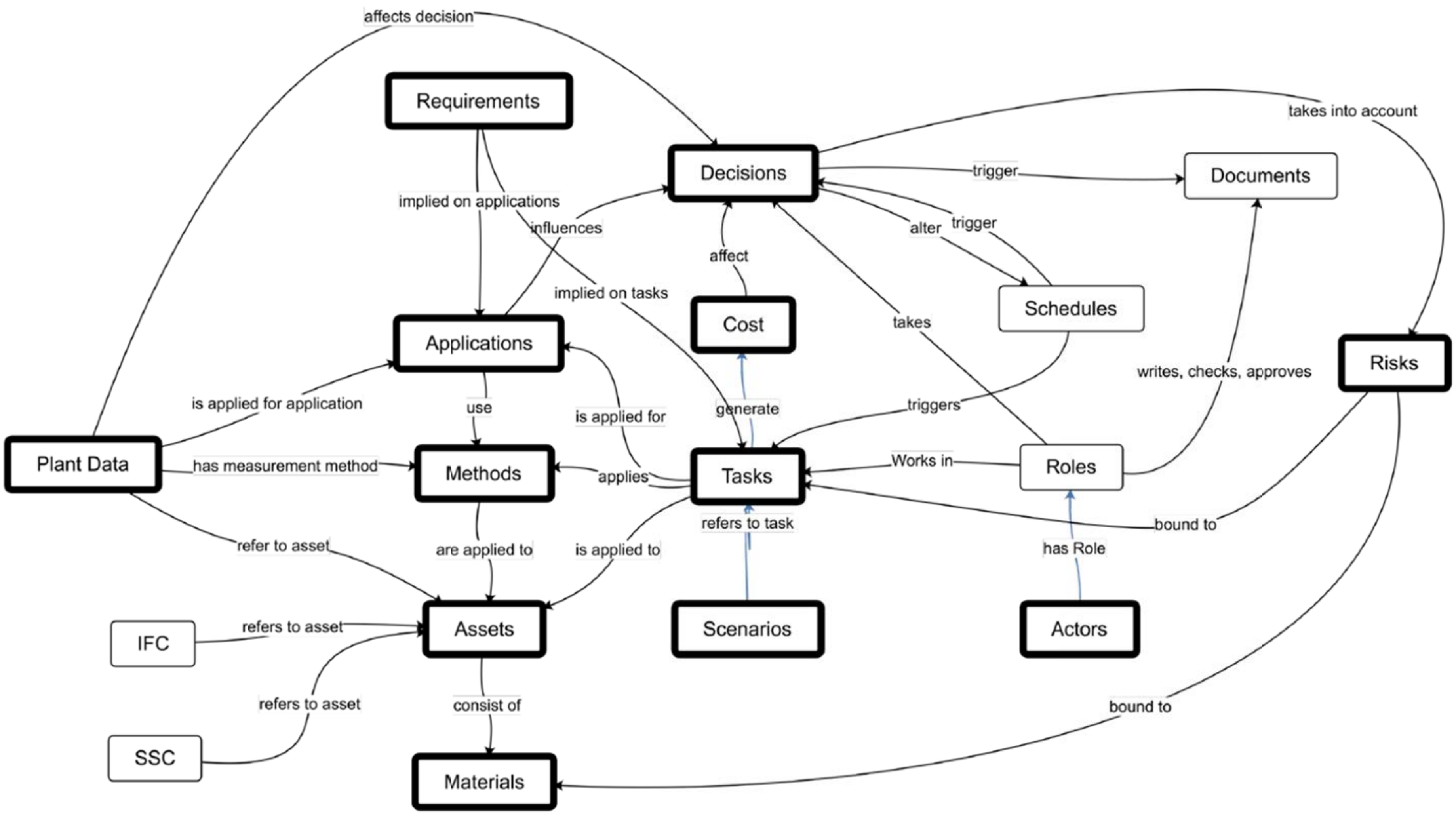

FIG.8. Decommissioning core ontology of the PLEIADES project (courtesy of PLEIADES consortium)

APPENDIX II PROJECT MANAGEMENT TERMINOLOGY

The cross-cutting domain of programme management is fundamental to the implementation of decommissioning. It includes, for example, activities in the areas of programme and project management, contracts, supply chain management, financial management, human resources management, knowledge management and management of interactions with interested parties.

Some of the terminology within the cross-cutting domain of programme management is well-established in nuclear decommissioning, for example project management terminology, and there is considerable international guidance relating to some areas, such as cost estimation for nuclear decommissioning and knowledge management for nuclear organizations. For other areas within this domain, there is limited international guidance specifically applicable to nuclear decommissioning, or the consideration of these topics at the international level is at an early stage or evolving, such as human resource management and programme management. Moreover, in many of the areas within the domain, there is considerable variation between states and organizations in terminology, definitions and practice in these areas. From this perspective, further consideration is needed before recommending specific terminology and definitions for the programme management domain in nuclear decommissioning.

Many of the areas within the domain are not unique to decommissioning, and the sorts of programme management activities that are of interest in the context of a decommissioning taxonomy are also of interest in other contexts, and terminology in widespread use are defined by other organizations and communities. There is a need to recognize these wider uses when selecting and defining the terms for cross-cutting domain of programme management in the context of nuclear decommissioning. Given the cross-cutting nature of these issues, it may be appropriate to give greater weight to established and internationally supported definitions for these cross-cutting terms where these are in common use outside of the narrower nuclear decommissioning context, unless there is a clearly demonstrable benefit to having bespoke programme management terms and definitions specifically for nuclear decommissioning.

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DEFINITIONS

Definitions are primarily taken from internationally recognized sources including the IAEA Nuclear Safety and Security Glossary [4], the International Structure for Decommissioning Costing [2] and the IAEA General Safety Requirements Part 6 [5]. Where the term is widely used to represent a different concept within the decommissioning domain, the definition has been adjusted accordingly. This does not prejudice any definition associated with the generic use of the term, nor does it seek to redefine the broader concept the term represents, it merely reflects the fact that within the decommissioning knowledge domain the term has become widely associated with a slightly different concept.

PRIMARY DOMAIN – DECOMMISSIONING

Term	Synonym(s)	Definition	Explanatory Notes
Decommissioning		Decommissioning is the set of administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. This does not apply for that part of a disposal facility in which radioactive waste is emplaced.	Taken from the IAEA Nuclear Safety and Security Glossary.
Preparation		Activities required for authorizing decommissioning.	This definition is aligned with requirements contained with IAEA General Safety Requirements Part 6, Sections 4 to 7 inclusive (Requirements 7 to 11 inclusive). For a definition of the specific term 'authorization' see the IAEA Nuclear Safety and Security Glossary.
Financing	Decommissioning fund	Activities required to ensure adequate financial resources are available when necessary for safe decommissioning.	This definition is aligned with the IAEA General Safety Requirements Part 6, Section 6 (Requirement 9).
Decommissioning planning		In accordance with regulatory requirements, the preparation and maintenance (throughout the facility lifetime) of a plan to show how decommissioning can safely achieve the defined end state.	This definition is aligned with the IAEA General Safety Requirements Part 6, Section 7 (Requirements 10 and 11). Note, an aspect of decommissioning planning will produce a *decommissioning plan*, but the definition encompasses a broader range of preparation activities.
Management system	Integrated management system	The set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner.	This definition aligns with the IAEA Nuclear Safety and Security Glossary and the IAEA General Safety Requirements Part 6, Section 4 (Requirement 7).
Logistics reconfiguration		Modification of logistics facilities and services to enable decommissioning activities.	A proposed definition, adapted from ISDC 'modification of auxiliary systems'.

Term	Synonym(s)	Definition	Explanatory Notes
Post operation	Deactivation, transition to decommissioning	Activities relating to the permanent cessation of operation of a nuclear facility.	Adapted from a combination of IAEA Nuclear Safety and Security Glossary and ISDC. The term applies to key activities undertaken to safely transition the facility from an operational shutdown state to decommissioning or other longer term quiescent state and includes activities such as defueling, draining of systems, closed loop decontamination, removal of operating wastes and sludges, etc. This stage primarily addresses the requirements of IAEA General Safety Requirements Part 6, Requirement 14 (section 8.10), but has been given a broader definition to encompass useful decommissioning preparation activities undertaken prior to dismantling as reflected in the IAEA Nuclear Safety and Security Glossary (which recognises some limited physical preparation for decommissioning)
Spent fuel removal	Defueling	Removal of spent fuel from a reactor core or spent fuel pool and transfer of fuel to spent fuel storage.	This is a proposed definition adapted from ISDC.
Post operational cleanout		Actions undertaken following permanent shutdown of a nuclear facility to reduce radiological and chemotoxic hazards in a facility to a level at which plant safety can be assured by primarily passive means.	This is a definition proposed from UK practice. Following fuel removal, POCO embraces activities such as the removal of any residual operational wastes or operational furniture, removal of residual liquid heels and removal of sludges and any closed loop decontamination allowed under the authorization. This activity is congruent with the IAEA Nuclear Safety and Security Glossary term 'shutdown' which recognises the need for preparation activities before decommissioning.
Dismantling		The taking apart, disassembling and tearing down of the structures, systems and components of a facility (within a radiologically controlled area) for the purposes of decommissioning.	Adapted from a combination of IAEA Nuclear Safety and Security Glossary and ISDC. The intent is to distinguish those activities that are nuclear knowledge domain specific (i.e., require radiological controls to be exercised) from generic demolition activities (see below). Note that most non-nuclear industries would not differentiate dismantling from demolition.

Term	Synonym(s)	Definition	Explanatory Notes
Facility reconfiguration		Modification of structures, systems, components and access routes within the facility to support decommissioning activities, including where necessary the provision of safe enclosure(s).	A proposed definition, adapted from ISDC 'modification of auxiliary systems'.
Cutting	Segmentation	The act of separating or dividing structures, systems, components or waste using force or energy to divide the material.	Proposed definition based on the scientific principles behind cutting. It uses the word 'divide' to distinguish from the concept of disassembly, which is merely dismantling by reversing the operation of features used during original installation.
Decontamination		The complete or partial removal of contamination by a deliberate physical, chemical or biological process.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Containment		Methods or physical structures designed to prevent or control the release and the dispersion of radioactive substances.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Remote operation	Remote control	The ability to perform activities that are physically distant from an operator.	Proposed using typical English usage. It makes no distinction on what activity is performed, and thus allows the term to be used in combination with and/or as a modifier to other methods such as cutting or material handling.
Material management	Material handling	The setting up of routes for and subsequent removal of structures, systems, components and material in the facility.	Proposed using typical English usage. The term material is used to distinguish this concept from the subsequent waste management activities.
Demolition		The taking apart, disassembling and tearing down of the structures, systems and components of a facility (outside of a radiologically controlled area) for the purposes of decommissioning.	ISDC definition i.e., this is effectively dismantling applied out with any radiologically controlled area. It is distinguished from dismantling because the knowledge domain for this application is generic and not nuclear specific. Normal industrial practice would apply.

Term	Synonym(s)	Definition	Explanatory Notes
Cleanup	Remediation	Removal of contaminated soil and other materials from an area within the authorized boundary of a facility, typically performed under the authorization for decommissioning for the purpose of reaching the defined end state.	Adapted from the IAEA Nuclear Safety and Security Glossary definition; the term is contained within the scope of decommissioning definition. Extended to include materials as well as soil because some sub-surface structures or residual waste items etc. may be removed during this stage. Cleanup uses techniques comparable to remediation, but the activity takes place within the authorized facility.
Termination of authorization	License termination, release from control, delicensing, termination of authorization	Termination of the nuclear decommissioning authorization or license for the facility, either unconditionally or with stipulated conditions on the future use of the facility site.	This is a proposed definition, aligned with the IAEA General Safety Requirements Part 6, Section 9 (Requirement 15). For a definition of the specific term 'authorization' see the IAEA Nuclear Safety and Security Glossary.
Final radioactivity survey		Final radiological characterization survey of the facility and site following the completion of decommissioning to assure the end state for the facility has been achieved.	This is a proposed definition adapted from ISDC. For a definition of the term 'end state' used within the definition see the IAEA Nuclear Safety and Security Glossary.
Post- decommissioning arrangements	Conditional release	Establishing arrangements to assure that any remaining authorized responsibilities are adequately fulfilled.	This is a proposed definition adapted from ISDC which takes account of the concept of authorized responsibilities that extend beyond the decommissioning stage as described in IAEA General Safety Requirements Part 6, Section 9.
Facility management	Plant management	Activities to verify and assure the performance of facility structures, systems and components of a nuclear facility, to assure the safety and security of the facility and to coordinate decommissioning activities across a facility.	This is a proposed definition. It is based on the IAEA Nuclear Safety and Security Glossary definition of maintenance but is extended to embrace the need for maintaining nuclear security and the requirements for ongoing cross facility management.
Maintenance		The organized activity, both administrative and technical, of keeping structures, systems and components in good operating condition, including both preventive and corrective (or repair) aspects.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary. This includes all systems, whether safety critical or otherwise. Also, the term 'operating' refers the functionality as required under the decommissioning regime.
Inspection	Surveillance	Examination, observation, surveillance, measurement, or tests undertaken to assess structures, systems and components and materials, as well as operational activities, technical processes, organizational processes, procedures and personnel competence.	Based on the definition of Inspection from the IAEA Nuclear Safety and Security Glossary.

Term	Synonym(s)	Definition	Explanatory Notes
Site security	Nuclear security; security.	The prevention and detection of, and response to, criminal or intentional unauthorized acts involving nuclear material, other radioactive material, associated facilities or associated activities.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Characterization		Determination of the physical, chemical and radiological nature of something for the purpose of informing activities and decisions.	Adapted from the IAEA Nuclear Safety and Security Glossary but expanded to include all informational attributes that might be required to effectively plan or execute decommissioning or waste management.
Facility characterization		Determination of the physical, chemical and radiological nature of the structures, systems and components for the purpose of informing activities and decisions.	Adapted from the IAEA Nuclear Safety and Security Glossary but expanded to include all informational attributes that might be required to effectively plan or execute decommissioning or waste management.
Site characterization		Determination of the physical nature of a site, and of any potential chemical and radiological contamination for the purpose of informing activities and decisions.	Adapted from the IAEA Nuclear Safety and Security Glossary but expanded to include all informational attributes that might be required to effectively plan or execute decommissioning or waste management.
Waste characterization		Determination of the physical, mechanical, chemical, radiological and biological properties of radioactive waste to establish the need for further adjustment, treatment or conditioning, or its suitability for further handling, processing, storage or disposal.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.

PRIMARY DOMAIN – MANAGEMENT FOR SAFETY

Term	Synonym(s)	Definition	Explanatory Notes
Management for safety	Safety management	All administrative and operational activities specifically involved in eliminating, reducing or managing the potential of harm to people and the environment.	This is a proposed definition adapted from the definition of safety within the IAEA Nuclear Safety and Security Glossary.
Licensing		The process leading to issue of a legal document issued by the regulatory body granting authorization to perform specified activities relating to a facility or activity.	Adapted from the IAEA Nuclear Safety and Security Glossary.
Safety regulation	Regulatory control	Any form of control or regulation applied to facilities and activities by a regulatory body for reasons relating to nuclear safety and radiation protection or to nuclear security.	From ‘regulatory control’ within the IAEA Nuclear Safety and Security Glossary.
Environmental protection	Environmental management	All administrative and operational activities specifically involved in protection of the environment.	Protection of the environment is defined in the IAEA Nuclear Safety and Security Glossary as “protection and conservation of: non-human species, both animal and plant, and their biodiversity; environmental goods and services such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media such as soil, water and air; and natural processes such as carbon, nitrogen and water cycles”.

PRIMARY DOMAIN – WASTE MANAGEMENT

Term	Synonym(s)	Description	Explanatory Notes
Waste management		All administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste.	Taken verbatim from the IAEA Nuclear Safety and security Glossary definition of ‘radioactive waste management’.
Pre-treatment	Pre-treatment	Any or all of the operations undertaken prior to waste treatment, such as collection, segregation, chemical adjustment and decontamination.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Treatment		Operations intended to benefit safety and/or economy by changing the characteristics of the waste by changing its composition, reducing its volume or removal of radionuclides.	From the IAEA Nuclear Safety and Security Glossary but adjusted slightly to form a single sentence.
Conditioning		The operations that produce a waste package suitable for handling, transport, storage and/or disposal.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Storage		The holding of radioactive sources, radioactive material, spent fuel or radioactive waste in a facility that provides for their/its containment, with the intention of retrieval.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.
Transport	Transportation, waste transport	The deliberate physical movement of radioactive material (other than that forming part of the means of propulsion) from one place to another.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary. Note, in the context of decommissioning this definition typically applies to waste moved out of the facility or area being decommissioned (c.f. ‘material management’).
Disposal		Emplacement of waste in an appropriate facility without the intention of retrieval.	Taken verbatim from the IAEA Nuclear Safety and Security Glossary.

ABBREVIATIONS

CDLM	Standing Technical Committee on Decommissioning of Nuclear Installations and Legacy Management
EC-JRC	European Commission – Joint Research Centre
ECKM	Expert Group on Knowledge Management for Radioactive Waste Management Programmes and Decommissioning
EGKM	Expert Group on Knowledge Management for Radioactive Waste Management Programmes and Decommissioning
EGSSC	Expert Group on a Data and Information Strategy for the Safety Case
iNFCIS	Integrated Nuclear Fuel Cycle Information System
INIS	International Nuclear Information System
ISDC	International Structure for Decommissioning Costing
OECD-NEA	Organization for Economic Cooperation and Development – Nuclear Energy Agency
OWL	Web Ontology Language
PRIS	Power Reactor Information System
RDF	Resource Description Framework
RRDB	Research Reactor Database
SKOS	Simple Knowledge Organization System

CONTRIBUTORS TO DRAFTING AND REVIEW

Bales, B.	International Atomic Energy Agency
Brandauer, M.	OECD Nuclear Energy Agency
Borrmann, F.	Institut für Umwelttechnologien und Strahlenschutz, Germany
Candy, S.	Consultant
Carroll, S.	Vattenfall, Sweden
Chabeuf, J.-M.	Orano, France
Clark, A.	OECD Nuclear Energy Agency
Day, J.	Sellafield Limited, United Kingdom
Guisset, J.-P.	European Commission
Hubert, P.	European Commission
Kancsar, E.	International Atomic Energy Agency
Kinker, J.	International Atomic Energy Agency
Kockerols, P.	European Commission
Lewis, R.	Nuclear Regulatory Commission, USA
Maugis, V.	National Waste Management Agency (ANDRA), France
O'Sullivan, P.J.	International Atomic Energy Agency
Peerani, P.	European Commission
Piagentini, A.	European Commission
Piciaccia, L. A.	Norwegian Radiation and Nuclear Safety Authority, Norway
Vakula, O.	International Atomic Energy Agency
Yagi, M.	International Atomic Energy Agency

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