Redevelopment and Reuse of Nuclear Facilities and Sites

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Summary

With an increasing number of nuclear facilities getting to the age of retirement, the question of the reuse and redevelopment is attracting strong interest. The question of preserving the heritage is becoming also a consideration. And the answer includes a mix of technical and regulatory feasibility, economic and environmental aspects and local stakeholder's expectations.

If some nuclear facilities have been brought to a so-called "greenfield" unrestricted use status (ie removed from nuclear regulatory control) at the end of their life, with all their buildings and equipment dismantled and disposed of, many have got a second life. If one end of the spectrum is the "greenfield" case which opens a full range of opportunities for new use, the other end of the spectrum would be facilities within a nuclear site which have changed function (from production to waste treatment as an example). But there are in the middle of the spectrum many examples of buildings and sites turning from a nuclear related use to another industrial use (Greifswald in Germany for instance), or moving from nuclear research to non-nuclear research (Fontenay aux Roses in France is a successful illustration). In some cases, landmark architecture has been maintained, in some other cases some "non-contaminated equipment" such as control rooms have been preserved; however, this is more the exception than the rule.

The publication of the IAEA on "Redevelopment and Reuse of Nuclear Facilities and Sites, Case Studies and Lessons Learnt" provides already a useful reference of what can be done, grounded in the strategy and the technical steps taken by these completed projects. And further additional work related to this topic is on-going.

Definitions

The following definitions have been devised:

- Reuse: the use of a facility or building for a purpose other than that for which it was originally intended and/or used, following the termination of its original use or the reuse for the original purpose but under new circumstances.
- Redevelopment: planning, further development, re-planning, redesign, clearance, reconstruction or rehabilitation of all or part of a project area.

Introduction

The International Atomic Energy Agency (IAEA) is part of the United Nations. It was established in 1957, with a mandate of seeking to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. The work of the IAEA is aligned with supporting the United Nations Sustainable Development Goals. Today 168 States are members of the IAEA. The fields of activities of the IAEA include safeguards and verification of nuclear material, the development of nuclear safety standards which are a reference for Member States' own nuclear safety regulations and of nuclear security series, and nuclear science and technology concerned with nuclear energy as well as nuclear applications such as health, food, or monitoring of the environment. The IAEA gathers good practices and supports scientific development, and ensures dissemination of safety standards, security series and technological and operational good practices through publications, networks, peer review services, conferences and a program of technical cooperation to provide focused support to requesting Member States. The IAEA maintains an extensive library, searchable on-line, with more than 1.3 million print and electronic items in its collection.

Trend in life cycle management: nuclear energy is reaching 60 years

Nuclear energy, still young compared to many other means of energy production, is however reaching the milestone of 60 years. The time has come for the pioneering facilities, which often carry a strong heritage value, to retire. Looking at nuclear power plants, out of 448 in operation as of October 2017[1] more than 50 % are already more than 30 years old. With a usual lifetime spanning from 40 to 60 years, it means that a significant number will be shut down and decommissioned in the coming two decades. It adds to the already 164 nuclear power plants already shut down. This is certainly not the end of nuclear power: there are at the same time 57 new nuclear power plants under construction, either replacement or new capacities in countries which have decided to include nuclear power in their energy mix. And there is a renewed interest in developing new technologies such as small and modular reactors (SMR) or so-called Generation 4 reactors.

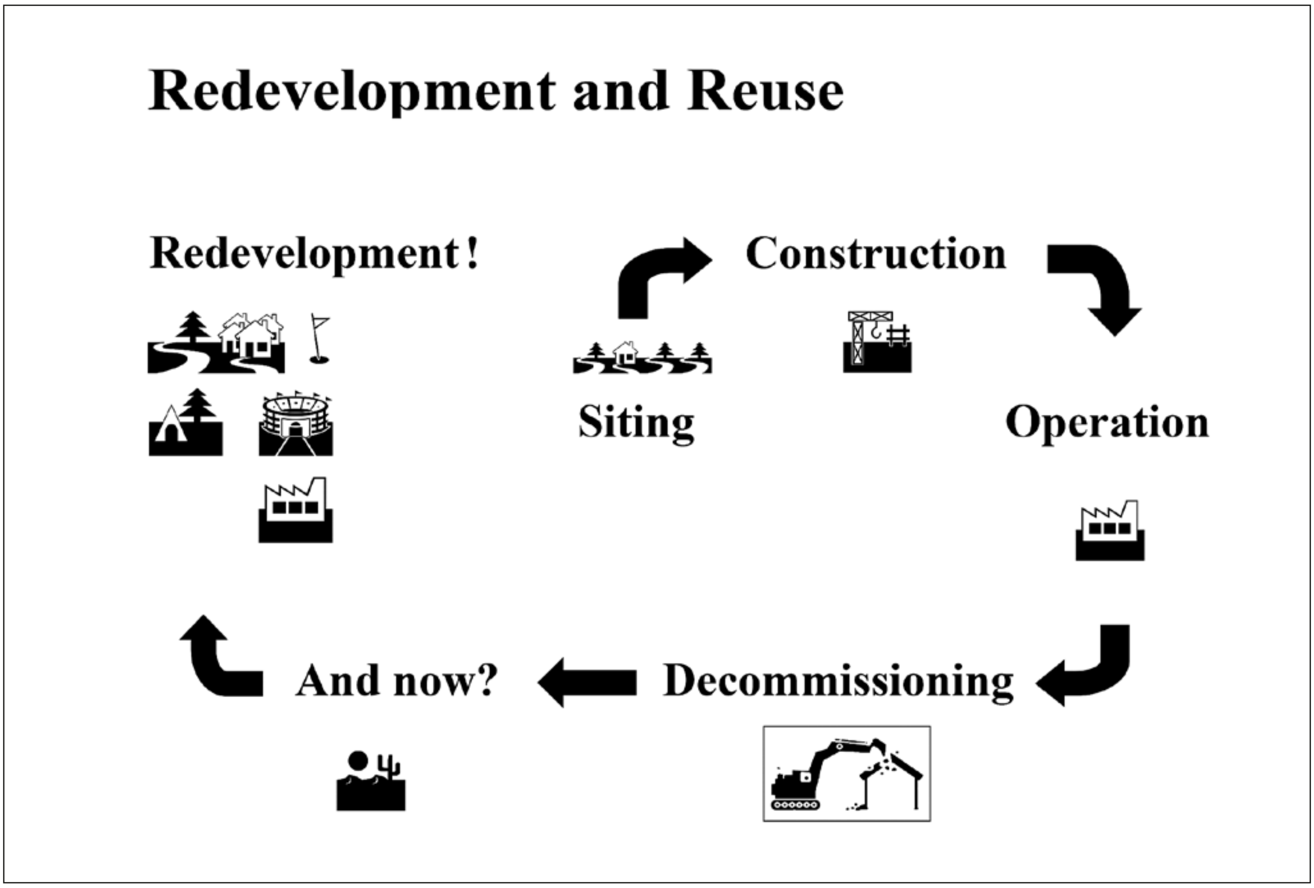

Fig. 1: Growing needs of decommissioning.

Conversely, nuclear is entering a new phase of its life cycle: dismantling and decommissioning.

Nuclear power reactors are not the only nuclear facilities. Research reactors are smaller facilities, many of them having contributed to the early development of nuclear energy in the 50s and 60s, many of them being in use for education, training, basic research needs and nuclear applications such as isotope production used in hospitals for diagnosis or for cancer treatment. There are currently 225 research reactors in operation worldwide[2] and nine under construction; conversely around 200 are currently not operating, around 50 of them being already in the stage of decommissioning; and slightly more than 300 have been already decommissioned. Nuclear fuel cycle facilities include plants for processing uranium, fabricating fuel or recycling spent nuclear fuel. Many have also contributed to the pioneering of nuclear energy. There are currently around 330 nuclear fuel cycle facilities in operation, while close to 130 have been already fully decommissioned and around 170 are shut-down. Research reactors and fuel cycle facilities can be stand-alone but are often part of a nuclear research centre or of a large fuel cycle facility site.

It is therefore clear from these facts that there will be a significant increase of nuclear facilities, especially of pioneer facilities of preservation interest, which will reach the end of their operational life and will have to be decommissioned and dismantled. The recommended policy, and the policy indeed applied in most countries, is to start decommissioning as soon as reasonably possible so that the burden of end of life is not unduly passed to future generations. In this respect, the question of preservation of heritage is timely, as well as the question of the future of sites or land which have hosted nuclear facilities.

Towards a potential reuse: the main steps of the decommissioning process

The life cycle of any facility starts at the time of defining its need and purpose, preparing a feasibility study, and taking a decision to build. From then on, the next steps are siting, and design of the facility. From that point onwards, a nuclear safety regulator will be involved. The mission of the regulator is to protect people and the environment from the harmful effects of radiation, and this mission will be maintained over the whole life of a facility and over all related activities. A nuclear facility will be licensed. At the end of the life of a facility, the decommissioning work aims at "de-licensing" or as more precisely defined in the IAEA Safety Glossary,[3] decommissioning the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. In addition, the waste arising from

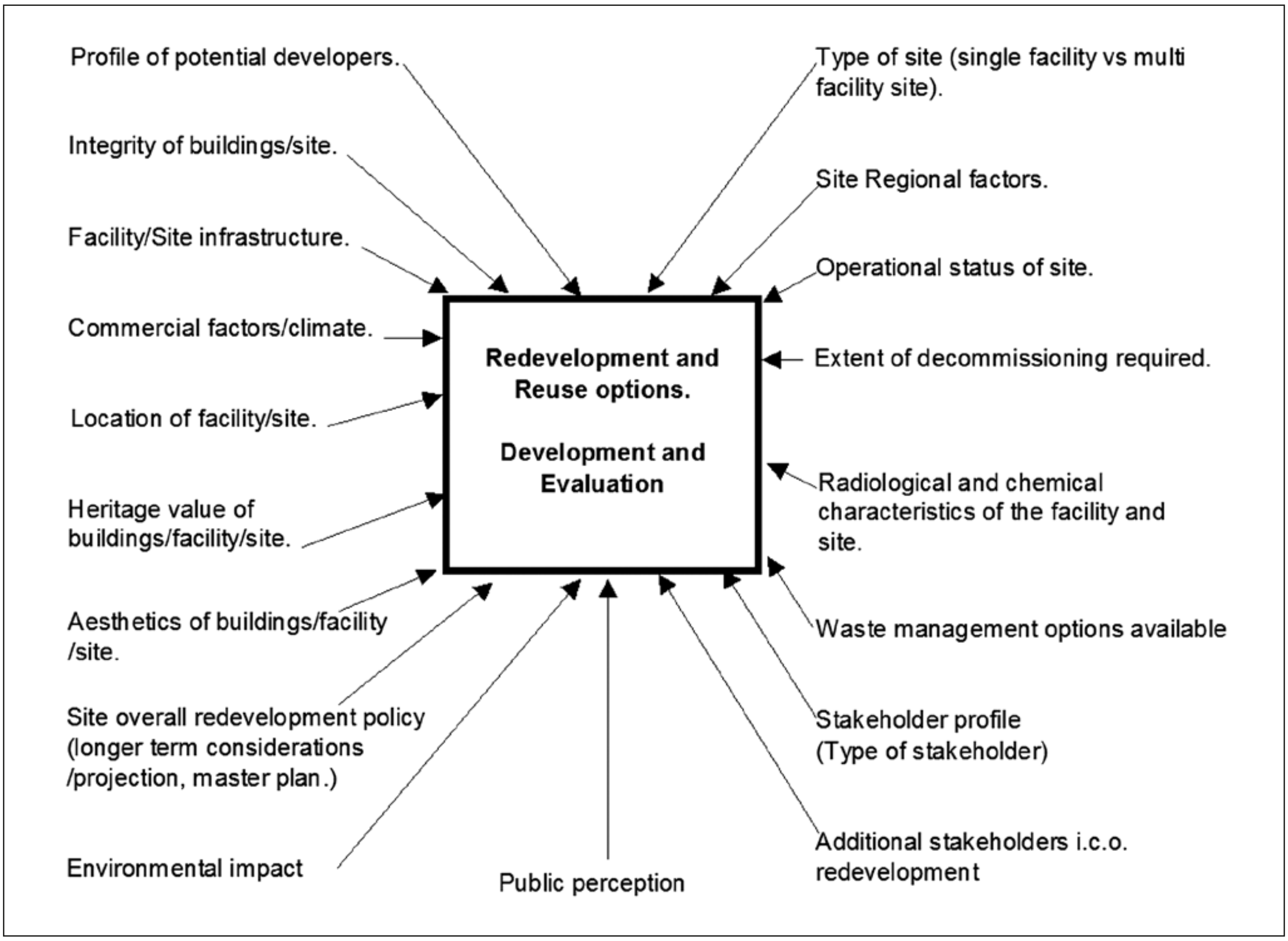

Fig. 2: Redevelopment and reuse.

the dismantling or cleaning of a facility or a site, when they remain radioactive or are contaminated, must be managed according to nuclear safety regulations; clearance can be given for equipment which has been checked and confirmed to be non-radioactive and non-contaminated. Otherwise its storage, reuse when possible and disposal must be approved by the nuclear safety authority of the country.

The decommissioning process starts with planning when the facility is still in operation, and should be anticipated in so far as possible from the time of design (it was certainly not the case for the pioneer and first generation facilities which have to be decommissioned today). There is a transition phase between operation, shut-down and start of dismantling. The strategies for decommissioning that have been adopted or are being considered by Member States include immediate dismantling and deferred dismantling. A combination of these two strategies may be considered practicable depending on safety requirements, environmental requirements, technical considerations and specific conditions, such as the intended future use of the site. The decommissioning plan must be approved by the nuclear safety authority.

The first steps of the work will be the physical and radiological characterization of the site or the facility. This may have to be performed up to each room. This key step will allow determining the level of remaining radioactivity, and defining whether decontamination, total or partial, should be implemented. When there is an intention to reuse the whole or part of the building, this will be critical to assess the feasibility of such reuse.

Next will be the physical dismantling of the equipment and, in most cases, of the buildings. This may include decontamination. The waste generated has to be sorted, possibly treated and conditioned, and be ready for disposal. Some of the buildings on the site can be re-purposed for housing waste or effluent treatment systems, for measurement for sorting or clearance purpose, or for interim storage of waste. Having a defined route for final disposal of waste at the time of dismantling is best. The final disposal site is, in nearly every case, in a different location than the nuclear facility, allowing for a reuse or redevelopment of the land or the buildings.

Another step, which does not need to be the final one, is to assess possible soil and groundwater contamination. When such a situation occurs, a strategy must be designed to assess the impact, the possible remediation plans and decide on a target end state. The decontamination target related to this end state for soil remediation will also take into account the expected reuse of the land when such an option is technically possible (most of the time, it is) and considered.

Survey of the site or the buildings must of course be performed upon completion of the work and demonstrate measurements compliant with the target. This is one of the conditions to allow the nuclear safety authority to release the site for unrestricted or restricted use. Further monitoring may be required.

In case of an uranium mine, the overall approach would be similar: plan, characterize, implement remediation work as necessary, and survey. And possible further monitoring.

Criteria to define a reuse or a redevelopment plan

Redevelopment or reuse of sites or buildings is the next logical step in the life cycle of a site or a facility. And having plans for redevelopment or reuse before starting work will help defining target end state, and is useful to set the right technical decommissioning or remediation approach.

The International Atomic Energy Agency has collected experience gained in its Member States on this specific topic of redevelopment or reuse of nuclear facilities and has published two reports, one in 2006[4] and one in 2011[5], also available for free download through the Agency's website. The networks of practitioners (International Decommissioning Network – IDN and Environmental Management and Remediation Network – Environet) as well as the wiki being developed provide further opportunities to share experience.

In practice, most of nuclear sites and former uranium mines can be redeployed.

The typical redeployment and reuse options are as follows:

- Release for unrestricted use and redeployment. This would be the reference strategy in many cases, allowing completely new projects to be developed, from real estate (for example for sites close to or having become part of urban centers) to natural park (for example for former uranium mining sites). When relating to building, it could also provide opportunities to create museums.
- Release as "brown field" for other industrial use. Such other industrial use could be for example a different non-nuclear energy project, or a research center on a non-nuclear topic.
- Reuse for another new nuclear project. This could be the case to build a new reactor replacing the one being shut down. It happens also for instance in large nuclear research centers or fuel cycle sites where some old laboratories or processing units are dismantled and then replaced by other new facilities.
- Reuse some buildings for other purpose on the site. It could be for instance housing waste treatment facilities on a nuclear site. It could also be a repurposing of a facility for interim storage of low level radioactive waste on a site which major activity remains or not focused on nuclear (the facility itself will in any case be subject to nuclear safety authority licensing).

Several factors will ultimately guide the decision on a reuse or redevelopment approach. And good practice is that any decision should be taken after consultation with the stakeholders, including the site's neighbours and the local authorities. A good quality relationship with them during the operation phase will help to have a good level of engagement when addressing this final leg of the life cycle of the site and, hopefully, to come to a consensual agreement on what do to next. Figure 1[6] gives an image of some of the key factors to be considered.

A strategy for reuse or redevelopment will be taken based on several factors, ranging from expectations of a replacement economic activity to technical feasibility of different options, and taking into consideration nuclear safety, environmental regulation aspects and the stakeholder's perspective.

Some examples of criteria to define a strategy are given below:

- Value of the land. This could be an important consideration for sites which are located close to urban centres. In this type of environment, especially when the demography has transformed a relatively isolated place to a residential area, there may be a double pressure of neighbours no longer comfortable to live close to an industrial site and attractiveness of the land to real estate development. Conversely, when nuclear facilities or uranium mines are located in scenic locations, there may be value to return the land to a natural environment.
- Taking advantage of existing infrastructure. This could range from access to the electricity grid at site level, making it easier for instance to redevelop another electricity power plant (whether nuclear or not) to benefit, at a building or facility level, of a site having already a nuclear license, making easier to reuse the building or redevelop another facility on the same site. It could also include the availability of a skilled workforce, or of a web of supporting environment such as supply chain, laboratories, training centres, etc.
- Socio-economic consideration. The closure of a nuclear facility or a mining operation may have a significant impact on the local economy. The local authorities and the local stakeholders may expect a plan to redevelop the economy. Such plan can make good use of a redevelopment of the site for other purposes, whether industrial or more service and tourism oriented depending on the situation.
- Financial considerations. This consideration is not completely independent from the other criteria. Any reuse or redevelopment plan must be grounded in sound economics to be sustainable. It means a sound business plan, and the availability of sufficient funds for investment.
- Safety and environmental aspects. These considerations can be an asset (related to availability of existing infrastructure for instance) or a liability (such as expanding urban centres or higher level of regulation).

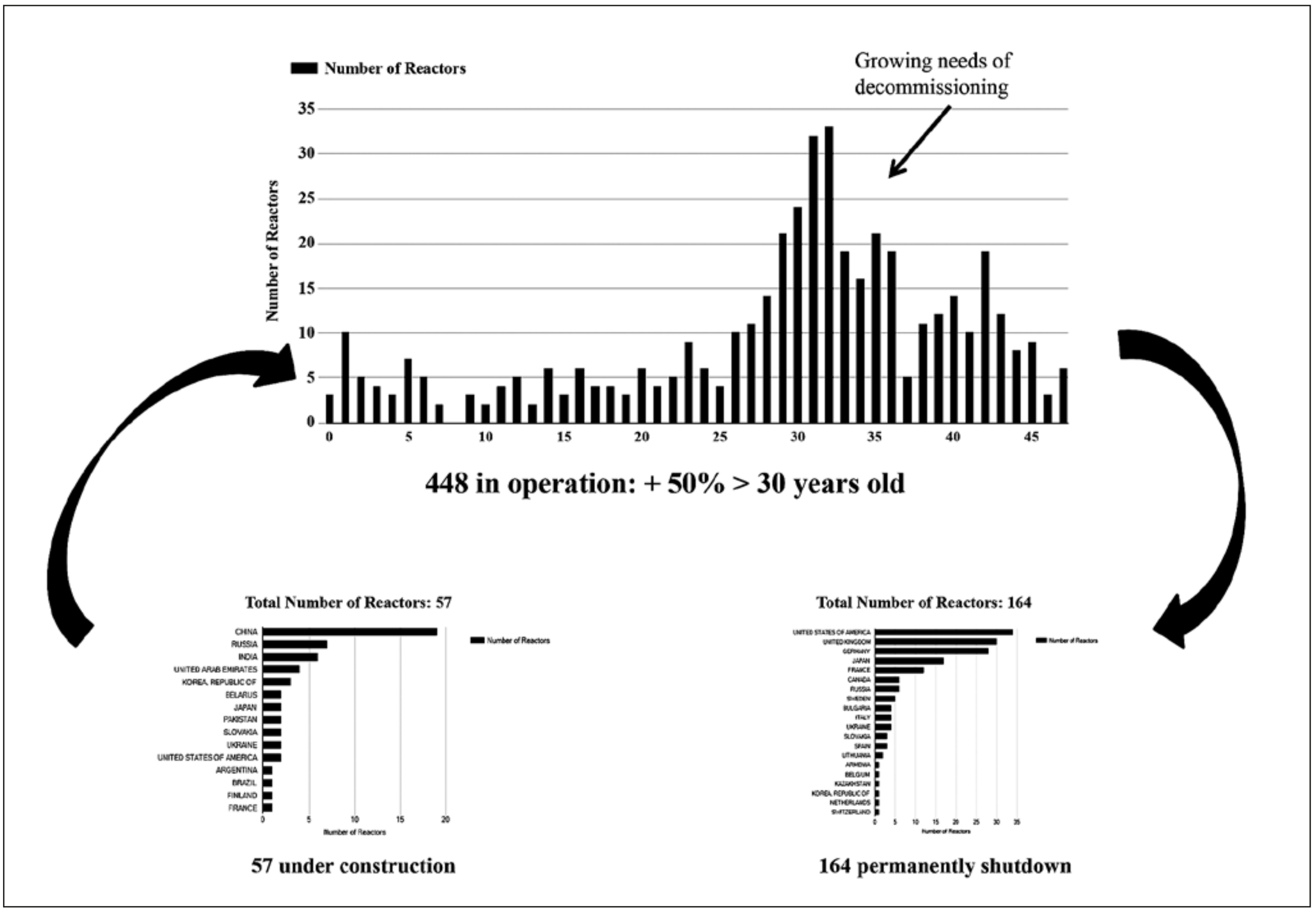

Fig. 3: Redevelopment and reuse options. Development and evaluation.

– Technical feasibility. This is also related to financial aspects. The resources and efforts of returning a site or a facility to a pristine unrestricted "green field" will vary depending on the type of facility and its history.

In some cases, the historical value and considerations of heritage preservation will also be criteria. But, as mentioned above, this must be balanced with safety and regulatory aspects (eg chimneys are architectural landmarks but are not favoured by safety regulations, even in countries with lower risk of earthquakes) or financial aspects (maintenance cost of a site even when the facility is no longer a nuclear licensed site). So having these criteria to prevail is challenging.

Some example of reuse or redevelopment

There are many examples of reuse at buildings at a nuclear site or redevelopment within a nuclear site for further nuclear related use. On the latter aspect, it is the usual life of large centres to have facilities set-up, used, dismantled and replaced and examples could be found in many nuclear pioneering countries. On the former aspect, there are several occurrences of converting a former nuclear building into a radioactive low-level waste interim storage such as the Seibersdorf former research reactor in Austria. Another example is reusing the turbine hall of a nuclear power plant to house a decontamination facility such as in the A1 nuclear power plant in Slovakia.

There are also many examples of redevelopment of former nuclear sites for other scientific or industrial purposes. In the city of Grenoble in France, located between a river and mountains and where land is a scarce asset, the initial nuclear research centre has been fully dismantled and has been replaced by a research centre devoted to new technologies (IT related and renewable energies related). In Germany the Greifswald nuclear power plant site provides a good example of a redevelopment strategy taking advantage of existing infrastructure and willing to provide socio-economic continuity. There are plans for a new fossil energy project and manufacturing of components for maritime cranes and wind mill (not fully implemented at the time of writing this paper).

Now, there are also many cases where the return to greenfield with no or little industrial redevelopment was sought. This is often the case with former uranium sites, examples ranging from return to forestry use in Germany or pastoral use in the USA. But it also happens with nuclear power plants located in isolated places, such as Yankee Row in the USA: all land has been released for unrestricted use except a small part where spent fuel is stored pending a final disposal site.

Keeping the memory alive

Despite the challenges of heritage and preservation, there are fortunately some examples where this has been achieved. The above-mentioned example of Austria allowed to keep the landmark structure of the building. In other instances, nuclear facilities have been turned into museums, such as the Hanford's historic B reactor in USA or the FZK Forschungsreaktor 2 in Germany. France provides another interesting example: a former reactor has been dismantled and decontaminated and then converted into an on-site hall devoted to dismantling technologies, which can also be open to public.

In most cases, it was not possible to keep the buildings, and certainly not possible to recover used major equipment as they are contaminated or radioactive activated. But there are still some options to preserve memory, as there are parts of a nuclear facility that are critical for its operation but which were not in direct contact with radioactivity. The best examples are historical control rooms, which have been preserved and are now shown in memorial or exhibition halls.

Finally, knowing the history of a nuclear facility, especially those pioneer facilities where many first of a kind scientific or technological work was conducted, is useful to plan its decommissioning. Knowledge management and knowledge preservation methodologies are being developed in this respect in many countries. The records gathered are not currently used for heritage preservation, and there is no current plan to keep them beyond the completion of the decommissioning. However, it could be a resource worth looking at by the heritage preservation community.

In 2050, will nuclear be a "has been" or a "hero"?

There are several views on nuclear energy. Some countries are willing to phase out a means of producing electricity that they perceive as dangerous, while others are adding nuclear power plants at a fast pace in their energy mix. Taking a mid to long term view, the new global frontier is to address the challenges of global warming, widely recognized as being linked to carbon emission. The environmental priority is shifting in many countries towards the de-carbonization of our economies and of our energy mix. The Paris Agreement gives a strong impetus in this direction.

It is a fact that nuclear energy is one of the available options to produce electricity with virtually no carbon emission. It could be therefore a significant asset to contribute to the de-carbonisation of our energy mix. In this context, if further expansion of nuclear power is not a given as of today, it cannot either be ruled out. In such a case, its heritage value would increase.

Nuclear industrial sites do not figure currently in the World Heritage List, but nuclear is still a young industry. And if nuclear energy becomes a "hero technology" for its contribution to addressing climate change, some nuclear facilities may one day be considered to be added to the List.

Zusammenfassung

Rückbau und Nachnutzung von Kernkraftwerken und ihren Anlagen

Mit der zunehmenden Zahl von Kernkraftwerken, die den Ruhestand erreichen, kommt der Frage, wie diese saniert und nachgenutzt werden, große Bedeutung zu. Gleiches gilt für die Frage des Erhalts des damit verbundenen Kulturerbes. Die Antwort auf die Fragen ist eine Mischung aus technischer und rechtlicher Realisierbarkeit, wirtschaftlichen und ökologischen Aspekten und den Erwartungen lokaler Interessenvertreter.

Wenn nukleare Anlagen, ihre Einrichtungen und die Ausstattung am Ende ihrer Laufzeit vollständig zur „grünen Wiese" zurückgebaut werden und dadurch den Status uneingeschränkter Wiedernutzbarkeit erhalten (indem sie z. B. nicht mehr der atomrechtlichen Aufsicht unterliegen), haben viele ein zweites Leben. An einem Ende des Spektrums steht das Szenario der „Grünen Wiese" mit der vollständigen Auswahl an Möglichkeiten für eine neue Nutzung. Am anderen Ende stehen Kernkraftwerke mit geänderter Funktion – z. B. von Produktion bis zu Abfallbearbeitung. In der Mitte dieses Spektrums gibt es zahlreiche Beispiele von Gebäuden und Anlagen, die aus der nukleartechnischen Nutzung in eine andere Form der industriellen Nutzung überführt worden sind (so z. B. Greifswald in Deutschland), oder die von der Atomforschung zu einer anderen Forschung übergegangen sind (wie es erfolgreich in Fontenay aux Roses in Frankreich der Fall ist). In einigen Fällen wurde die Architektur als Wahrzeichen beibehalten, in anderen Fällen wurde nicht-kontaminierte Ausstattung wie Kontrollräume erhalten; diese Fälle sind jedoch eher die Ausnahme als die Regel.

Die Publikation der IAEA zur „Rückbau und Nachnutzung von Kernkraftwerken und ihrer Anlagen. Fallstudien und gewonnene Erkenntnisse" stellt nützliche Hinweise zur Verfügung, was, basierend auf der Strategie und den notwendigen technischen Schritten, innerhalb der stillgelegten Anlagen getan werden kann. Zusätzliche weitergehende Werke zu diesem Thema sind in Arbeit.

[1] Source: PRIS database – available through IAEA's website.

[2] Source: Research Reactor Data Base – available through IAEA's website.

[3] IAEA Safety Glossary, 2007 Edition, Vienna (2007).

[4] IAEA Technical Report Series no. 444, redevelopment of Nuclear Facilities after Decommissioning.

[5] IAEA Nuclear Energy Series NW-T-2.2, Redevelopment and Reuse of Nuclear Facilities and Sites: Case Histories and Lessons Learned.

[6] IAEA Nuclear Energy Series NW-T-2.2, page 74.