First Decommissioning of a Commercially Operated Nuclear Power Plant in Switzerland

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The decision to shut down the Mühleberg nuclear power plant in 2019 will lead to the first ever decommissioning of a commercially operated nuclear power plant in Switzerland. After a brief explanation of Switzerland's energy strategy and the consequences this has for BKW, the reasons for the shutdown are outlined. This is followed by a discussion of the technical and staffing challenges that will arise during the last years of operation in terms of guaranteeing safe operation. These challenges include in particular how to ensure that knowledge is retained, how to transform the operational organisation into a project organisation and how to communicate these measures in the right way. The main section then describes the decommissioning itself. Both technical and regulatory aspects of project development and execution are discussed. The technical aspects not only cover the actual dismantling process, but also post-operations and preparatory measures, such as using the turbine building as a materials and waste processing centre. The preconditions necessary to allow dismantling to start as soon as decommissioning is directed, regardless of any nuclear fuel still present in the plant, are also discussed. The regulatory framework for decommissioning in Switzerland is addressed, including the decommissioning strategy, licensing procedures, regulators and responsibilities, as well as the involvement of third parties. The details of the project for decommissioning Mühleberg nuclear power plant are also outlined. These include not only project organisation, but also strategic considerations to ensure appropriate preparation in the years leading up to final shutdown.

Contents

1. Introduction

1.1 Switzerland’s Energy Strategy

Switzerland's energy mix and Energy Strategy 2050

The main source of energy in Switzerland is hydropower. It provides nearly 60% of domestic electricity production. In second place are the five nuclear power plants, which together produce more than 36% of Switzerland’s electricity and therefore make an important contribution to its energy mix. Thermal power plants play a minor role, contributing less than 4%. At present, the other renewable energy sources (photovoltaics, wind power etc.) only make up a small part of the energy mix[1].

Despite Switzerland's long and successful history with nuclear energy, the Federal Council and Parliament made the basic decision in 2011 (although not yet ratified by the Swiss sovereign) to gradually phase out the use of nuclear energy. The five existing nuclear power plants are to be shut down at the end of their safe operating life and will not be replaced by new ones. This decision, together with the changes in the global energy situation, will require restructuring of the Swiss energy system. In order to achieve this, the Federal Council developed the Energy Strategy 2050. In this strategy the Federal Council provides an initial package of measures to secure energy supplies in the long-term. The first of these measures relates to the consistent exploitation of existing potential for greater energy efficiency and the second to the balanced utilisation of the existing potential in terms of hydropower and renewable energy sources. In a second stage, the existing distribution system is to be replaced by an energy management system.

Despite the decision to gradually phase out nuclear energy, no maximum operating lives or firm decommissioning dates have been specified for the existing nuclear power plants. However, so far an operating life of 50 years has been assumed – for example in calculating the demand for renewable energy as part of the energy strategy. In October 2014 the Swiss Federal Nuclear Safety Inspectorate (ENSI) announced that, from a technical point of view, at least the newer plants (Leibstadt and Gösgen) could be operated for 60 years and beyond. As yet, no definitive date has been set for Switzerland to finally phase out nuclear energy.

1.2 BKW and KKM

BKW Energie AG (BKW) is a semi-public company in the energy supply sector with strong roots in the north western part of Switzerland. Its core activities are procuring, trading, distributing and selling electricity as well as the associated energy services. It owns factories and plants, holdings and subscription rights throughout Switzerland and abroad.

Mühleberg nuclear power plant (KKM) is 100% owned by BKW and is currently its largest production facility. It is located in the centre of the region traditionally supplied by BKW, which includes the Cantons of Bern and Jura and parts of the cantons of Solothurn, Basel-Landschaft and Neuchâtel. KKM produces around 30% of the electricity from all BKW power plants and holdings or around 40% of the energy used by customers directly supplied by BKW. The reliable and safe operation of this plant is therefore of great importance.

[1] DETEC, Swiss electricity statistics 2013; DETEC; Swiss renewable energy statistics, 2013 edition.

2. Safe Operation and Final Shutdown of KKM

2.1 Reasons for shutting down KKM

In October 2013, BKW decided to continue operating KKM until 2019 in compliance with all the safety requirements and then to take it off the grid. This business decision took account of all known technical, economic, regulatory and political aspects.

The investments required for long-term operation would have resulted in high costs for BKW, which, given the prevailing economic, regulatory and political conditions, could not necessarily be recouped. BKW is also expecting that, in the medium term, there will be further technical, economic and political imponderables, which are not yet defined or quantifiable, which would further increase the financial risks of long-term operation. The current and forecast market conditions are incompatible with the continued economic operation of KKM. BKW expects that, at least into 2020, the trade price for electricity on the European market will be lower than KKM's production costs.

Moreover, the decision to forego long-term operation will free up financial resources and enable BKW to pursue its corporate strategy of increasing its level of investment in new, alternative production capability and in innovative products and energy services. Opting not to invest in long-term operation considerably reduces the business risk and supports the increased expansion of hydropower and wind power both at home and abroad, as well as investments in new, innovative products and services.

The main reasons behind BKW's decision to decommission in 2019 were:

- the projected investment in KKM,
- the need for orderly shutdown and adequate preparation time,
- a robust solution in terms of electricity price development and
- limitation of political uncertainties.

2.2 Safe operation to the very last

Until operation ends in 2019, all KKM staff will continue to be employed at the plant. No redundancies are planned. Instead, the primary aim is to retain the specialists and experts currently working at KKM for the rest of the plant's operational life and for the post-operating and decommissioning period.

The organisational structure, which is currently designed for operating a plant, will be revised, at the latest, when the preparations for dismantling begin. After final shutdown, it will no longer be a case of operating a nuclear power plant, but rather a nuclear facility, which will initially still contain some nuclear fuel. There will therefore be different requirements and operating conditions. Work in the facility will increasingly be divided into a number of different projects, which will require a different way of working and a different organisational structure. Safety will continue to be the priority, but there will be completely different objectives in terms of chronological sequences and costs. This will have the following consequences:

- The organisational structure and the management system, especially the processes oriented towards operation, will have to be revised as quickly as possible and adapted to the new management lines and organisational structure that will be necessary.
- Procedures and work during post-operation and dismantling or during the entire decommissioning process must be planned and controlled by establishing an appropriate project management system. This is the only way it is possible
  - to allow for the necessary change management,
  - to address the employees' need for job security and good future prospects, and

- to enable the licensee to plan at an early stage for the further development of employees based on their age structure.

Only by implementing a new organisational structure at an early stage and promptly identifying and addressing the needs of staff will it be possible to keep staff motivated and committed and develop them to ensure that dismantling is done safely and efficiently.

3. Regulatory Framework of the Decommissioning Project

3.1 Licensing situation following final shutdown

The final shutdown[2] of a nuclear power plant is based on the licensee's decision to cease using the plant for electricity production. The licensee's decision can also be triggered by the supervisory authority demanding retrofitting work that the licensee is unwilling to carry out (for technical, financial or any other reasons)[3].

At the time of final shutdown, the licensed operator therefore changes the purpose of the nuclear power plant, insofar as it forgoes part of the operating licence, namely the permitted reactor output[4]. The plant owner is also obliged to shut it down[5].

If it has not been revoked[6], the existing operating licence continues to form the basis for preparing for decommissioning until such time as the decommissioning direction comes into force and, in principle, beyond that time until the site is granted clearance under nuclear energy legislation.

3.2 Licensing situation in post-operation

If necessary, post-operation follows on from final shutdown[7]. This lasts until the decommissioning direction comes into force. It includes activities and administrative measures to maintain safe operation of the systems still required and of the plant as a whole, under the conditions of the operating licence, after final shutdown has taken place. It also incorporates measures to decommission systems that are no longer required and prepare for dismantling activities. Post-operation is not explicitly regulated. This is not necessary because the conditions that apply on final shutdown, and in particular the obligation to obtain clearance[8], continue to apply[9]. Post-operation is therefore covered by the operating licence, albeit with the restriction that the permissible reactor output[4] now consists solely of the residual power of the nuclear fuel.

With the cessation of electricity generation, during post-operation the essential nature of plant modifications[10] is assessed differently than during power operation. The basic precautions[11] continue to apply, as do protective measures[12]. However, some of the safety barriers or safety

[2] There is a clear distinction between final shutdown and provisional shutdown. The latter occurs when one or more of the criteria specified due to Art. 22 Para. 3 of the Nuclear Energy Act [1] in Art. 44 of the Nuclear Energy Ordinance [2] is/are fulfilled. In contrast to final shutdown, a provisional shutdown can be ordered by the supervisory authority in the face of certain events or situations.
[3] If the licensee fails to fulfil an instruction or a required measure, despite a warning being given, then, pursuant to Art. 67 Para. 1 Nuclear Energy Act [1], the Department can revoke the operating licence and order the plant to be shut down. The conditions specified in the operating licence, and required for the safety of the nuclear facility even after shutdown, remain in force pursuant to Art. 69 Nuclear Energy Act [1] even after revocation or cancellation of the licence until such time as the decommissioning work is directed or the decommissioning direction comes into force.
[4] Art. 21 Para. 1b Nuclear Energy Act [1]
[5] Art. 26 Para. 1 Nuclear Energy Act [1]
[6] in accordance with Art. 67 Nuclear Energy Act [1]
[7] There will not be post-operation if the decommissioning direction is legally effective at the time of final shutdown.
[8] Art. 40 Nuclear Energy Ordinance [2]
[9] Art. 69 Para. 1 Nuclear Energy Act [1]
[10] as stipulated in Art. 65 Nuclear Energy Act [1]
[11] Art. 4 Nuclear Energy Act [1]
[12] Art. 5 Nuclear Energy Act [1]

systems or components of the same are no longer relevant to safety. Thus, while still complying with the reporting[13] and clearance obligations[8], it is possible to dispense with many components without in any way adversely affecting the safety objectives. For example, these components might include the reactor pressure vessel and the building structures surrounding it.

3.3 Licensing situation after the decommissioning direction

The obligation to decommission that arises with the final shutdown decision[5], includes a requirement for the owner of the plant to submit a project for the intended decommissioning to the nuclear regulator[14], which outlines[15]

- the decommissioning stages and schedule,
- the individual dismantling and demolition steps,
- safety measures,
- staffing requirements and organisation,
- disposal of radioactive waste, and
- the overall costs and proof that the operator has secured adequate finance.

On the basis of the decommissioning project, the Federal Department of the Environment, Transport, Energy and Communications (DETEC) will then direct the decommissioning work by means of a decommissioning direction and specify what work is required for clearance by the supervisory authorities[16]. As specified[17], the decommissioning direction establishes

- the scope of the decommissioning work,
- the individual decommissioning stages,
- in particular, the duration of any secure containment of the nuclear facility,
- the limits for discharge of radioactive substances into the environment,
- monitoring of emissions of radioactive substances and direct radiation, as well as
- organisation.

Decommissioning is finished once the decommissioning work has been properly completed and DETEC has been able to establish that the plant no longer represents a radiological hazard and is therefore no longer subject to nuclear energy legislation[18].

While the requirements to reporting obligations[13] continue to apply as appropriate[19], the obligation to obtain clearance[8] is (re)regulated[16], especially for[20]

- the procedure for measuring the arising materials and releasing them as non-radioactive,
- conditioning of the arising radioactive wastes,
- demolition of buildings after they have been decontaminated and cleared as being non-radioactive,
- the recycling of plant components for non-nuclear purposes before decommissioning has been completed,
- the lifting of safety measures, and
- the decommissioning of nuclear power plants and for the dismantling of the reactor pressure vessel and the building structures surrounding it.

[13] Arts. 38 respectively 39 Nuclear Energy Ordinance [2]
[14] in accordance with Art. 26 Para. 1 Nuclear Energy Act [1]
[15] Art. 27 Para. 2 Nuclear Energy Act [1]
[16] Art. 28 Nuclear Energy Ordinance [2]
[17] Art. 46 Nuclear Energy Ordinance [2]
[18] Art. 29 Para. 1 Nuclear Energy Act [1]
[19] Art. 49 Nuclear Energy Ordinance [2]
[20] Art. 47 Nuclear Energy Ordinance [2]

4. Thoughts on possible decommissioning sequence

Whilst substantial parts of the decommissioning project[21] – at least when final shutdown is planned in advance – can be worked on during plant operation and agreed with the nuclear regulator to as great as possible an extent, the actual dismantling operations can only take place once DETEC has approved decommissioning.

In an ideal situation, the decommissioning direction would take effect the day after final shutdown. Dismantling actions could thus be performed in addition to the activities covered by the operating licence.

However, preparatory operations prior to dismantling are in any event already carried out as part of post-operations, immediately after final shutdown. Table 1 shows a possible sequence of events.

Table1 Possible decommissioning procedure with preparatory measures during post-operation, two decommissioning phases and subsequent completion of decommissioning

Post-Operation	**Dismantling** in two phases		**Closure of Decommissioning**
incl. preparing dismantling	1. with nuclear fuel	2. without nuclear fuel	
▪ Post-Operation – Unloading of last core and control rods into spent fuel pool – Transport of conditioned radioactive operational waste to an external nuclear facility ▪ Preparatory Measures: – Conditioning of RPV internals (reactor waste) – System decontamination – Creating autonomous spent fuel pool operation – Setting up center for materials logistics and decontamination – Installing (conventional) replacement systems	▪ Dismantling of all systems no longer required ▪ Once autonomous spent fuel pool operation has been established: – dismantling RPV ▪ dismantling biological protective shield ▪ Removal of fuel elements, followed by lifting of security measures	▪ Dismantling of all water-carrying systems ▪ Dismantling of all remaining systems and connection to replacement systems ▪ Controlled zone given clearance ▪ Lifting of zones ▪ Removal of security guard	▪ Conventional dismantling work provided for in the decommissioning project – demolition of turbine building – demolition of reactor building ▪ Discharge from provisions enshrined in the nuclear energy laws
Post-Operation ends with coming into force of decommissioning direction.	**Phase 1 ends with achieving absence of nuclear fuel**	**Phase 2 ends with controlled zone given clearance**	**Decommissioning ends with site granted clearance under nuclear energy legislation.**

The procedure is based on the following considerations:

- The possibility of a delay in the decommissioning direction coming into force cannot be ruled out, whether because it takes longer than anticipated to draw up the commissioning project, ENSI requires more time for its expert report than planned, DETEC does not issue the direction as fast as it is required by the licensee, or legal proceedings delay the process (by years in certain circumstances).
- Removing the nuclear fuel might take longer than anticipated based on current assumptions.

As a result, flexibility is essential so that the dismantling operations can be classified in the decommissioning phases specified[22], which in turn leads to the following considerations:

- The licensee must be in a position to prepare as extensively as possible for decommissioning during post-operation. This includes providing the infrastructure required for dismantling and removing equipment such as turbine generators and condensers in the turbine building (so as to make room for this infrastructure, especially in boiling water

[21] Differentiation between decommissioning concept, decommissioning plan and decommissioning project s. e.g. contribution to Kontec 2011 [5]
[22] Art. 27, Section 2 (a) of the Nuclear Energy Act [1]

reactors), but also systems such as the control rod drive mechanism in the reactor building. The reactor pressure vessel also needs to be prepared for dismantling at a later stage. To this end, all removable components in the vessel are removed and, after establishing that these cannot be recycled, these are classed as reactor waste rather than decommissioning waste. Another important preparatory activity is removing large components that are no longer required, especially in pressurised water reactors.

- The licensee needs to perform any major dismantling operations in the first phase of decommissioning, with particular emphasis on starting to dismantle the reactor pressure vessel or preparing for this operation. Specific requirements must be met in individual parts of the plant for this to be possible, however. So that the maximum number of dismantling operations can be carried out before removing the nuclear fuel, post-operation and the first decommissioning phase should be organised such that it is possible to dismantle everything not required to maintain safety targets, remove the fuel rods or for further dismantling work.
- The safety and security requirements for each decommissioning phase and the plant components still required need to be defined. This should be taken into account in the safety report. When approving a decommissioning phase, the regulator confirms the new, lower safety and security requirements in keeping with the reduced radiological hazard potential, which means that additional systems can be dismantled. The end of a decommissioning phase is defined by reaching one or more milestones and not by completion of all operations scheduled in this phase.
- To minimise the administrative tasks involved, it can be useful to divide the decommissioning operation into as few decommissioning phases as possible. Two dismantling or decommissioning phases are the minimum required, one for dismantling operations with the nuclear fuel present and one for dismantling operations once the nuclear fuel has been removed and until decommissioning is complete.

5. The BKW Decommissioning Project

Dismantling a nuclear plant requires a legally binding decommissioning direction. BKW's objective is to obtain this direction by the time the nuclear plant is finally shut down. A decommissioning project needs to be submitted by way of an application for the decommissioning direction[14].

5.1 Content, direction procedure and drafting process

Content

The content of the decommissioning project is defined in detail in the Nuclear Energy Act [1] and the Nuclear Energy Ordinance [2] and described in regulatory requirements[23]. Nuclear Energy Act[15] and Nuclear Energy ordinance[24] also form the basis for the content. In addition to technical content, the decommissioning project also describes organisational and financial issues, including the decommissioning procedure and the proposed stages. The decommissioning application comprising the decommissioning project and other explanatory documents, including the environmental compatibility report is submitted to the Swiss Federal Office of Energy (SFOE) as a complete package.

Direction procedure

The decommissioning direction procedure commences when the application documentation is submitted to the Swiss Federal Office of Energy and ends when the decommissioning direction, issued by DETEC, is effective. A preliminary inspection by the SFOE is carried out in the first instance. In the subsequent procedure, ENSI draws up an expert report and the Cantons and the

[23] ENSI-G17 Guidelines [3]
[24] Art. 27 Nuclear Energy Act [1]

affected departments may submit further comments on the application. If necessary, additional concepts and detailed concepts for the decommissioning operations requiring authorisation may be submitted to ENSI after the application documents as part of the authorisation procedure. Public involvement is sought via a public disclosure process. After notification of all comments and expert reports, the decommissioning direction is drafted and issued by DETEC. However, if the affected parties lodge appeals, this can lead to considerable delays in the proceedings.

BKW strives to follow a streamlined and results-oriented official procedure by involving the relevant authorities and cantonal departments at an early stage. DETEC has set up a support group to clarify process engineering issues and corresponding working groups to clarify the regulator's requirements with regard to the format and content of the decommissioning project. This should guarantee legally compliant application documentation and a streamlined procedure.

Drawing up the decommissioning project

The decommissioning project should take an overview and define the outline conditions for decommissioning[25]. The decommissioning project is drawn up in three stages:

- The **overview** defines the content of each chapter, appoints the individuals responsible for each chapter and sets out a schedule. It provides a guide for work within BKW on the decommissioning project.
- The **rough draft** includes the existing content of each chapter based on technical concepts, the existing safety report and other relevant documents.
- The chapters are then **drafted in detail and finalised**, including compilation of any missing content and subsequent consolidation in the document as a whole.

The decommissioning project combines the overall concepts thus created. These include the technical concept, waste management concept and the finance concept. Together, they form the basis for the application documentation. This procedure guarantees that the necessary content will be compiled systematically, thus reducing the risk of an insufficient level of detail or delays in drawing up all the required documents.

5.2 Project organisation

The KKM decommissioning project is based on the assumption of a hybrid project organisation with four project parts. Organisation of the project is based in the Group's head office until final shutdown. The majority of the decommissioning procedure is planned by specific full-time staff, who represent the core team. This core team reports to the Overall Decommissioning Project Manager. All subjects relevant for planning purposes will be structured in this context and appropriate resources made available. Technical planning is the responsibility of KKM employees. These are based in a Projects Department and report to the Overall Project Manager. The department forms part of the nuclear power plant hierarchy.

The core team is backed up by technical experts who may be from the nuclear power plant or the Group's head office. These staff form the extended team and a fixed proportion of the workforce is assigned to work on the project. This includes legal experts and incident analysis specialists in the case of the decommissioning project. The staff in the extended team are also employed in line organisation tasks or other projects in addition to working on the project.

The KKM management team has set up a Technical Decommissioning Committee for KKM to ensure that the plant management is involved in the project. In particular, this is intended to guarantee that the project results are verified to ensure they comply with nuclear safety and operating requirements. The Technical Committee also ensures that sufficient numbers of technical staff are available to work on the project.

[25] see Explanatory Report [4] on the ENSI-G17 Guidelines [3]

The fact that organisation of the project is based in the Group's head office ensures that the Group is responsible for planning decommissioning until the plant shuts down and the plant is still able to focus on ensuring safe operation of the plant itself.

5.3 Challenges for the decommissioning project

The decommissioning project is based on a series of overall concepts and the content of these concepts is combined in accordance with the specifications of the Nuclear Energy Act [1], Nuclear Energy Ordinance [2] and regulatory Guidelines[23]. The challenge for the decommissioning project is to systematically consolidate the content of the various overall concepts and define an appropriate level of detail, without prejudicing any factual information. As, to date, there is no benchmark for decommissioning a commercial nuclear power plant in Switzerland, BKW will need to take on a pioneering role in this field. It is therefore important to work with the authorities to establish mutual understanding of the specified legal framework. This includes clarifying issues such as the tasks to be performed under the operating licence, assuming this is still valid, or the decommissioning direction as the plant's hazard potential reduces over time.

Against the background of differing requirements for plant operation and decommissioning, it is of paramount importance for the KKM Decommissioning Project to ensure a transition from a safety-oriented operating culture to a large-project culture whilst still guaranteeing nuclear safety. Continuing plant operations until 2019 whilst simultaneously preparing for decommissioning is therefore a possible area of conflict and this fact is given due acknowledgement by involving operating staff and creating staff forecasts for decommissioning at an early stage.

6. Technical Aspects of Decommissioning

The technology and sequence of decommissioning differ widely from plant to plant and from licensee to licensee. For the most part, technical details relating to the site or the nuclear power plant respectively are the determining factors that cannot be generalised or simply transferred to other plants. Take, for example, the differences between boiling water and pressurised water reactors which have an effect on the dismantling work required.

The considerations presented below refer in detail to the Mühleberg nuclear power plant with its specifics. These considerations are based partly on experience gained from past dismantling projects and reflect only the conditions pertaining to KKM (use of the turbine building as a waste processing centre), while on the other hand they also include innovative approaches from a technical point of view (self-sufficiency of the fuel pool).

6.1 The turbine building as a waste processing centre

A basic requirement for decommissioning to run smoothly is to separate materials handling, the approval procedure and the conditioning of radioactive waste for a deep geological repository from the actual dismantling work.

As a rule, processing equipment for materials handling will already be in use during the operation of KKM. This equipment, however, does not satisfy the requirements for dealing with the significantly higher mass flows that occur during decommissioning and such equipment must, therefore, first be acquired and set up in the plant.

Due to the high costs anticipated for a new building in which the radioactive materials and waste arising could be processed for disposal, the aim in KKM is to use the turbine building instead. The pivotal reasons for this are:

- limited space on the site,
- the licensing and completion time for a new building which relates to conventional planning permission and the nuclear operating licence,

- it will be possible to use the turbine building after final shutdown of the plant without any major time delay.

The amount of space available in the turbine building means that work on setting up the processing equipment must be closely coordinated with the dismantling work necessary. The turbine hall, which will be cleared as early as possible, is mainly affected. The components of both turbine groups will be removed without further disassembly or treatment other than the preparations for outward transport. They will be disassembled in an external handling area before being disposed of.

The size of the components which still have to be processed afterwards in KKM, timescales and the waste management targets then determine the timing of setting up work, the design and the space requirements of the processing machines including the necessary infrastructure areas, such as the buffer areas.

Preparations can be carried out while KKM is still operating so that, at the time of final shutdown, the planned equipment is ready-to-go and can gradually be installed and commissioned alongside the construction of components in the turbine building:

- Planning of a buffering system from radioactive raw waste packing drums in KKM’s turbine building to conditioning for the deep geological repository.
- Drafting and agreement of a concept for subsequent dismantling, decontamination and clearance of components.
- Drafting of a detailed workflow schedule for the removal of components and the installation of handling equipment.
- Preparatory work such as the removal of splinter shield blocks around the turbine groups immediately after final shutdown or completion of radiological characterisation in the turbine building.

So on one hand, space for setting up the processing facilities can be created relatively early in the turbine building, while on the other this procedure optimises the workflow overall.

The machines necessary for processing, decontamination and dismantling during decommissioning should, where possible, take the current operational situation into consideration. Dry dismantling and decontamination procedures are used in preference.

The processing machines are not designed to cover a peak load as this would incur considerable additional costs for oversized machines. They are rather selected to handle a large part of the arising materials and wastes can be processed.

6.2 Self-sufficiency of the fuel pool

During decommissioning planning, a time-critical path emerges that is different for every plant. However, it is not immutable, but rather evolves continuously and also depends frequently on external constraints that are not quantifiable.

To optimise the workflow and the overall duration of decommissioning, it is advisable to divide each time-critical path into several work packages that are independent of each other and run in parallel so that the work processes can be decoupled from each other. Firstly, this brings about flexibility with regard to changing constraints, and secondly it is possible to shorten the timing of a time-critical path in some cases.

BKW therefore intends to build an autonomous, redundant fuel pool cooling system (Arbek) as early as possible. This means the installation of a self-sufficient fuel pool cooling system which comprehensively meets the safety targets for fuel element cooling. The reactor pressure vessel and the primary containment as well as most of the former safety systems will no longer be needed to fulfil safety-target-related tasks. As a result they can be included in dismantling at an earlier stage and in each case can be disassembled as a priority, taking capacity utilisation of the waste management routes into consideration.

Self-sufficiency of the fuel pool consists on one hand of

- safety-related, operational and emergency equipment which comprehensively meets the relevant safety targets for fuel element cooling, and
- structural protection of the safety equipment which protects it against malfunction, load transfer and fire (retroactive protection of the dismantling measures on safety equipment).

Overall, this ensures deterministically adequate safety of the fuel elements in the fuel pool in the design-basis accidents that relate to the plant. Probabilistic improvements are already met by measures with a deterministic effect, but further improvements will be achieved by means of additional emergency management measures.

The autonomous, redundant fuel pool cooling is made up of the following five sections:

- Arbek-Z, a secondary lock in the channel between the fuel pool and reactor pit which, as a redundant barrier in addition to the stop log, safeguards the water inventory in the fuel pool.
- Arbek-S, a safety system which guarantees the control of design-basis accidents during decommissioning and also (during the final years of commercial operation) achieves a probabilistic safety gain.
- Arbek-B, a streamlined operational fuel pool cooling system.
- Arbek-N, a variety of emergency equipment or emergency measures for further probabilistic improvements and limiting the consequences of beyond-design-basis accidents where indicated.
- Arbek-R, the retroactive protection of this equipment to prevent adverse effects of dismantling activities.

As a result, it is possible to make a start on larger-scale decommissioning activities in the reactor building even when fuel elements are still present in the fuel pool. This parallelisation of tasks makes it possible to incorporate the masses arising in the processing cycle in the turbine building in an optimised manner. The autonomous, redundant fuel pool cooling makes a significant contribution to optimisation of the decommissioning process.

6.3 Waste management

Waste management includes all processes and activities that are employed in the utilisation and recovery of materials and the elimination of waste. The waste management of radioactive waste includes conditioning, interim storage and storage in a deep geological repository as well as any associated transport processes. The waste management targets available are basically clearance, decay storage with subsequent clearance and conditioning as radioactive waste.

All radioactive and non-radioactive substances are to be disposed of in their entirety during decommissioning. This also includes, where appropriate, clearance of building structures which remain on the site and which, after decommissioning is complete, are discharged, together with the site, from the nuclear energy legislation.

Priority among the waste management targets is given to clearance, possibly also after decay storage. The least favoured solution is the geological repository, which requires prior conditioning and interim storage of radioactive wastes.

Nuclear fuel removal

In Switzerland, spent fuel elements can be put into dry interim storage in the high-active Zwilag repository. BKW has already put storage casks with nuclear fuel and waste from reprocessing into storage there. One special feature is that it is not possible to handle any large transport and storage casks in KKM and removal therefore takes place using a smaller transport cask. This increases the complexity of shipments compared to larger plants and necessitates transhipment in the Zwilag facilities. The processes have been proven with the result that smooth execution is anticipated. At present, BKW plans to remove a number of fuel elements before final shutdown. This will ensure safe and rapid outward transport of the remaining fuel elements after 2019. Depending on the design of the last refuelling operations, the plant will be free from nuclear fuel approximately three to five years after final shutdown.

Radioactive waste

During the decommissioning of KKM, a waste volume of approximately 3,500 Mg will arise which will have to be put into long-term interim storage prior to storage in a deep geological repository. Allowing for the type of waste containers currently used, this corresponds to an interim storage volume of around 6,400 m^3.

Radioactive waste must be conditioned in such a way that the resulting waste products, together with their packaging can be handled as a unit (package) without interfering with their integrity and can be routed to the other waste management steps of transport, interim storage and deep geological repository. The use of a conditioning process and the types of waste packages or individual packages that are produced as a result are subject to supervision by ENSI. The proper conditioning of radioactive waste and the procedure for obtaining individual and type approvals are specified[26].

It is expected that a deep geological repository will be available in Switzerland from 2050. It is therefore possible to rule out transport operations directly from KKM to the deep geological repository. The packaged waste and spent fuel elements from KKM will be stored centrally until being put into the deep geological repository in the halls of Zwilag' s interim storage facility and will be transported from there to the deep geological repository at the given time.

By optimising the choice of waste containers and how they are loaded with radioactive waste and by selecting optimised transport concepts, it will be possible to reduce the volume of interim storage required and thus to save costs.

Radiological clearance

In the version of the Radiological Protection Ordinance which is still valid at present [7], the averaging areas are defined as 100 cm^2, although higher averaging areas are anticipated as part of the current revision of this ordinance.

Without an increase in the averaging areas, demonstrating that existing building structures do not reach the limit values will entail a high level of expense. Modern measuring techniques (for example, in situ gamma spectrometry) would be virtually ruled out.

The same applies to granting clearance for the dismantled plant sections on which radiological measurements are to be carried out as appropriate after decontamination. These measurements also have a direct effect on the other problem arising during clearance, that is disturbing the mass flow from the site as little as possible. Particularly in smaller plants such as KKM, logistics plays a huge role in decommissioning.

Decay storage

According to the Radiological Protect Ordinance[27], waste that, no later than 30 years after its origin, falls outside the scope of the Radiological Protection Ordinance due to radioactive decay, must be separated from other radioactive waste if there is no more favourable alternative available for mankind and the environment overall. It must be packed appropriately, identifiably marked, documented and stored securely.

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[26] ENSI-B05 Guidelines [6]
[27] Art. 85 Radiological Protect Ordinance [7]

According to regulatory Guidelines[23], it must be stated where decay storage should take place and that appropriate storage capacities are available. Due to the half-life of the leading nuclide Co-60, decay storage is particularly relevant for activated metals or metallic components with low contamination.

Although the duration permissible for decay storage is up to 30 years, for the materials arising during dismantling only a fraction of this period will be available as long as decay storage can only take place in KKM. For practical reasons alone, the period available will be barely more than a maximum of 10 years. Decay storage must therefore be made accessible at an external location.

7. Conclusion

The legal framework for the decommissioning of nuclear facilities is different in Switzerland to the situation in other countries and it is imperative to take this into consideration with regard to the transferability of foreign experience, at least in respect of procedures. BKW's decommissioning project is the first decommissioning of a commercial nuclear power plant in Switzerland. In conjunction with the legal and official regulations not yet tested in practice, this includes opportunities insofar as there are still considerable options regarding design at present. There is also the risk, however, that the design freedom will be restricted by an excessively conservative approach – be it on the part of the regulator or even on the part of the licensee making the application. Proper, legally and regulatory compliant preparation for decommissioning many years before final shutdown is also intended to minimise these risks.

It goes without saying that experience gained in previous decommissioning projects is also very valuable for decommissioning of the Mühleberg nuclear power plant. BKW will endeavour to use such experience, adapted to the conditions in Switzerland. This applies to both technical and also other – for example organisational – aspects. In addition to the large amount of valuable experience gathered to date, BKW will strive to further optimise the decommissioning process, for example by consistent repurposing of the turbine building as a materials handling centre or by means of innovative concepts, such as autonomous, redundant fuel pool cooling.

Even before the final shutdown, but also during post-operation and dismantling, special staffing challenges arise in addition to the technical challenges. By planning and communicating a new organisational structure at an early stage and identifying and implementing staff needs in good time, BKW will strive to maintain staff motivation and commitment and to develop it further to the benefit of safe and efficient dismantling.

BKW has set itself the target of creating a positive example for the Swiss nuclear industry with a decommissioning process that is optimised in terms of technology and procedures, makes optimum use of its existing staff and, last but not least, is cost-efficient.

8. Concluding Remark

In the considerations regarding the specific procedure for dismantling a nuclear power plant, it has been noticed that there is potential for optimisation as regards taking the licensee's needs into consideration in nuclear energy legislation, particularly in the Nuclear Energy Ordinance. Consideration must be given as to what extent adjustments are required.

The upcoming amendment to the Radiological Protection Ordinance (anticipated on 1 January 2016) raises the expectation of a decrease in the clearance values. The as yet unanswered question of possibly protecting the existing clearance values is particularly relevant and must definitely be clarified given that other amendments cannot be ruled out in the future. Without such protection of the existing values, it could be necessary to reclassify decay waste as radioactive waste following further amendments of the Radiological Protection Ordinance.

References

[1] Nuclear Energy Act of 21 March 2003 (KEG), SR 732.1 (as at 1 January 2009)

[2] Nuclear Energy Ordinance of 10 December 2004 (KEV), SR 732.11 (as at 1 May 2012)

[3] Guidelines for Swiss Nuclear Facilities ENSI-G17, Decommissioning of Nuclear Facilities, April 2014 edition

[4] Explanatory Report on the ENSI-G17 Guidelines, Decommissioning of Nuclear Facilities, April 2014 edition

[5] von Gunten, Anton; Parmar, Yogesh; Ritter, Max; "Decommissioning concept as part of the planning for new nuclear facilities in Switzerland, with reference to general licence applications for the replacement nuclear power plants Beznau and Mühleberg"; Kontec 2011, 10th International Symposium "Conditioning Radioactive Operational and Decommissioning Wastes"; Dresden, April 6–8, 2011

[6] Guidelines for Swiss Nuclear Facilities HSK-B05, Requirements for Conditioning of Radioactive Wastes, February 2007 edition

[7] Radiological Protection Ordinance of 22 June 1994 (StSV), SR 814.501 (as at 1 January 2014)