Managing Nuclear Knowledge

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1 Introduction

Nuclear knowledge has been developed and accumulated over decades of research and development of nuclear technologies for power and non-power applications. Our present generation is the owner and custodian of that body of nuclear knowledge. It can be expected that large parts of this knowledge will be used in the future — most importantly for the continued use of existing nuclear installations, but also for future innovations and for socioeconomic development. Unfortunately, the present status of nuclear knowledge and its management still remain in an unsatisfactory condition. Since nuclear knowledge is unique in many ways, managing this knowledge requires specific programmes and needs to achieve specific objectives. Without diligence in managing this knowledge, substantial portions could be lost due to staff retirements as well as disuse and discard associated with changing priorities. Good management of nuclear knowledge, however, can contribute to economics, safety and innovation.

This article describes the development of nuclear knowledge in the past, its present status and unique characteristics and defines the concept of nuclear knowledge management. It then outlines how nuclear knowledge management programmes can contribute to meet a number of higher level objectives in the future development and application of nuclear technologies and discusses the IAEA role in managing nuclear knowledge.

2 Nuclear Knowledge

There exist many definitions of knowledge but for the purpose of this paper 'knowledge' will be defined to include everything from technical information (documented on paper or on electronic media) to insights, capabilities and skills embodied in people. Knowledge extends beyond 'information'. Knowledge includes the expertise required to turn raw information into an understanding of the relevant issues and provide a meaning to the information. 'Nuclear knowledge' is knowledge specific or relevant to nuclear related activities, including, but not limited to, technical engineering knowledge.

Nuclear knowledge is owned today by many different parties at all levels. Wide varieties of stakeholders claim interests in managing, using, applying, developing and sharing that knowledge — each with specific objectives, requirements and limitations. These stakeholders include governments, including regulators, designers, vendors, utilities, operators, suppliers, consultants and support organizations; training and academic institutions; R&D organisations, the public and non-governmental organizations (NGOs) and international organizations.

2.1 Historical development of nuclear knowledge

The first thoughts on nuclear matter were developed some 2500 years ago in ancient Greece and were of a philosophical nature. Progress in science over the past two centuries generated the first scientific or technical insights, and true scientific knowledge has been developed and accumulated over the past century. Following initial applications for medical purposes, the first larger scale application of nuclear knowledge was for defence purposes, where high levels of government support

were supplied to aid in such development. Nuclear knowledge was possessed by relatively small groups of professionals and was shrouded in secrecy, yet initial efforts to restrict its spread were not successful. Subsequently, the immense potential of the application of nuclear knowledge for human development was widely recognized, along with the need to carefully manage nuclear knowledge to harness its benefits while preventing its use for destructive purposes. The establishment of the IAEA constituted the first step by the international community to manage nuclear knowledge.

After the initial phase, the development of nuclear knowledge for civilian applications relied predominantly on an empirical approach. Priority was given to experiments, and the data collected were applied without the benefit of comprehensive analyses. The need for a systematic and consistent description of that knowledge was recognized, but the level of computer development and information technology was simply insufficient to achieve meaningful databases. Early assumptions about inexpensive and abundant nuclear energy led to the rapid growth of a wide variety of nuclear applications, including nuclear power plants and non-power applications in industry, medicine and agriculture. This rapid growth created some difficulties, including the need to develop the necessary culture as a pre-requisite for using nuclear knowledge for civilian purposes in a safe manner and preventing its misuse.

In the next phase, the nature of nuclear knowledge evolved gradually from being a national and strategic resource to a commercial resource. Some governments began to reduce support to the development, utilization and management of nuclear knowledge since it was assumed that market forces would be capable of handling these aspects. National nuclear regulatory regimes evolved to ensure that nuclear knowledge was used in a safe manner. However, a few serious accidents in nuclear power plants and nuclear facilities, along with the failure of the nuclear community to adequately communicate with the public, resulted in a global stagnation of the nuclear industry for over two decades. This stagnation caused a loss of attractiveness of nuclear science and technology to the younger generation — resulting in low enrolments on nuclear engineering programmes and a subsequent widespread concern that the natural processes of transferring nuclear knowledge from one generation to the next could be seriously interrupted.

Another relevant factor potentially impeding the natural flow of nuclear knowledge to subsequent generations has been globalization, which has led to a greater mobility of nuclear professionals carrying their tacit knowledge with them. Also, nuclear security requirements have resulted in the development of legal controls to prevent the free flow of persons with certain types of knowledge that could be used for military purposes. An additional factor has been the maturing of some segments of the nuclear industry, wherein competition has restricted the free flow of knowledge for proprietary reasons.

2.2 Present status of nuclear knowledge

Scientific nuclear knowledge has been accumulated over about one century, with specific operational experience acquired over approximately six decades. At present, nuclear knowledge is at a mature stage and has made significant contributions to a wide variety of applications. For example, in the field of nuclear power, a statistically significant collection of operational data from well over 12 000 reactor years of operational experience has taken place. National databases have been developed on operational nuclear facilities, and criteria for assessing and improving the performance of nuclear facilities have been established. Similar progress has been achieved in the area of non-power applications of nuclear technology in agriculture, industry and medicine.

However, some of the nuclear knowledge — developed with government support over the past six or more decades at considerable cost — may have exceeded the current commercial demand for it and some of it is facing the danger of being permanently lost. While some parts of nuclear knowledge are being constantly developed, and freely shared, other parts are ‘stranded’, restricted or not being used. Owing to these inconsistencies, there is often a lack of effective mechanisms to transfer the knowledge from one generation to the next.

Since the turn of the century, the nuclear field has experienced a period of unprecedented change. The nature and pace of this change are affected by technological, economic, environmental, political and social factors. In view of these driving forces, the present status of nuclear knowledge and its management remains in an unsatisfactory condition to support the anticipated growth in nuclear power use to meet the future needs of global development. A key reason for this is the number and diversity of nuclear knowledge owners and stakeholders. Nuclear knowledge is being perceived differently by these diverse stakeholders and there is a lack of adequate coordination among the owners of these knowledge resources for their effective utilization. Unfortunately, the public is often confused by inconsistencies in communicating nuclear knowledge, causing negative public attitudes that have often unnecessarily impeded the healthy growth of the nuclear industry.

Within the commercial nuclear industry, the relevant nuclear knowledge necessary to maintain high performance is generally adequate. However, most commercial ventures have a fairly short term vision, expecting their governments to fund longer term development needs. Such governmental support has been inconsistent from country to country, resulting in an irregular appeal for attracting students into the nuclear profession. As a result, some countries have responded by initiating nuclear knowledge management activities in a systematic manner and others are following.

3 Future Needs for Nuclear Knowledge

Given the significant impact of nuclear technology on our daily life over the past century, there is widespread consensus that the need for nuclear knowledge will only increase in the future. The four primary areas of need are:

- The continued successful and safe operation of existing nuclear facilities;
- The short term and long term issues associated with decommissioning and waste management;
- The design and construction of new nuclear facilities;
- Increasing the contribution of nuclear applications to medicine, agriculture and industry — in particular in developing countries.

3.1 Continuing operation and decommissioning of existing installations

Irrespective of the future growth or decline of nuclear power, the existing nuclear installations will continue to be operated as long as they remain commercially viable. Nuclear power plants were originally expected to have a service life of about 30 years, but operational experience has demonstrated that most well managed plants can continue to operate and are likely to have an economic service life of 60 years or more. Thus, knowledge of the design and construction aspects of the plant and operational experience has to be managed effectively and made available to successive generations of employees of the utilities, regulators and other associated organizations. The overall life cycle of many nuclear power plants from cradle to grave is likely to be in excess of 100 years, with the decommissioning and waste management phases lasting a number of decades afterwards. This makes the availability of appropriate nuclear knowledge an imperative for being able to successfully manage the facility through all its phases to its green field end state.

3.2 Facilitating the growth of nuclear power

Concerns regarding global climate change and availability of economically exploitable fossil fuels are driving many countries to reconsider the use of nuclear energy in a significant way. If nuclear power is to become a major long term source of energy, compatible with environmental stewardship,

the international scale-up in developing new nuclear power plants could be substantial. The innovations, required to design and construct new plants compatible with national needs and constraints, must be built upon a strong foundation of well sustained nuclear knowledge. A nuclear renaissance would be unthinkable without innovation. This requires an effective system of managing nuclear knowledge that facilitates appropriate sharing of knowledge, both in its current application and also in the creation of new knowledge.

3.3 Sustaining nuclear knowledge for non-power nuclear applications

The application of nuclear technology to areas such as medicine, agriculture and a wide variety of industrial applications has resulted in an immense array of humanitarian benefits in many nations — sometimes resulting in economic impacts even larger than that of nuclear power. Such applications tend to be less controversial than nuclear power and generally enjoy positive public perception. Knowledge in these areas is broadly disseminated and in most cases freely shared. Given the huge potential for much wider global impact, it is essential that a good system of managing the knowledge is in place for developing newer and more widely used applications.

4 The Unique Characteristics of Nuclear Knowledge

Nuclear knowledge is unique in many ways — different from knowledge developed and used in other industrial domains. It is complex, involving high development costs often requiring significant governmental support. Nuclear knowledge must be developed and retained over long time frames to service operational nuclear facilities and over even longer time frames to enable global sustainable growth. Special constraints exist due to the dual (peaceful and non-peaceful) nature of nuclear technology, and these characteristics have often led to serious public concerns. As further elucidated below, these unique characteristics make efforts to effectively manage nuclear knowledge most desirable or even mandatory.

4.1 Complexity

The effective use of nuclear power and other nuclear applications for the benefit of humanity at large requires highly complex and multifaceted knowledge of several disciplines, including many branches of basic science and engineering, law, economics, finance, commerce, management and public communication. The acquisition of considerable nuclear knowledge is a necessary pre-requisite for any country aspiring to harness the benefits of nuclear science and engineering. The uniqueness of this technology, especially the strict requirements for proper control, necessitates an intensive knowledge base in considerably more breadth and depth than for other technologies.

Owing to this complexity, and in contrast to other resource types, the nuclear knowledge base is finite — both at the national and international levels. Whereas it may be possible to inject huge financial resources into some areas of endeavour to greatly accelerate progress, such as building low income or temporary housing to provide accommodation in the aftermath of a natural disaster, there is simply no way to short-circuit the time necessary to create or re-create nuclear knowledge. Once a crucial piece of it is lost, the time necessary to recreate such unique knowledge is very substantial.

4.2 High costs

Largely due to its complexity, the development of nuclear knowledge is quite costly. Nuclear facilities, including many experimental facilities, are large, incorporating highly sophisticated components. Highly specialized multidisciplinary problem solving skills are required of nuclear professionals. The development and retention of the necessary human resources required for success

are inherently expensive. Due to this cost, a high level of government support and close monitoring of activities is essential during the development, application and transfer of nuclear knowledge.

4.3 Long term development and utilization

The timescales involved in generating nuclear knowledge are relatively long due to the long gestation periods of nuclear facilities for research and industrial applications. The knowledge developed in each area of application is required to be preserved over several decades and effectively transferred to successive generations of professionals, due to the very long life cycles of many nuclear facilities.

4.4 Importance of international cooperation

Nuclear knowledge has been used successfully in the past by many countries as a catalyst for socioeconomic development. It is becoming increasingly clear that a wide range of benefits can be obtained from the appropriate use of nuclear power and other nuclear applications. However, the 'appropriate' use presupposes a certain level of maturity in the industrial and societal context, especially in terms of accountability and decision making systems and a general awareness and understanding of nuclear issues beyond mere technological aspects. Hence, it is not surprising that international cooperation has played a crucial role in the development of nuclear knowledge right from the very beginning of its application for civilian purposes. Indeed, the importance of international cooperation to any country embarking on a nuclear programme today is a unique characteristic of nuclear science and technology.

4.5 Balance between sharing and protection

The inherently dual nature of nuclear technology necessitates constraints on the sharing of nuclear knowledge. In contrast to knowledge in other scientific domains, the sharing and use of nuclear knowledge are restricted due to concerns about nuclear safeguards and proliferation. On the other hand, ensuring safety requires ready availability of high quality, well documented experience and knowledge. The risk to nuclear safety from the loss of or lack of access to nuclear knowledge could be very high. Thus an appropriate balance between nuclear safety and safeguard requirements needs to be established in managing nuclear knowledge.

4.6 Government involvement

Owing to the long term return on investment compared with other industries, as well as safety, security and non-proliferation issues, a high level of government involvement and close monitoring of activities is essential during the development, application and transfer of nuclear knowledge. This involvement is necessary not only to underwrite a large portion of the development cost but also to manage nuclear liability (including its trans-boundary nature), nuclear safety concerns and the prevention of nuclear knowledge misuse under all circumstances.

5 Nuclear Knowledge Management

Given the generally unsatisfactory state of nuclear knowledge and its management — resulting from a combination of governmental budgeting inconsistencies, demographic gaps in the professional workforce, the pressure for strong growth in nuclear technology applications worldwide and the lack of awareness of the importance of managing nuclear knowledge in the past — the timing for developing and implementing effective nuclear knowledge management programmes is urgent.

Knowledge is the basic economic resource in our age. As such, it needs to be carefully managed. By concentrating on the three fundamental components: people, processes and technology modern knowledge management strategies, methods and tools have been developed for all stages of the knowledge cycle. The application of those strategies, methods and tools is fundamental in coping with the unique challenges posed for managing nuclear knowledge.

5.1 Scope of a nuclear knowledge management strategy

The scope of an effective nuclear knowledge management strategy can include a wide range of elements in three typical areas (although not all of them need to be present in each programme): (1) to *maintain* and protect existing nuclear knowledge, (2) to *share* nuclear knowledge or (3) to *develop new* nuclear knowledge. This scope includes:

- Creating an awareness that nuclear knowledge is a fundamental resource;
- Developing and using effective mechanisms for capturing, preserving and transferring explicit, implicit and tacit knowledge;
- Identifying core competencies to be captured and prioritized, taking into account scheduled retirements;
- Creating appropriate mechanisms, including effective collaborations with training and academic institutions, for attracting and developing future nuclear workers;
- Continuously updating and introducing new training programmes as an integral part of the organizational commitment to optimize staff nuclear knowledge;
- Maintaining and developing R&D capabilities;
- Fostering a knowledge sharing culture and effectively applying existing knowledge to create new knowledge to meet sustainability criteria.

Nuclear knowledge management can eventually contribute to meeting a number of higher level objectives in the future development and application of nuclear technologies such as:

- Achieve *safe* operation and maintenance of all nuclear facilities by sharing of operational experience;
- Achieve *gains in economics and operational performance* through effective management of the resource knowledge;
- Maximize *the flow of nuclear knowledge from one generation to the next* and attract, maintain and further develop a dedicated cadre of highly competent professional staff to sustain nuclear competence;
- Facilitate *innovation* to achieve significant improvements in the safe, economical operation of all new nuclear projects;
- Achieve *responsible use* by properly identifying and protecting sensitive knowledge from improper use.

In order to contribute effectively and efficiently, nuclear knowledge management should become an *integral part of all nuclear activities* at the project, corporate and national levels; that is part of all large nuclear *projects* but also part of the corporate or institutional management system of

all *organizations* involved in research, development and utilization of nuclear energy and radiation technologies;

When implementing nuclear knowledge management programmes in organizations or institutions, an appropriate nuclear knowledge management culture needs to be established. Nuclear knowledge management should be established as a continuing and sustainable activity, properly addressed in the integrated management system, and should be well funded. Nuclear knowledge management programmes should be implemented and supported through development and adoption of appropriate approaches, equipment and tools, and their effectiveness should be monitored and evaluated through appropriate metrics.

6 IAEA' role in Nuclear Knowledge Management

Managing Nuclear Knowledge is an issue that concerns all Member States that use nuclear technologies for either power or non-power applications. It needs to be addressed to ensure the continued safe use of these technologies. There is a strong consensus view that preserving and enhancing nuclear knowledge is a topic on which the Agency is well suited to take a leading role, particularly in terms of promoting Member States' increased awareness of the issues involved, and in facilitating international and regional collaboration.

- Both nationally and internationally, there is increasing recognition about the need to address issues related to the management of nuclear technology. The continued safe use of all nuclear technologies – including both power and non-power applications – depends on well-trained capable personnel relying on and having access to a sound base of nuclear experience and technology.
- Two central issues to nuclear knowledge management are succession planning and nuclear knowledge preservation. The "next generation" must be capable of applying, regulating, and further developing nuclear technologies. They must know what, how, and why. They must have access to "nuclear" education and practical training opportunities.
- There are growing concerns about an approaching shortage of next generation "nuclear" personnel. Action must be taken to address these concerns. This is vital irrespective of growth. It is an absolute requirement for growth in all applications of nuclear technologies.
- There is a strong role for international co-ordination and collaboration. Exchange of information and experience is key. The Agency provides a very useful forum for such exchange of views and experiences. It has an important role to raise awareness of the issue. The Agency is also well suited to provide assistance in nuclear knowledge preservation at the request of Member States.

Knowledge management related to nuclear science and nuclear technology is not a new area of activity at the Agency. Many of the Agency's regular budget and technical co-operation programmes support activities that are aimed at developing and sustaining the technical competence needed to apply nuclear technologies and operate nuclear facilities in Member States. Extensive training, mentoring and fellowship activities — as well as activities focused on preserving, archiving and making available for retrieval vast amounts of scientific and technical data and documentation — have always been a visible, vigorous part of the Agency's programme, although these activities have not necessarily been highlighted as part of an overall "knowledge management" agenda. Detailed information on the specific activities of the IAEA in managing nuclear knowledge can be further explored at http://www.iaea.org/inis/nkm.