Safety Reports Series
No. 105

Managing Nuclear Safety Knowledge: National Approaches and Experience

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MANAGING NUCLEAR SAFETY KNOWLEDGE: NATIONAL APPROACHES AND EXPERIENCE

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SAFETY REPORTS SERIES No. 105

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Foreword

Nuclear knowledge is the basis of all nuclear activities, and the need to manage this knowledge has long been recognized by the IAEA and by Member States. Today, nuclear knowledge management has been established in many nuclear organizations and has been identified as one of the key factors that can contribute to safe, secure and efficient use of nuclear techniques.

For nuclear safety in particular, nuclear knowledge management is of high importance, since securing an adequate nuclear safety knowledge base is essential for both operators and regulatory bodies, and a lack of nuclear safety knowledge can have significant implications. Managing nuclear safety knowledge is also complex, since various types of knowledge need to be dealt with, different types of nuclear safety knowledge may have different owners, and long timescales need to be considered.

Nuclear safety knowledge management is defined in this publication as the management of knowledge relevant to or required for nuclear safety. Nuclear safety knowledge management entails using knowledge management approaches, tools and techniques for the purpose of nuclear safety.

The ultimate objective of all nuclear safety knowledge management activities is to sustain and improve the competence of individuals and the capacity of organizations or countries to use knowledge effectively and responsibly for safety (i.e. for achieving the fundamental safety objective of protecting people and the environment from harmful effects of ionizing radiation).

Member States are in different phases of implementing nuclear safety knowledge management activities. At the organizational level, many nuclear safety knowledge management activities are being undertaken, in particular in regulatory bodies and technical and scientific support organizations. At the national level, there are additional elements to consider, including the role of governments, country-wide stakeholder involvement, national human resource development, cross-organizational learning and sharing of regulatory experience, developing a national memory, national knowledge resilience, and coping with changes in technology or society.

This publication provides the conceptual basis of nuclear safety knowledge management, suggests key national level approaches and summarizes experience gained to date by Member States. The experience gained by some Member States and the lessons learned could be a basis for other Member States to develop their national level strategy or a national level coordination mechanism for nuclear safety knowledge management. In this context, this publication can serve as an additional resource that complements the previous publications relating to this subject.

The IAEA would like to express its appreciation to all of the experts who contributed to the development and review of this publication. The IAEA officer responsible for this publication was Y. Chaari of the Office of Safety and Security Coordination.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Nuclear knowledge management is a well established professional discipline in nuclear organizations and Member States, as has been reported in different international conferences dealing with human resource development and knowledge management. The IAEA has issued several publications that provide general and technical guidance on the subject to support its implementation. It has been identified as one of the key factors that can contribute to safe, secure and efficient use of nuclear sciences and technology in Member States, and its importance has been highlighted in several IAEA General Conference resolutions, most recently in 2017 in resolutions GC(61)/RES/11 [1] and GC(61)/RES/8 [2].

For nuclear safety in particular, nuclear knowledge management is of high importance, as reflected in several IAEA publications and conferences, including, among others, IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [3], the General Safety Requirements publications [4–10], the IAEA Action Plan on Nuclear Safety [11], the IAEA Report on Capacity Building for Nuclear Safety [12], the proceedings of the IAEA International Conference on Human Resource Development for Nuclear Power Programmes: Building and Sustaining Capacity [13] and the proceedings of the IAEA Third International Conference on Nuclear Knowledge Management: Challenges and Approaches [14].

In the context of this publication, the term 'nuclear safety knowledge management' is defined as the management of knowledge relevant to or required for nuclear safety. Nuclear safety knowledge management entails using knowledge management approaches, tools and techniques for the purpose of nuclear safety. However, nuclear safety knowledge management is specific and unique in the following ways:

— Securing an adequate nuclear safety knowledge base is essential for both operators and regulatory bodies.
— A lack of nuclear safety knowledge can have significant implications (i.e. well beyond an undesirable lack of efficient use of knowledge as a commercial resource).
— Various types of knowledge need to be dealt with (e.g. legal, technical and operational knowledge).
— Different types of nuclear safety knowledge may have different owners (e.g. regulatory bodies, technical and scientific support organizations (TSOs), vendors and operators).

— Long timescales need to be considered (e.g. the decision basis for regulatory decisions needs to be kept available beyond the lifetime of a particular facility or duration of an activity).

The regulatory body has a dual role with regard to nuclear safety knowledge management: as an individual organization, the regulatory body uses knowledge management to support its own functions as a regulatory body; as a regulator of facilities and activities, the regulatory body performs functions relating to knowledge management activities by others (e.g. authorized parties) in line with national regulations.

This publication provides the conceptual basis for managing nuclear safety knowledge at the organizational, national, regional and global level, but with a focus on the national level. The IAEA provides additional guidance on nuclear knowledge management at the organizational level, for example, IAEA Nuclear Energy Series No. NG-T-6.10, Knowledge Management and Its Implementation in Nuclear Organizations [15].

The information provided in this publication is in line with and supports the IAEA General Safety Requirements publications [4–10], based on the Fundamental Safety Principles [3], and various IAEA Specific Safety Requirements and Safety Guide publications [16–21]. These include requirements on human resources, education and training, information, knowledge and competences, establishing procedures, retention of records and reports, as well as the exchange of information, related to nuclear, radiation, transport and waste safety. These requirements can be addressed through, among other things, national level knowledge management.

This publication also supports the objectives and approaches featured in the IAEA Strategic Approach to Education and Training in Nuclear Safety 2013–2020 [22] and the IAEA Strategic Approach to Education and Training in Radiation, Transport and Waste Safety 2011–2020 [23].

Unless otherwise noted, safety related terms used in this Safety Report are to be understood as defined in the IAEA Safety Glossary [24].

1.2. OBJECTIVE

The objective of this publication is to provide practical guidance to support Member States in implementing IAEA safety standards relating to managing nuclear safety knowledge at the national level (i.e. beyond individual organizations' boundaries).

This publication is in line with the ultimate objective of all nuclear safety knowledge management activities, which is to sustain and improve the

competence of individuals and the capacity of organizations or countries to use knowledge effectively and responsibly for safety, that is to say, for achieving the fundamental safety objective to protect people and the environment against harmful effects of ionizing radiation [3].

1.3. SCOPE

This Safety Report articulates the underlying concepts, drivers and benefits of managing nuclear safety knowledge, with a focus on specific considerations in the Member States that have provided national reports and papers (see Annex II) describing their current national approaches and experience.

This publication is intended for use by governmental decision makers, managers, and technical and legal experts responsible for or concerned with national level safety knowledge management activities, ranging from higher level strategy development to concrete national activities and technical solutions.

This information and practical guidance will also be of interest to organizations that are part of the national nuclear safety framework and manage knowledge related to safety, including nuclear, radiation, waste and transport safety, as it applies to all nuclear facilities and activities. This includes operators of facilities and activities, nuclear safety regulatory bodies, TSOs, research organizations and universities, intergovernmental organizations, suppliers of equipment and services and other interested parties that participate in securing nuclear safety.

This publication could be beneficial to all Member States that are in the process of establishing or strengthening their programme for knowledge management in nuclear safety. This may include countries with radiation sources, those with existing nuclear power programmes and those embarking on a nuclear power programme. Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.4. STRUCTURE

This publication is divided into four main sections, with two additional annexes[1]. The annexes are available on the publication's individual web page at www.iaea.org/publications.

[1] The annexes have been prepared from the original material as submitted for publication and have not been edited by the editorial staff of the IAEA.

Section 2 describes the conceptual basis of knowledge, knowledge management and nuclear safety knowledge management, as well as the different levels on which nuclear safety knowledge management can be applied, focusing on the national level.

Section 3 describes the drivers and benefits of using nuclear safety knowledge management, first in general terms and then specifically at the national level. The national level drivers and considerations described include, but are not limited to, the role of governments, stakeholder involvement, national human resource planning, avoiding knowledge loss, transferring and preserving knowledge, and addressing or managing technological, societal and other changes.

Section 4 presents short summaries of some Member States' national approaches to nuclear safety knowledge management and experience gained to date. The information in this section highlights the importance of a coordinated national approach in order to ensure that all issues, topics, interested parties and national priorities on nuclear safety knowledge management are addressed in a systematic, coordinated and effective manner. The scope, size and depth of the coordinated national approach, strategy or mechanism varies from country to country, depending on national priorities and needs. The national experiences highlight the importance of a coordinated national approach while developing a national nuclear safety knowledge map, the establishment of national nuclear safety networks and participation in international nuclear safety networks.

The annexes contain a list of publications for further reading and selected national reports and papers presented by Member States to the IAEA Technical Meeting on Managing Nuclear Safety Knowledge.

2. CONCEPTUAL BASIS

During recent decades, knowledge management has become an established professional discipline on which nuclear safety knowledge management can be based and further developed. A number of knowledge management approaches and concepts are introduced in the subsections that follow, on the basis of which nuclear safety knowledge management will then be introduced.

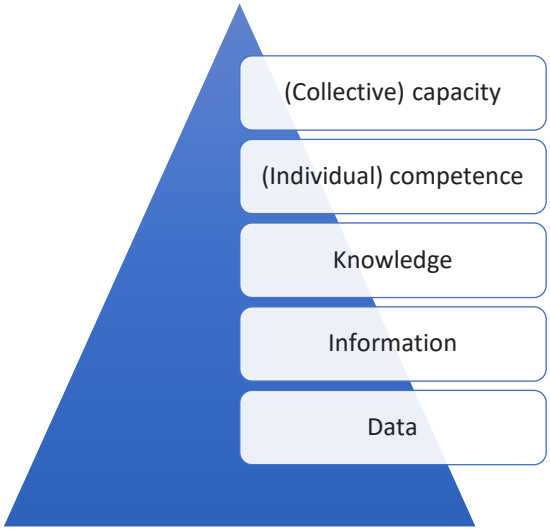

FIG. 1. The knowledge pyramid.

2.1. KNOWLEDGE

Figure 1 illustrates the knowledge pyramid, a commonly used approach to describe the relationship between data, information, knowledge, the competence of individuals and the collective capacity of groups or organizations as successively higher level entities.

The IAEA's Safety Reports Series No. 79 [25] describes the competence of a person as a combination of knowledge (as shown in Fig. 1) plus skills and attitudes (known as a set of KSAs).

Knowledge can also be thought of as the capacity for action. This connection between knowledge and action is important because it means that knowledge cannot be confused with information. It is based on the understanding that having information is not equal to being able to use it for action, in other words, only knowledge confers "capacity for effective action" [24].

2.2. KNOWLEDGE MANAGEMENT

Knowledge management has many different elements or applications, such as knowledge generation, knowledge sharing, knowledge pooling, knowledge preservation or knowledge transfer. A wide range of tools and techniques are available from the professional knowledge management sector that support or

FIG. 2. Knowledge management can have a wide range of possible applications.

facilitate each of these applications. It is important to understand that this wide variety of possible applications of knowledge management could also be used to protect knowledge or to restrict access in a structured manner. Figure 2 illustrates the variety of knowledge management applications.

The most commonly used model or description of knowledge management is the 'people — processes — technology' scheme. It suggests that knowledge management always encompasses or addresses these three essential domains, which can be found in any organization or system, and their interactions. All three are given equal consideration. Figure 3 illustrates this holistic approach.

Knowledge management, as a professional discipline today, appears to have origins in three different environments:

— People — origins in human resource management in larger companies;
— Processes — origins in professional services and consulting (mostly performance consulting);
— Technology — origins in the information technology sector (often driven by progress in available information and communication technology).

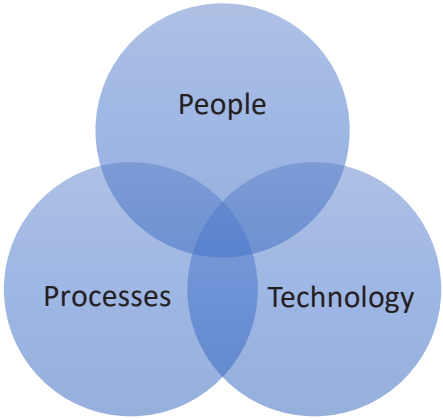

FIG. 3. Knowledge management addresses three domains: people, processes and technology.

The following example illustrates the joint consideration of people, processes and technology:

— A training course was held on a given technical subject, and 12 participants completed the course (the people component). Adding the process component would mean ensuring that the newly trained experts are linked to situations in which their new knowledge can be used (e.g. through amended job descriptions, new communities of practice or connections with untrained colleagues so that the knowledge is shared at peer level). This use of the new knowledge would then be supported by information and communication technology, for example through a web based platform for the community of practice (the technology component). All three components together would constitute knowledge management.

2.3. NUCLEAR SAFETY KNOWLEDGE MANAGEMENT

On the basis of the fundamental knowledge management concepts introduced above, this publication defines nuclear safety knowledge as that subset of knowledge owned by an organization, or other entity, that is relevant to or required for nuclear safety, as shown in Fig. 4.

For example, a regulatory body has the knowledge required for daily conduct of business. A subset of this knowledge is nuclear knowledge, and a subset of this is nuclear safety knowledge.

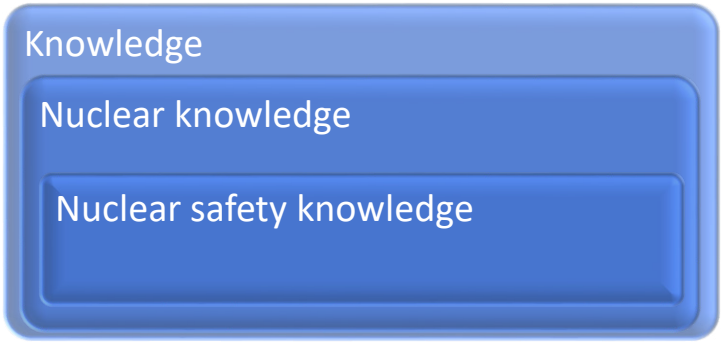

FIG. 4. Nuclear safety knowledge as the subset of nuclear knowledge that is relevant to or required for nuclear safety.

An example of knowledge that is not nuclear knowledge or nuclear safety knowledge is knowledge needed for the general daily operation of the organization (e.g. human resources, financial matters).

On this basis, nuclear safety knowledge management is defined as the management of knowledge relevant to or required for nuclear safety. Nuclear safety knowledge management entails using knowledge management approaches, tools and techniques for the purpose of nuclear safety.

2.4. NUCLEAR SAFETY KNOWLEDGE MANAGEMENT: ROLES AND RESPONSIBILITIES

As described in Section 1, the management of nuclear safety knowledge has to support the achievement of the fundamental safety objective to protect people and the environment from harmful effects of ionizing radiation [3]. Therefore, it is not limited to nuclear facility operations, or radiation protection, but encompasses all individual and collective competences in relation to the safe operation of facilities and activities, existing and new. It also includes all relevant scientific and technical disciplines related to the use of radiation sources, the nuclear fuel cycle, transport of radioactive material and radioactive waste management, with due consideration of all safety measures that need to be performed under routine conditions for preventing or reducing radiation risks or in emergency situations for mitigating the consequences of incidents and accidents.

Considering its broad scope and objective, nuclear safety knowledge management is applied at the global, regional, national, organizational and individual levels. At each level, specific phenomena, challenges and circumstances exist, which need to be addressed through separate programmes

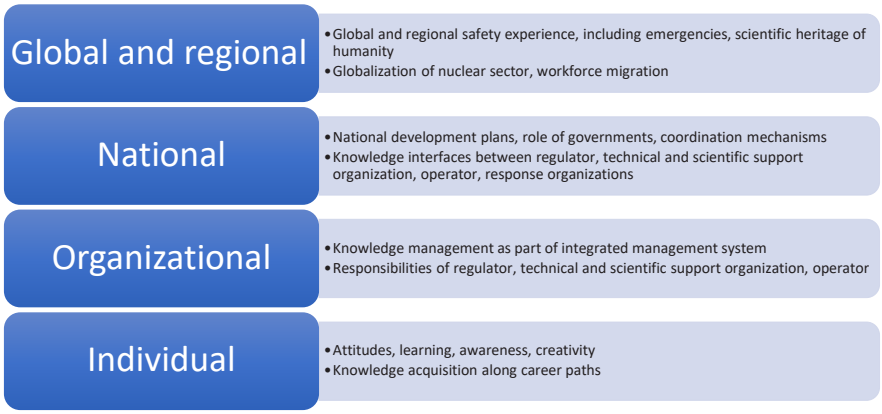

FIG. 5. Nuclear safety knowledge management is applied at several levels.

and often by different actors. Figure 5 illustrates these four levels of nuclear safety knowledge management and the unique issues that have to be dealt with at each level.

3. DRIVERS AND BENEFITS

3.1. GENERAL DRIVERS AND BENEFITS

The ultimate objective of all nuclear safety knowledge management activities is to sustain and improve the competence of individuals and the capacity of organizations and countries to use knowledge effectively and responsibly for safety, that is, for achieving the fundamental safety objective to protect people and the environment against the harmful effects of ionizing radiation [3].

The following benefits of using nuclear safety knowledge management approaches, tools and techniques have been identified for all types of nuclear organizations, facilities or activities. Each potential benefit constitutes a driver for using nuclear safety knowledge management. It is clear that not employing nuclear safety knowledge management would prevent realization of the benefits listed in subsections 3.1.1. to 3.1.11.

3.1.1. Achieve safe operation

Using nuclear safety knowledge on operational experience and lessons learned from previous incidents or accidents is an important prerequisite to reduce the occurrence of accidents and incidents during the full life cycle of nuclear installations (the safety driver).

3.1.2. Support culture for safety

Culture for safety is commonly recognized as a continuous effort to increase the commitment of a nuclear organization to consider safety improvement as an important driver of its activities. Implementation of a culture for safety requires a strong commitment by managers to encourage all individuals in an organization to maintain:

> "A common understanding of safety and of safety culture, including: awareness of radiation risks and hazards relating to work and to the working environment; an understanding of the significance of radiation risks and hazards for safety; and a collective commitment to safety by teams and individuals" [5].

It also includes a commitment by managers to ensure safety oriented behaviour from all staff. Reaching an adequate level of culture for safety is possible only if every individual has a deep knowledge of the safety aspects related to his or her tasks, and all staff members have a proper attitude to ensure that they understand the significance of their duties and the consequences of mistakes arising from misconceptions or lack of diligence. Sound and responsible management of safety knowledge is thus a key component of a culture for safety.

3.1.3. Support leadership and management for safety

Reinforcing the concept of leadership and management for safety described in GSR Part 2 [5] is one of the most important knowledge management objectives, and systemic knowledge management implementation can make an important contribution to effective leadership and management for safety.

3.1.4. Support the integrated (systemic) approach to nuclear safety

The integrated approach to nuclear safety was first suggested in the IAEA Report on Human and Organizational Factors in Nuclear Safety in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant [26]. It includes

recommendations on human resources and several knowledge management issues and suggests the development of an integrated approach to nuclear safety, which would address "human, organizational and technological factors that contribute to safety but also the complexity of the interrelationships between them" [26]. With these three factors to be considered, the systemic approach to nuclear safety connects directly to and can be supported by knowledge management, with its established three components of people, processes and technology.

3.1.5. Achieve efficiency gains

Efficiency gains can be achieved through identifying lessons learned, improvements in processes and practices, and sharing results and improvements (the efficiency driver). These gains can be in the area of economics, but also in organizational performance or in other areas.

The safety and efficiency drivers are captured and illustrated in Fig. 6. Their difference becomes most apparent when considering the loss of knowledge in each area:

— The safety driver would consider nuclear safety knowledge mandatory for operations and for regulatory activities, and makes knowledge availability essential. Loss of nuclear safety knowledge might lead to ceasing operations or regulatory oversight.
— The efficiency driver would consider knowledge primarily as a resource, which needs to be managed efficiently like every other resource. Inefficient management of that resource would yield less efficient national or organizational performance.

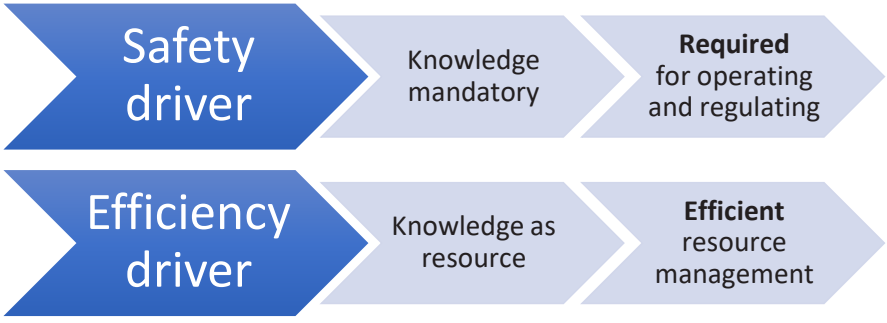

FIG. 6. 'Two driver model' for using knowledge management in the nuclear sector.

In addition to these two main drivers, there are a number of additional drivers or benefits of using nuclear knowledge management for nuclear safety, described in the subsections that follow.

3.1.6. Support intergenerational knowledge transfer

Ensuring that relevant knowledge is passed on from one generation to the next contributes to national knowledge continuity and stability, preserves accumulated scientific and technical investments and heritage and allows for planning human resources in the medium and long term.

3.1.7. Facilitate innovation and learning

Knowledge management helps to foster and facilitate innovation, problem solving and development of new approaches. It also helps facilitate sharing of knowledge and experience for organizational and interorganizational learning.

Effective knowledge management includes the deliberate and focused transfer of tacit and experience based knowledge, which facilitates the transformation of information into knowledge for entry level professionals. Knowledge transfer as a focused learning outcome improves individual competence and the development of actionable knowledge.

3.1.8. Identify and protect sensitive knowledge

Knowledge management is a key instrument for identifying, protecting and sharing knowledge with a structured and controlled approach and achieving responsible use of nuclear knowledge. This is particularly important when managing sensitive security knowledge and safeguarding intellectual property knowledge, which is an essential part of nuclear activities.

3.1.9. Contribute to an efficient and effective response in a nuclear or radiological emergency

Managing relevant information and knowledge at the preparedness stage ensures that adequate capability is in place at the organizational, local, regional and national levels, and, where appropriate, at the international level, for an effective response in a nuclear or radiological emergency. During the urgent and early phases of an emergency, decisions are made based on existing knowledge; as time elapses and the emergency progresses to the transition phase, new knowledge will be dynamically created. Thus, mechanisms are best established at

the national level to manage the newly created knowledge and use it for situation analysis, decision making and response adjustment.

3.1.10. Support public awareness

Knowledge management can help to provide accessible and objective information and knowledge to the general public. The IAEA encourages governments to actively engage with the public when considering the use of nuclear science and technology. Communication and consultation with interested parties involves sharing concise and relevant information to engage and educate these parties. As a result of the responsible sharing of nuclear safety knowledge, public confidence in the nuclear industry can be increased.

3.1.11. Support capacity building

Knowledge management is also an important facilitator of capacity building at both the organizational and national levels. As illustrated by the 'umbrella approach', capacity building consists of four essential elements: human resource development, education and training, knowledge management and knowledge networks. Figure 7 illustrates this approach, in which nuclear safety knowledge management finds a natural place as a component of capacity building for nuclear safety.

3.2. NATIONAL LEVEL DRIVERS AND CONSIDERATIONS

The nuclear sector is governed by different national priorities and approaches according to the particular country. Thus, nuclear safety knowledge management activities are tailored to the specific national context.

As a concept and prime objective, safety is the same across all Member States, but the organization of nuclear activities differs from country to country. While some countries work with highly centralized, large and often state owned nuclear organizations, other countries have a wide number of actors, many of which are privately owned and act in competitive environments. In the first case, nuclear safety knowledge management at the national level might be similar to corporate nuclear safety knowledge management. In the latter case, stakeholder engagement and knowledge interfaces among organizations might dominate, and national nuclear safety knowledge management will go far beyond organizational knowledge management.

In countries where there is no nuclear power programme in place, managing safety knowledge means mainly managing knowledge for radiation

safety. For countries that are considering or have already decided to embark on a nuclear power programme, the safety infrastructure and consequently the safety knowledge have to relate to both nuclear safety and radiation safety.

In all cases, there are several considerations and challenges that need to be dealt with at the national level and reflected in the national nuclear safety knowledge management approach. These considerations and challenges are discussed in detail in subsections 3.2.1. to 3.2.18.

3.2.1. The role of governments

The role of governments is of prime importance in nuclear safety knowledge management for the following reasons:

— Nuclear safety is a topic of key national interest and a national governmental responsibility embedded in a global safety regime.
— There are many interested parties at the national level who are all involved in nuclear safety knowledge management (regulatory bodies, operators, vendors, response organizations, research and development communities,

FIG. 7. Capacity building — the umbrella approach. Nuclear safety knowledge management is a component of capacity building for safety (reproduced from Ref. [12]). TSOs — technical and scientific support organizations.

academia, the public and others), a process effectively supported by governments.
— Some nuclear safety knowledge management challenges, such as national human resource development, transnational workforce migration, participation in international activities or managing emergency preparedness and response can be best addressed through governmental support (see the following subsections).

Governments might have different roles, depending on national circumstances and priorities, in promoting nuclear safety knowledge management. An important leadership role of governments might be to stimulate nuclear safety knowledge management across all the different national activities and institutions. Governments might also actively coordinate or even lead national level nuclear safety knowledge management activities.

3.2.2. Involving all interested parties

At the national level, the wide range of interested parties poses the following two challenges:

(1) Nuclear safety knowledge resides in and is owned by a large number of individual organizations or individuals (i.e. not all knowledge relevant to nuclear safety is with any single organization). As a result, effective national level nuclear safety knowledge management needs to consider knowledge from different sources and owners and to combine this knowledge to yield a single integrated picture at the national level.
(2) In terms of communication and outreach, an even wider group of interested parties needs to be considered, including media and the general public, who all have different expectations and understanding of nuclear science and technology.

An important challenge for a national nuclear safety knowledge management approach is to overcome barriers between different organizational, scientific and technical cultures and to address potential role conflicts. There are a number of professional tools and techniques for stakeholder involvement, including IAEA Nuclear Energy Series No. NG-T-1.4, Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [27].

3.2.3. Linking organizations through knowledge interfaces

In the nuclear sector, no organization operates fully autonomously, or without links to other organizations, to governmental policies and institutions and to international frameworks and agreements.

Some organizations, such as regulatory bodies, have individual nuclear safety knowledge management programmes in place. These organizational level knowledge management programmes might not be connected at a higher level. This might lead to a lack of efficiency or effectiveness, friction, losses and a risk of segmentation. If the individual organizations' knowledge management programmes are not connected, this might leave gaps, which need to be closed at the national level through well defined knowledge interfaces.

Specifically, regulatory bodies often have close and direct organization-to-organization safety knowledge interfaces with related TSOs, with operators and with other relevant regulatory bodies so that knowledge crosses organizational boundaries in both directions.

An important new challenge is changing business models, in particular in the area of nuclear power, which often means increased reliance on external knowledge. For nuclear safety, stable, proven and robust knowledge interfaces are necessary to ensure that nuclear safety knowledge that is external to an organization is and will remain available.

In the area of emergency preparedness and response, the integration and coordination of planning processes and emergency arrangements among various response organizations (e.g. operating organizations and response organizations at the local, regional and national levels), including associated nuclear safety knowledge, are key elements for achieving an effective and efficient response in case of a nuclear or radiological emergency.

3.2.4. Planning human resources at the national level

At the national level, the management of the workforce in the nuclear sector is shared across the sector as a whole. No single organization is in a position to manage the entire national nuclear safety related workforce independently from other institutions. Development of the nuclear workforce in a specific country could be planned and achieved through either university level education or transnational workforce migration. Sustaining or growing the national nuclear pipeline capacity includes developing workforce plans, assessing risk/shortages, setting national nuclear development objectives and engaging all relevant education and training institutions and recruiting organizations.

In particular, the following can be considered:

— A national level human resource management plan based on supply and demand is a good mechanism to ensure that sufficient staff is available for all nuclear activities, and that no activity compromises the others in terms of depleting the same human resource pool. The plan usually covers a time frame of 5 to 15 years, depending on the organization. Management of recruitment, training and staff turnover need to be carefully analysed. The analysis and planning need to consider whether particular skills could be better met using TSOs, consultants or secondment of staff from other organizations.
— Cataloguing nuclear knowledge and potential future gaps at the national level, by surveying employed staff with nuclear safety expertise and decision makers to determine future needs, can help to ensure that the supply meets demand.
— Establishing direct partnerships between organizations requiring nuclear safety knowledge and organizations that educate or train human resources has proven to be a very effective mechanism. This can involve joint planning, shared curricula, internship programmes, practical training, funding of teaching staff and other joint measures.

3.2.5. Cross-organizational learning

An important objective of nuclear safety knowledge management is to facilitate and promote learning between and among organizations at the national and international level. This includes in particular the exchange of regulatory experience among regulatory bodies through national, regional and global knowledge networks. This can be done through dedicated nuclear safety knowledge exchange processes, through defining interfaces (see subsection 3.2.3) or through national forums or platforms. These mechanisms need to be introduced proactively at the national level, ideally with governmental support, to ensure that all nuclear safety related knowledge is shared and used and contributes to nuclear safety.

In this regard, arrangements for coordination of emergency preparedness and response and protocols for operational interfaces between all response organizations, such as operators and public authorities, are developed while capturing relevant knowledge for decision making and the implementation of response actions. As part of cross-organizational learning, the relevant personnel for emergency response (including those dealing with response to conventional emergencies) participate and improve their knowledge, skills and abilities through coordinated training and full scale emergency response exercises conducted at

the national level. The lessons learned from the evaluation of these exercises are used for improving the collective nuclear safety knowledge.

3.2.6. Avoiding knowledge loss

Avoiding the loss of knowledge is a key driver of nuclear safety knowledge management initiatives. Guidance on assessing the risk of knowledge loss at the organization level is provided in the IAEA publication Risk Management of Knowledge Loss in Nuclear Industry Organizations [28].

At the national level, efforts need to be undertaken to preserve knowledge, and nuclear safety knowledge is an essential part of this. Avoiding the loss of knowledge is primarily the responsibility of the respective knowledge owner, usually an organization. However, national level efforts are often necessary to preserve knowledge and assess the risk of knowledge loss. This applies where specific knowledge has several owners with shared responsibilities, or where knowledge is owned by organizations that cease to exist, or where knowledge is owned by networks or informal communities that have no legal status. National level coordination for knowledge loss risk assessments will also help to avoid duplication in preservation efforts and can make the overall management of knowledge more effective and efficient.

3.2.7. Transferring and preserving knowledge

Knowledge transfer necessitates the identification of knowledge holders and knowledge recipients. A primary recipient of knowledge will be future decision makers in implementing organizations, as well as the regulatory body and external oversight organizations. In addition, the knowledge management system includes mechanisms to inform the public. The basis for key decisions that have an importance in terms of providing safety are discussed in the safety case as part of the knowledge transfer and management approach. Different versions of the safety case can be produced for different audiences at several levels: the first safety case is written for the technical audience and experts in an operating organization and in the regulatory body. The second version, a less technical and abbreviated safety case, could be written for a more general audience such as societal decision makers and upper level managers. The third version could be written for the general public. In some instances, three tiers of documentation would be needed to be effective. As part of a sound knowledge management approach, the safety case describes what is known as well as what is uncertain, and provides the path forward to improving understanding for the next step in the project life cycle.

In the context of emergency preparedness and response, the IAEA safety standards include specific requirements for documenting, protecting and preserving, to the extent possible, data and information important for the analysis of the circumstances during an emergency response [10]. The knowledge gained based on this analysis can be shared not only among operating organizations, but nationally and internationally with all safety related organizations. It can be used to enhance nuclear safety practices and improve emergency response arrangements.

In the area of transport safety, owing to the global importance of IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material [20], the transport community recognized several years ago that knowledge management is important to transfer knowledge to the next generation of experts, who will become the custodians of these regulations.

Nuclear safety knowledge management includes preserving information and knowledge and continually updating it as new information becomes available. There are serious issues concerning the form in which information is preserved. Some formats and some media may not be readable over very long time frames.

3.2.8. Achieving knowledge resilience over longer timescales

At the national level, the nuclear safety knowledge management programme takes into account the medium and longer timescales. This is particularly important for new installations, operation, spent fuel management and decommissioning (i.e. to address the full cradle-to-grave life cycle of nuclear facilities, as well as the full cycle of radioactive sources). Decommissioning requires preserving nuclear safety knowledge related to a facility over several decades (GSR Part 6 [9], para. 7.7). It might also be necessary to keep the capacity to work out specific safety provisions that might not have been anticipated in the design of a facility. Final disposal facilities in particular are characterized by long to very long timescales on which only national actors can ensure knowledge continuity and knowledge resilience.

3.2.9. Changing policy environments

National nuclear programmes that are not implemented in a stable and continuous manner pose challenges, for example, when a government decides to postpone, restart or slow down the implementation of a programme. For these programmes, achieving nuclear safety knowledge resilience is very difficult, since knowledge tends to disappear with time if not used. In these cases, active efforts are needed at the national level in order to achieve knowledge resilience.

3.2.10. Addressing changes in the knowledge base

Nuclear safety knowledge is subject to continuous change, which is not always possible to anticipate. New knowledge might become available through routine research and development, new research triggered by new requirements, next generation reactor designs or site exploration (e.g. for disposal facilities), and many other factors. Together, these factors result in continuous change in the knowledge base.

Changes in the knowledge base can lead to revision of past decisions. With a limited knowledge base, it is prudent to document the technical and other bases of major decisions. If necessary, these decisions can then be reassessed or changed when more knowledge is available. Changes in the knowledge base can best be addressed at the national level in a coordinated effort involving all organizations maintaining that knowledge.

Nuclear safety knowledge is used for making decisions in a nuclear or radiological emergency. The individual tacit knowledge of decision makers, critical in emergency management operations, can change during an emergency, as experience during past incidents and accidents has shown. This is due to a number of factors that cannot be controlled a priori. In the aftermath of an emergency, the knowledge base changes based on lessons learned. This takes place once the analysis of the accident causes and of the emergency response is completed. Therefore, the ways to cope with changes to the knowledge base for the purpose of decision making have to be considered during planning. This allows governments to manage nuclear safety knowledge changes in all phases of the emergency.

3.2.11. Managing technological change

Technology is evolving rapidly and today's technology is totally different from what was used when most nuclear power plants currently in operation were built. Technology changes have occurred in nuclear reactor design concepts, applications of radiation sources, nuclear engineering materials and approaches, instrumentation and control systems, civil engineering and construction technologies, tools and equipment, and information and communication technology. Knowledge about this changing technology base is in many instances safety relevant and thus constitutes nuclear safety knowledge that needs to be managed.

3.2.12. Managing societal change

As time progresses, there are changes in the way society understands, develops, manages and plans science and technology. These changes include changes in mentalities, decision making mechanisms, risk perceptions and public acceptance, attitudes towards the use of science and technology and approaches to responsibility, governance, quality standards and regulatory approaches for selected industries. This is of particular relevance to nuclear science and the peaceful use of nuclear technology. A national nuclear safety knowledge management approach needs to consider the effect that these changes might have on nuclear safety.

3.2.13. Considering starting or restarting nuclear programmes

The context of the national nuclear power programme, including its development perspectives, needs to be fully considered, particularly if changes in the programme are expected (e.g. new or rapidly growing programmes, or those which are being phased out). In these cases, nuclear safety knowledge management needs to consider the anticipated changes at the national level. For embarking countries, a national approach is necessary for building the requisite nuclear safety knowledge, which cannot be accomplished by a single organization.

3.2.14. Linking to regional and international activities

The international context for nuclear safety includes international organizations, global or regional nuclear safety networks or other multilateral cooperation initiatives that an organization or country participates in, as considered under the global nuclear safety and security framework. This international context needs to be considered by all countries with nuclear safety related activities. An example is a shared knowledge base, for State parties to international agreements and conventions, for exchange of nuclear safety knowledge and operational experience or other purposes. The interactions within the international context take place directly between an organization in a country and relevant international bodies or through national interfaces. In both cases, the national nuclear safety knowledge management approach will need to address the links and interfaces between national activities and nuclear safety knowledge and the international environment.

The regional and international contexts are very important when building and strengthening national systems for radiation emergency management with the purpose of harmonizing emergency preparedness and response. In addition to the safety knowledge related to normal operation of facilities and activities, the

national approach for managing nuclear safety knowledge can also incorporate the relevant knowledge for mitigation of the radiological consequences of incidents and accidents, as well as for protecting the public and emergency workers, with due account taken of the regional and international context.

3.2.15. Developing a national memory

An important aspect of any nuclear safety knowledge management programme, at the organizational or national level, is to document both its technical basis and the decisions taken on that basis. These include alternative options, development pathways explored but eventually not pursued, as well as data and information used to substantiate the decision making process, including stakeholder engagement, as appropriate.

While rules might exist at the organizational level that govern archiving standards (and serve to meet legal requirements), no single organization may be responsible for this aspect at the national level. A nuclear safety knowledge management programme at the national level builds and operates a mechanism that ensures that essential knowledge is captured and maintained as an accessible source for future generations. This can be achieved, for example, through the establishment of a national nuclear archive.

As described in subsection 3.2.14, an important aspect at the national and international levels is learning from past incidents or accidents, their history, causes, response actions and recovery actions. The focus here is on both technical causes and lessons learned — which are dealt with by responsible organizations — and on the experience of a country as a whole, including all interested parties, the reactions, and changes in attitudes and approaches, and the priorities and programmes of all societal institutions. All of these aspects, reflected in revised consolidated knowledge, are addressed in a national nuclear safety knowledge management approach.

3.2.16. Ensuring appropriate resources for national level activities

Nuclear safety knowledge management at the national level might need dedicated human and financial resources. It cannot be assumed that resources for national level activities can be provided by the individual organizations. A national nuclear safety knowledge management approach or strategy includes provisions for the allocation of appropriate and sufficient financial and human resources by the government.

3.2.17. Nuclear safety knowledge management in the context of emergency preparedness and response

The management of nuclear safety knowledge at the national level relevant to preparedness and response for a nuclear or radiological emergency needs special considerations. These include: defining essential knowledge for radiation emergency management; integrating the knowledge of all relevant stakeholders, including those responsible for conventional emergencies; addressing knowledge management at the preparedness stage and during the response to a nuclear or radiological emergency (in the three phases of an emergency: urgent, early and transition); and considering knowledge related to public awareness. In emergency preparedness and response, a broad spectrum of essential knowledge has to be properly addressed and managed. The organizations concerned with safety have to become knowledgeable about emergency management and making decisions in emergencies in general. The organizations concerned with response, which deal with conventional emergencies (e.g. police, customs, intelligence, first responders), have to become knowledgeable about the particularities of responding to a nuclear or radiological emergency. Achieving an adequate level of knowledge for all those responsible to respond in a nuclear or radiological emergency is part of emergency preparedness. As presented above, training at the national level for emergency preparedness and response, including training for decision makers, national scale emergency response exercises and development of adequate documents such as plans, procedures, guidelines, databases and manuals, tools, interfaces and emergency arrangements are important elements to be considered as part of the national approach for managing nuclear safety knowledge. The knowledge base for emergency preparedness and response, built at the preparedness stage, includes: assessment of hazards and their potential consequences; development of a protection strategy and concept of operations; elaboration of emergency plans and implementing procedures at the national level and at the level of each response organization (including operating organizations, as identified during the hazard assessment); establishment of all infrastructural elements as per GSR Part 7 [10] and practical arrangements for emergency management.

For the post-accident phase, during the transition and after the termination of the emergency, the newly created nuclear safety knowledge regarding emergency preparedness and response will include the characterization of the radiological situation, decision making and the implementation of long term operations for the resumption of social and economic activity in the affected areas and the analysis of the emergency (root causes and circumstances) and its response.

Managing nuclear safety knowledge for emergency preparedness and response includes considerations on public awareness at the preparedness stage

and on public communication throughout all phases of the emergency. After the accident at the Fukushima Daiichi nuclear power plant, keeping the public informed and maintaining public trust became officially recognized goals of emergency response. Paragraph 5.72 of GSR Part 7 [10] states:

> "The government shall ensure that a system for putting radiological health hazards in perspective in a nuclear or radiological emergency is developed and implemented with the following aim:
>
> — To support informed decision making concerning protective actions and other response actions to be taken;
> — To help in ensuring that actions taken do more good than harm;
> — To address public concerns regarding potential health effects."

Requirement 10 of GSR Part 7 [10] specifies the responsibilities of governments in providing instructions, warnings and relevant information to the public for emergency preparedness and response, including arrangements to be made:

> "to provide…before operation and throughout the lifetime of the facility, …information on the response to a nuclear or radiological emergency. This information shall include information on the potential for a nuclear or radiological emergency, on the nature of the hazards, on how people would be warned or notified, and on the actions to be taken in such an emergency" [10].

3.2.18. Considering intellectual property

An important challenge for the nuclear sector is to achieve an appropriate balance between the protection of intellectual property and knowledge sharing, with due consideration of nuclear safety as the prime objective. This challenge exists at the level of individual organizations, but also at the national level. Governments can help to promote an environment that supports a knowledge sharing culture for nuclear safety.

In today's highly globalized market, information and knowledge have significant market value and all organizations try to keep their knowledge away from their competitors. This is currently one of the biggest factors working against knowledge sharing and transfer. However, in the nuclear sector there is a potential for organizations to gain competitive advantage by collaborating on scientific endeavours, including projects on nuclear safety. For example, in the nuclear power industry, owing to the high research investment costs linked to

advanced reactors, results could not be obtained without close cooperation of the leading design companies, even though they are competitors in the supply chain. In general, before a successful partnership can start, organizations will have to negotiate ownership and access to the intellectual property produced as a result of the joint effort. While some collaborative projects are not created to pursue commercial gains, outputs of collaboration may have commercial application. Experience shows that the framework for the collaboration is best determined through an agreement that describes the project and the future ownership, management and exploitation of the intellectual property. The attractiveness of a collaborative project is increased if such a framework can be negotiated in a timely manner. It is important that the partners agree on the allocation of ownership, transfer and access to intellectual property before the project starts. This is done to reduce uncertainties and to protect the rights of the partners. Partners agree not only on the ownership of the future intellectual property but also on the ways for subsequent commercial exploitation of the results of the collaboration. An intellectual property ownership and management framework that has been successfully negotiated and finalized in a timely way plays a key role in protecting partner investments and ensuring the successful exploitation of the results of the collaboration.

Experience shows that the negotiation between partners over a framework for collaboration (with regard to ownership and access to intellectual property) involves three main considerations, namely, the input of intellectual property, the input of resources (e.g. financial, human), and the ability to exploit the output of the joint activity (an explicit plan on how to use the outputs of collaboration). Secondary considerations cover such items as the mechanisms of identification and protection of intellectual property (both background and foreground) and the transfer of ownership of the technology. Many years of experience also has shown that it is important to pay special attention to intellectual property that has applications across different industrial sectors. Since almost all collaborative projects are unique, the ownership, access and exploitation of the intellectual property and the results of the joint effort are generally negotiated on a project by project basis.

4. APPROACHES AND EXPERIENCE GAINED IN MEMBER STATES

This section presents experience gained in Member States to date, based on information provided at the Third International Conference on Nuclear

Knowledge Management held in 2016 [14] and the 2017 IAEA Technical Meeting on Managing Nuclear Safety Knowledge.

Subsection 4.1 presents a summary of the data from a 2016 nuclear knowledge management survey, followed by an outline of considerations for building a national level nuclear safety knowledge management approach (coordination, strategies, knowledge maps) in subsections 4.2 and 4.3. Subsection 4.4 then presents summarized examples from Member States of different experiences and good practices in nuclear safety knowledge management. This report presents only a limited number of examples or good practices. Examples have been chosen based on three criteria: they are about nuclear safety, they are on the national level, and they are about knowledge management (i.e. they consider people, processes and technology in an integrated manner).

4.1. NUCLEAR KNOWLEDGE MANAGEMENT SURVEY RESULTS

In 2016, in association with the Third International Conference on Nuclear Knowledge Management [14], the IAEA conducted a global Nuclear Knowledge Management Review Survey. Results of this survey give a good indication of the current status of nuclear safety knowledge management in Member States.

The survey collected answers to 29 questions related to the application and benefits of knowledge management practices in nuclear organizations. A total of 120 participants in senior positions from 46 Member States participated in the survey. It yielded useful information with respect to the use of knowledge management practices in the nuclear sector in general.

Figure 8 presents the survey results on the added value of knowledge management with respect to different organizational goals. Member States considered that the organizational goal that is most supported by knowledge management is “Knowledge transfer to new employees”, followed by “Building and sustaining core competencies”. The third organizational goal best supported by knowledge management is “Safety culture enhancement”, which shows that managers in the nuclear sector appreciate the importance of knowledge management for nuclear safety and safety culture.

4.2. COORDINATED NATIONAL APPROACH

4.2.1. National strategy or national coordination mechanism

For nuclear safety knowledge management, a coordinated national approach ensures that all issues, topics, interested parties and national priorities on nuclear

safety knowledge management are addressed in a systematic, coordinated and effective manner. There are two options for ensuring this effective coordination:

(a) Establishing a national strategy — a powerful approach for ensuring effective coordination;
(b) Establishing a national coordination mechanism as a first step, either formal or informal (e.g. a regular consultative meeting of senior officials of relevant organizations).

Several possible starting points for establishing one of the above exist. As discussed in subsection 3.2.1, governments are in a good position to either stimulate and coordinate or even lead national level nuclear safety knowledge management efforts. However, these efforts might also develop on the basis of ongoing knowledge management work in or between a few organizations, or around technical communities of practice that grow over time. No specific ideal starting point can be determined for all possible circumstances, but in all cases, the leadership role of governments is to be considered.

A nuclear safety knowledge management strategy can in many cases be included in a higher level national planning document (e.g. the national nuclear development plan or a national capacity building plan). If this is done, the preparatory effort can be reduced and the overall planning process can be

FIG. 8. Survey results — added value of knowledge management. Safety culture ranks among the top three priorities. The full text of the fifth organizational goal is "Key expert identification and their involvement in strategic tasks"; the full text of the tenth goal is "Converting organizational knowledge into intellectual property, commercial utilization and generating additional profits".

streamlined. It is useful, however, to include an explicit chapter on national nuclear safety knowledge and not to scatter the issue across different chapters.

Combining these latter points, a graded approach for nuclear safety knowledge management can be used, with:

— The role of governments ranging from stimulation to coordination or leadership;
— The scope and depth of the approach ranging from informal coordination to formal strategies;
— The number and scope of knowledge management activities varying from small starting points to comprehensive national level programmes.

4.2.2. Features

Figure 9 illustrates how the approach discussed in the previous subsection, be it either a national strategy or a national coordination mechanism for national level nuclear safety knowledge management, could be put into practice, including its potential features.

The national level nuclear safety knowledge management approach (hereafter 'the approach') is prepared with leadership by a governmental

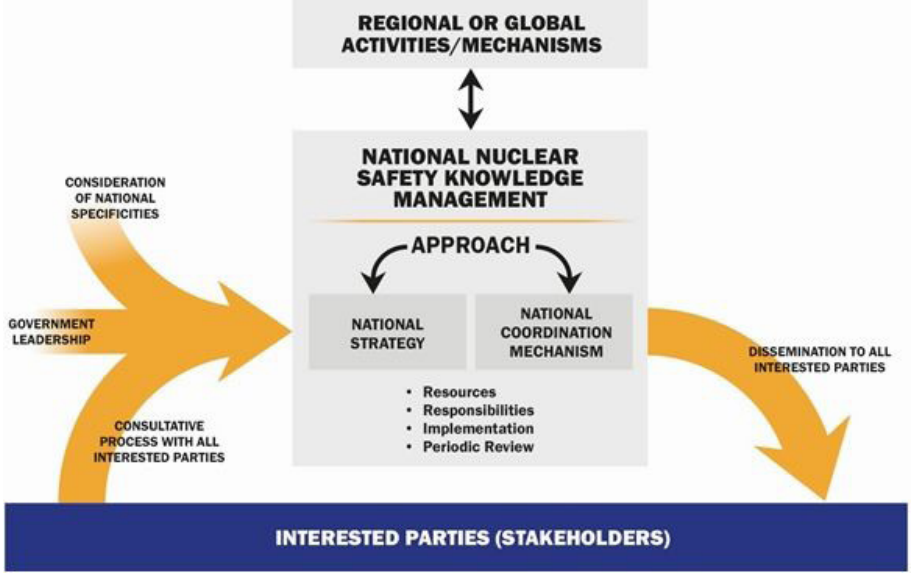

FIG. 9. Development and use of a national strategy or national coordination mechanism for nuclear safety knowledge management.

organization at the national level and through a consultative process involving all interested parties. It considers national priorities of a given country on the basis of country specific information.

The approach itself can take the form of a strategy or mechanism as discussed above. It has medium to long term validity, so that it provides a stable basis for planning at the national level as well as the organizational level. It needs to give full consideration to all three components of knowledge management: people (human resources), processes (interactions) and the connecting technology (e.g. information and communication technology). It also needs to include a clear allocation of responsibilities and provisions for implementation or enforcement. Resources (financial and human resources) are made available to ensure that the approach is pursued effectively and with due consideration for quality management. The approach can also provide for the linkage to regional and global levels (e.g. through links to knowledge networks or organizations operating at these levels).

After its establishment, the approach strategy or mechanism is disseminated to all interested parties and used by interested parties as guidance for their respective individual activities. Regular review and revision are important to address changes in the national context, experience gained and lessons learned and new issues that might arise.

In addition, the national nuclear safety knowledge management approach can be supported by the national regulatory body or bodies. This possible role of the regulatory body in the national level nuclear safety knowledge management approach is in addition to the organizational level knowledge management programme of the regulatory body itself.

The IAEA can provide assistance to Member States in the development of the national approach, including support through the IAEA technical cooperation programme.

4.2.3. Content

The scope, size and depth of the coordinated national approach strategy or mechanism will vary from country to country, depending on national priorities and needs. The following elements could be included in that approach:

— Development of a national nuclear safety knowledge map (see subsection 4.3) as an inventory of all nuclear safety knowledge, including all knowledge owners.

  The map can then be used as the basis for assessing the risk of knowledge loss and establishing targeted programmes for essential nuclear safety

knowledge preservation. The map can also be used as the basis for establishing knowledge interfaces between organizations to share nuclear safety knowledge in a structured manner.

— Establishment of national nuclear safety networks and participation in international nuclear safety networks, including the establishment of web based nuclear safety knowledge portals or platforms and of communities of practice.
— Promotion of a systematic national education and training approach with regard to nuclear safety and development of national human resource demand and supply forecasts for nuclear safety related areas.
— Promotion of systematic approaches to knowledge management, including agreed and shared definitions, standards or best practices among all interested parties for taxonomies, tools, document management systems, human resource management or curricula.
— Promotion of a knowledge management culture for nuclear safety and of an agreed understanding of the roles and responsibilities of all knowledge owners for the management of nuclear safety knowledge.
— Establishment of appropriate mechanisms for evaluation and continuous improvement of the knowledge management programme.

4.3. NATIONAL NUCLEAR SAFETY KNOWLEDGE MAPS

At the national level, a comprehensive nuclear safety knowledge management approach needs to consider knowledge from many sources, in many organizations, contexts and levels. For practical purposes (e.g. for conducting a systematic survey or for developing a national approach or strategy) it is possible to structure this knowledge in many different ways.

One possible way would be to use the following domains for national nuclear safety knowledge:

— Knowledge about national nuclear science and technology programmes and plans, including national nuclear education and training.
— Knowledge about the legal, governmental and international regulatory framework for nuclear safety, including radiation, transport and waste safety.
— Knowledge about nuclear safety relevant science and technology, with subsets for reactor technology; operation of nuclear installations (nuclear power plants, research reactors, fuel cycle facilities); operation of radiation sources (facilities and activities using radiation sources at fixed or mobile locations) or medical, industrial or agricultural applications.

— Knowledge about all nuclear safety knowledge owners and all relevant interested parties (usually organizations) at the national level, including those involved in radiation emergency management, and about the general public and interested members of the public.
— Knowledge about the linkages, relationships and processes that connect these knowledge owners or interested parties (e.g. dependencies, interfaces, working relations).
— Knowledge about the emergency management system for preparedness and response for a nuclear or radiological emergency (e.g. decision making process, managing operations during the response to a nuclear or radiological emergency and planning).
— Knowledge about the international context and bilateral and international activities (i.e. beyond national borders).

Figure 10 is a simple knowledge map that illustrates some of these areas and examples. This map is not meant to be a model showing all levels of detail; it is to be seen as an illustrative example of what a knowledge map could look like. The structure can be refined further as needed by adding additional levels (two levels are shown here).

A wide group of interested parties (usually organizations, but also individuals, networks, associations or informal groups) might have to be considered to effectively and comprehensively address nuclear safety knowledge management at the national level, including, among others, the following:

— National, regional and local authorities responsible for safety;
— Nuclear safety regulatory bodies;
— TSOs;
— Nuclear power utilities and operators of nuclear facilities and activities;
— Operators of facilities and activities involving the use of radiation sources;
— Legal institutions;
— National standardization organizations;
— Commercial institutions;
— Vendors, suppliers of radiation and nuclear technology, service providers and subcontractors;
— International organizations and associations;
— National, regional or global networks;
— Universities and other educational institutions and training centres;
— Research and development centres;
— Professional bodies and associations;
— Media and interested members of the general public;
— Non-governmental organizations;

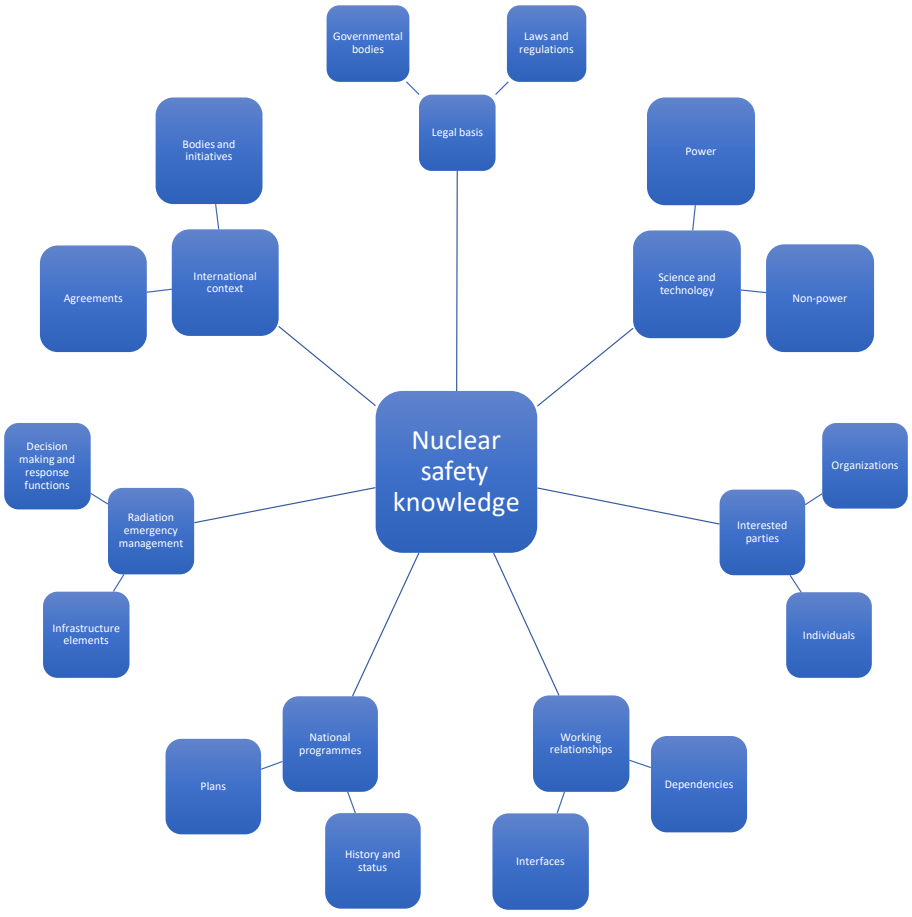

FIG. 10. Simple knowledge map for nuclear safety knowledge at the national level.

— National, regional and local response organizations and operating organizations involved in emergency preparedness and response for a nuclear or radiological emergency, as identified based on the results of the hazard assessment.

Some of these interested parties might be sole owners of knowledge, others might jointly own specific knowledge. Careful analysis and documentation of all knowledge owners is a prerequisite for developing a sound national level nuclear safety knowledge management approach, as discussed in subsection 4.2.

IAEA Safety Standards Series No. SSG-16 (Rev. 1), Establishing the Safety Infrastructure for a Nuclear Power Programme [21] contains another useful

sample structure of all issues to be considered, in this case for a new nuclear power programme. This structure could also be used to develop a nuclear safety knowledge map with a finer substructure.

4.4. EXPERIENCE GAINED IN MEMBER STATES

As discussed in subsection 4.2, a coordinated national approach to nuclear safety knowledge management is best. Such an approach can take several forms, for example as an explicit strategy, as a coordination mechanism, or, in some instances, as a newly created national organization. The approach can be led by an existing group or committee, or by a dedicated new group, and be consultative or authoritative in nature.

5. SUMMARY

The following examples from various Member States illustrate how a national coordination approach for nuclear safety knowledge management can be pursued:

— In 2010 Finland established the Committee for Nuclear Energy Competence in Finland, tasked to examine the long term competence needs of the nuclear energy sector. One of the key conclusions was that:

  "comprehensive high-standard national competence is needed by nuclear sector companies and research institutes, as well as by authorities. Training of experts and sector-specific research activities call for long-term investments and cooperation, both among national actors and on an international scale" [29].

— In Germany, the Alliance for Competence in Nuclear Technology (Kompetenzverbund Kerntechnik) was established in 2000 to ensure the continued availability specifically of nuclear safety knowledge during Germany's phase-out of nuclear power. The Alliance comprises all relevant ministries, research centres, the regulatory body and TSO, academia, industry and other organizations and works effectively as a soft coordination mechanism at the national level. It is one of the key mechanisms that connect relevant organizations for joint work and coordination at the national level.

— In the Russian Federation, the State Atomic Energy Corporation “Rosatom” is pursuing a comprehensive corporate approach for nuclear knowledge management, including nuclear safety knowledge management. Formally an organizational management approach, because of the size of Rosatom and its comparative weight in the national nuclear sector, this corporate approach might also serve as resource for designing national nuclear safety knowledge management programmes.
— Romania established a National Nuclear Safety and Security Strategy in 2014 with one of the objectives being the continuous improvement of the national competences for nuclear safety and security. The National Commission for Nuclear Activities Control has developed a model for regulatory body competences and started to develop its knowledge management process and associated procedure and tools in the framework of the Regional Excellence Project on Regulatory Capacity Building in Nuclear and Radiological Safety, Emergency Preparedness and Response in Romania.
— In Spain, the national Technological Platform for Nuclear Fission (CEIDEN) was established in 2007 to support national knowledge creation and exchange on nuclear energy. The platform also serves as a channel for proposing and jointly undertaking projects between industry, research centres and universities and acts as a single counterpart for the Government and international organizations. When addressing nuclear safety topics, it serves as the national mechanism to coordinate nuclear safety knowledge related activities.
— In Croatia, as a non-nuclear country, all activities related to nuclear safety knowledge management are carried out by the State Office for Radiological and Nuclear Safety and fall under the Civil Service Act and its regulations. As in many other countries, nuclear safety knowledge management activities are thus governed by rules and regulations that are valid across the governmental sector. For example, nuclear safety related human resource activities would be governed by the overall governmental approach for recruitment and replacement of retiring civil servants.
— The United Arab Emirates has embarked upon a new nuclear energy programme and has committed to extensive capacity development and nuclear knowledge management programmes. These programmes also govern nuclear safety in terms of nuclear safety knowledge transfer to The United Arab Emirates and internal national nuclear safety knowledge management. Khalifa University is the new national hub for nuclear education and training, including nuclear safety. A separate institute, the Gulf Nuclear Energy Infrastructure Institute, was established in addition to build expertise in safety, safeguards and security for the national programme.

— In South Africa, the National Centre of Excellence on Nuclear Safety and Security was launched in September 2016 to pool national resources and expertise in these areas (including nuclear safety knowledge). In this example, the national level nuclear safety knowledge management approach takes the form of a new and dedicated organization. The Centre's strategy also recognizes the need to foster nuclear knowledge management as a vital component of an integrated management system. In addition to nuclear safety, one key driver for the strategy was the facilitation of a transition to a knowledge economy, a wider socioeconomic goal.
— Nigeria has also embarked upon a new nuclear energy programme. The Atomic Energy Commission acts as leader and central governmental driver for the national nuclear power programme. As part of this role, the Atomic Energy Commission is also the national mechanism for a coordinated national nuclear safety knowledge management approach, at present focusing on building nuclear technology education and training programmes.
— Under bilateral agreements between the Russian Federation's Rosatom and recipient countries with new nuclear power programmes, Rosatom is promoting the use of nuclear safety knowledge management to achieve effective knowledge transfer and capacity building with the recipient nuclear energy programme implementing organization and the corresponding national regulatory body.
— In Mexico, work on nuclear safety knowledge management has been implemented mainly through two projects at the National Commission for Nuclear Safety and Safeguards. The first, a European Union Instrument for Nuclear Safety Cooperation project undertaken from 2012 to 2014, resulted in a knowledge management strategy and action plan. As a part of the second project, Knowledge Management in the Federal Public Administration (FPA), scheduled to run from 2013 to 2018, a maturity model on innovation and knowledge transfer was developed, which outlines barriers to innovation and knowledge transfer.
— In the Netherlands, the Dutch regulatory body has taken the initiative to start an international regulatory body group, bringing together regulatory bodies from Brazil, Germany, the Netherlands, Spain and Switzerland. The regulatory body group promotes closer cooperation among those countries to cope with the effect of the phase-out of nuclear power in Germany, which is expected to slowly reduce its importance as a source of operating and regulatory experience. In response to the knowledge management challenges for long term operation the Dutch regulatory body aims to enhance knowledge creation, preservation and transfer by means of starting a community of practice for long term operation and ageing management with participants from the regulatory body group.

Several nuclear safety knowledge networks exist on regional or global levels, including the Global Nuclear Safety and Security Network (GNSSN), and, at the regional level: the Arab Network of Nuclear Regulators, the Asian Nuclear Safety Network, the European Nuclear Safety Regulators Group and the European Technical Safety Organisations Network, the Forum of Nuclear Regulatory Bodies in Africa, the Ibero-American Forum of Radiological and Nuclear Regulatory Agencies and the Ibero-American Nuclear Platform for Operators in the Area of Safety and the European and Central Asian Safety Network.

These networks serve different specific purposes and different respective interested parties. Some have national 'branches' that serve as national nuclear safety knowledge management mechanisms. In other Member States, national nuclear knowledge networks have been established independently, and some of these address nuclear safety knowledge explicitly:

— In Canada, a joint partnership (the University Network of Excellence in Nuclear Engineering) between industry and 12 universities was established in 2002 in anticipation of a large number of nuclear staff retiring starting in 2010 and beyond. The focus of this network was to support nuclear related research in universities in support of the operating Canada deuterium–uranium reactor (CANDU) type nuclear plants. In some of its projects, the network addresses nuclear safety knowledge.
— In South Africa, with the renewed interest in nuclear power, nuclear knowledge gaps have been identified. In order to close these gaps, expertise and research facilities were combined into the South African Network for Nuclear Education, Science and Technology (SAN-NEST), which also addresses nuclear safety knowledge. SAN-NEST seeks to capture all nuclear education and research in an educational network as well as to establish new nuclear training and research facilities. SAN-NEST in turn is connected to the African AFRA-NEST.
— In Canada, the CANTEACH web based knowledge platform is a knowledge repository that provides technical documentation relating to the CANDU nuclear energy system. Contributors are industry experts who hold valuable knowledge and experience in diverse aspects of CANDU technology and its applications. This information is public and is intended for use in various aspects of education, training, design and operation.

The knowledge networks discussed above are often supported by a technical infrastructure that connects the individual participants. Information and communication technology and web based knowledge platforms have proven to be a good mechanism and are readily available from commercial suppliers. This

includes those that are part of personal computer based software, which can be used for smaller projects or limited national needs, such as the following:

— The GNSSN Nuclear Safety Knowledge Platform is a generic platform supported by the IAEA and available for all Member States to use. It is operated with Microsoft SharePoint, and the basic maintenance and technical support is provided by the IAEA. Member States can use this platform to build their own national platforms, a part of which can serve as an information server for all Member States, another as a protected collaboration area for use within the Member State.
— The Radiation Safety Information Management System (RASIMS) is a tool for information exchange and collaboration in nuclear safety knowledge at the national level for Member States under the IAEA technical cooperation programme. RASIMS is a web based platform that enables Member States and the IAEA to jointly collect, analyse and view information regarding the national infrastructure for radiation and waste safety and uses a topical structure for all nuclear safety knowledge.
— The Emergency Preparedness and Response Information Management System (EPRIMS) is an interactive, web based tool developed by the IAEA for Member States, to be used at the preparedness stage for performing self-assessment of national capabilities for emergency preparedness and response and for sharing information and knowledge relevant for emergency preparedness and response, in order to facilitate regional and international harmonization and coordination of planning and responding to a nuclear or radiological emergency. In addition to knowledge sharing of emergency preparedness and response capabilities, EPRIMS also contains a knowledge management database of static nuclear reactor technical information.
— In Germany, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and the Installation and Reactor Safety Company (GRS) as TSO cooperate through a shared web based platform for nuclear safety knowledge. The platform connects the internal ministerial platform and the internal GRS platform and provides a single, integrated web based solution at the national level. It allows for public access in selected areas.

As outlined in subsection 3.2, several important aspects of human resources, education and training and workforce planning and development are best addressed at the national level. Member States have gained experience with

national level human resource and knowledge development and education and training in a number of ways. Examples include the following:

— In Japan, a national human resource development network was established in 2010. The network has worked on: (i) elementary to high school education, (ii) university education, (iii) human resource development for engineers, (iv) internationalization of human resources, and (v) human resource support to newcomers. Based on its good experience with the network, Japan would like to recommend the introduction of a national nuclear human resource development network to countries embarking on a nuclear power programme.
— In Germany, national human resource demand and supply forecasting was introduced and conducted by the German Alliance for Competence in Nuclear Technology. The questionnaires are sent to both recruiting organizations (industry, operators, other) and to education and training organizations (universities, other) and yield valuable data to plan the national nuclear human resources needed for the German nuclear programme, in particular during its phase-out.
— Also in Japan, a national roadmap for light water reactor safety technology and human resources has been developed by the Special Committee on Nuclear Safety Research Roadmap within the Atomic Energy Society of Japan. Based upon the lessons learned from the Fukushima Daiichi accident, effective planning of research activities to improve safety can also contribute to enhancing human resources and management of the accumulated knowledge base in the future domestically and internationally.
— In Thailand, knowledge management projects are carried out under the Office of Atoms for Peace as a regulatory body under the Ministry of Science and Technology. Between 2006 and 2016, the Office implemented a knowledge management project called Nuclear Science and Technology Knowledge-Base Development which mainly addressed knowledge transfer to the general public. In parallel, from 2012 to 2013, the Office worked to improve the project by establishing a knowledge management committee and an internal knowledge management plan and system.
— In Serbia, which faces the challenges of ageing of human resources and emigration, the University of Belgrade proposed a unique approach for national nuclear safety knowledge management, via coordination mechanisms among relevant institutions, communities of practice and competence building. A new strategy for knowledge management is envisaged, for which the established communities of practice for young professionals could be a starting point.

— Cuba seeks to establish a strategic and sustainable approach to occupational skills in the nuclear field. A survey conducted in 2012 covered all institutions that are part of the system of the Agency for Nuclear Energy and Advanced Technologies, determining the projection of training needs from 2015 to 2024. The strategic approach is based on an analysis of the National Programming Framework, which defined development lines in the country. This was followed by a determination of the qualified workforce in the institutions under study, considering the fluctuation in the workforce and the existence of specialists.
— The Pakistan Nuclear Regulatory Authority was established in 2001. It initially utilized the staff who were overseeing nuclear safety within the already existing government run civilian nuclear programme. To fulfil the obligations of an independent nuclear regulatory body and the need for increased human resources for regulating the expanding nuclear power programme, it undertook extensive capacity building. Today, the Pakistan Nuclear Regulatory Authority and its associated TSO, the Centre for Nuclear Safety, have several nuclear safety knowledge management related programmes in place. These were started in an informal manner and have subsequently been formalized through the institutionalization of various practices.
— Greece has established a national strategy for education and training in nuclear, radiation, transport and waste safety, based on an IAEA methodology. The approach includes a high level policy document as a basis, a needs assessment for education and training, design of a national education and training programme and its implementation and regular review.
— In Spain, the CEIDEN F+ working group carried out a study of the national training capabilities on nuclear matters in 2010. The result of this study was a complete catalogue of 12 master's degree programmes on nuclear related topics. In 2011 the study was expanded to include the training activities specifically focused on training workers to perform their jobs in the nuclear sector. Usually these activities correspond to traditional classroom training and on-the-job training, in workshops or laboratories or specific training environments (such as simulators). This training is complementary to that received at universities or colleges and is necessary to meet the specific requirements of jobs in the sector. The result of this study is twofold: the creation of the first catalogue of training capabilities in Spain's nuclear industry, and the identification of the potential strengths and weaknesses of these capabilities.
— In the United Kingdom (UK), the National Skills Academy for Nuclear was established by nuclear employers and the Government to address the key skills challenges facing the nuclear programme. Its mission is to improve the

performance of companies in the nuclear industry through collaboration and action on skills. Its achievements to date include a wide range of innovative skills solutions such as a Nuclear Training Network and a Nuclear Skills Passport. The Academy is being developed based on the experience gained in other areas under the umbrella of the UK's National Skills Academies.

— In a cooperative effort between the European Commission and the Russian Federation, a joint higher education programme is being developed. The programme links educational institutions through a national level agreement. It will introduce double degree programmes in nuclear engineering in Russian and European Union universities and offer the same courses in different languages. The courses will be also used as the basis for new nuclear engineering programmes in the universities of newcomer states.
— For selected nuclear safety knowledge domains that are of national relevance, a national level knowledge preservation effort is being pursued. Objectives can be to preserve national scientific heritage, to ensure the availability of nuclear safety knowledge for future generations, in particular for spent fuel and waste knowledge, or to build a national memory of nuclear activities and lessons learned. As illustrated by the following examples, the existence of such national repositories is particularly relevant for the decommissioning and remediation work for a nuclear facility:
— In Belgium, Storage of Thermal Reactor Safety Analysis data (STRESA) is an online information system that contains three technical databases: (i) European nuclear research facilities, open to all online visitors; (ii) nuclear experiments, available only to registered users; (iii) results data, the core content of the information system, with different levels of access depending on the role and organization of each user. Its main purpose is to facilitate the exchange of experimental data on severe accidents, and to provide a secure repository for this knowledge.
— In Tunisia, the predecessor institute of today's National Centre for Nuclear Science and Technology (CNSTN), created in 1993, had been closed owing to changing national priorities. At the time of closure, no specific knowledge management provisions were made to preserve the accumulated knowledge at that predecessor institute. As a result, when creating the successor CNSTN in 1993, knowledge had to be retrieved and efforts made to identify and capture that knowledge.
— In Lithuania, a programme for knowledge preservation was established in 2015 for the decommissioning of Ignalina nuclear power plant. The focus of the work was on transforming an operating nuclear power plant into a decommissioning organization, which in turn has significant impact on human resource management at the national level, owing to the size of the country. Typical challenges encountered were: (i) organizational changes

according to the needs of different decommissioning phases; (ii) long term staff planning strategy for decommissioning demands; (iii) development of required decommissioning competences and staff training; and (iv) staff retention strategy according to the national requirements in decommissioning activities. The programme was supported by an IAEA Knowledge Management Assist Visit (KMAV) in 2017.

— In the UK, for nuclear facilities in transition from routine operations to project based decommissioning activities, the need has been identified for reconsidering the knowledge objectives, methodologies and tools to ensure that knowledge management practices are relevant to the new activities being carried out and provide solutions to the new challenges posed in decommissioning. The changes needed in preparation for and during the decommissioning phase are factored into knowledge planning to ensure that knowledge management activities are efficient and effective.
— The Spanish Nuclear Safety Council carried out a project to develop a methodology to preserve nuclear knowledge specifically adapted to its regulatory functions in 2015–2016. The project covered the development, implementation and verification of the methodology and the development of the necessary procedures and tools to align it with the Council's integrated management system. The project was complemented by a number of sessions to motivate the Council's management and train the staff in the use and implementation of the methodology.
— In the UK, a national archive of information (records, plans, photographs, drawings and other data) related to the history and development of the civil nuclear industry has been created. It was opened to the public in February 2017. The archive, funded by the Nuclear Decommissioning Authority and located in Caithness, Scotland, was built in response to the Authority's legal obligations to manage public records and to keep them safe, secure and accessible to the public and the nuclear community. The archive includes relevant documentation that has been accumulated over the decades at the main nuclear facilities in UK and will also act as a central repository for detailed records on radioactive waste related to the UK's planned geological disposal facility.

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For nuclear safety in particular, nuclear knowledge management is of high importance, since securing an adequate nuclear safety knowledge base is essential for both operators and regulatory bodies, and a lack of nuclear safety knowledge can have significant implications.

This publication provides practical guidance and information to Member States on how to manage nuclear safety knowledge at the national level (i.e. beyond the boundaries of individual organizations). It describes the underlying concepts, challenges and available approaches and tools, as well as by summarizing the experience gained by Member States to date. It provides important elements to be considered for building a coordinated approach to managing nuclear safety knowledge at the national level.

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