Safety Assessment for Decommissioning – an International Approach

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Abstract:

Safety of all facilities using radioactive material needs to be ensured through their lifetime and therefore evaluation and demonstration of safety is essential in the planning and implementation of decommissioning in accordance with the national legislation and internationally agreed recommendations. In order to assist operators, regulators and other experts involved in the planning, conduct and termination of decommissioning activities, the International Atomic Energy Agency (IAEA) implemented two international projects: “Evaluation and Demonstration of Safety during Decommissioning of Nuclear Facilities” (DeSa Project, 2004-2007) and “Use of Safety Assessment in Planning and Implementation of Decommissioning of Facilities Using Radioactive Material” (FaSa Project, 2008-2011). Representatives of about 30 IAEA Member States participated in both projects and contributed to the preparation of an international approach on safety assessments fordecommissioning.

An overview of this international approachis presented in this paper. Thisoverview addresses the multi-step methodology on how to perform a safety assessment and the evolution of the safety assessment especially in case of decommissioning projects with multiphase approaches.

1 INTRODUCTION

There is a large and increasing number of decommissioning projects worldwide at facilities using radioactive material, which are reaching the end of their lifetime; or have already been permanently shutdown as planned or prior to their expected lifetime (e.g. as a result of accidents, political, social or other reasons). The range of such facilities is wide and includes small e.g. research laboratories, research reactors, reprocessing facilities, fuel fabrication facilities, nuclear power plants, and mining and mineral processing facilities. Recent publications show that about 100 mines, 140 Nuclear Power Plants, 45 prototype reactors, over 250 research reactors and a number of fuel cycle facilities, have been retired from operation; some of these have been fully dismantled [1, 2].

In order to assist IAEA Member States ensuring safety during decommissioning and to assist operators, regulators and other experts involved in the planning, conduct, control and termination of decommissioning actions, the International Atomic Energy Agency (IAEA) launched in November 2004 an international project called “*Evaluation and Demonstration of Safety during Decommissioning of Nuclear Facilities*” (DeSa Project).
The support and active participation of over 50 experts from 30 Member States resulted in the:

- Harmonized safety assessment methodology for decommissioning;
- Demonstration of the application of the safety assessment methodology to three real facilities (a nuclear power plant, a research reactor and a nuclear laboratory);

- Recommendations on the application of a graded approach in the development of safety assessments for decommissioning;
- Recommendations for regulatory review of safety assessments for decommissioning.

The outcomes of the three-year DeSa Project (2004 – 2007) were incorporated in the IAEA Safety Guide WS-G-5.2 "Safety Assessment for the Decommissioning of Facilities Using Radioactive Material" [3], while a detailed project report will be published soon in the IAEA Safety Report Series [4].

During the last Joint Meeting of the DeSa Project in 2007, the participants recognized and recommended that further international cooperation and work is needed to explain the structure, content and interfaces between decommissioning plan and safety assessment; the use and application of safety assessment results in the planning and conduct of decommissioning; safety assessment for deferred dismantling and evolution of safety assessment through the facility lifecycle.

Based on such a recommendation a new *International Project on Use of Safety Assessment Results in Planning and Implementation of Decommissioning of Facilities Using Radioactive Material* (FaSa Project) was launched on in 2008. The key aspects addressed by the FaSa Project included the use of the safety assessment and its review during:

- Decommissioning Planning;
- Decommissioning Conduct;
- Decommissioning Termination;
- Implementation of safety assessment results, controls and their change management;
- Review of the implementation of safety assessment results, controls and their change management.

The three-year FaSa project illustrated the standardized safety assessment methodology, developed in the DeSa project, to demonstrate its wider application to adverse range of situations commonly found in decommissioning. Its outcomes will be described in a new report, which is intended to be published as part of the IAEA Safety Report Series [5].

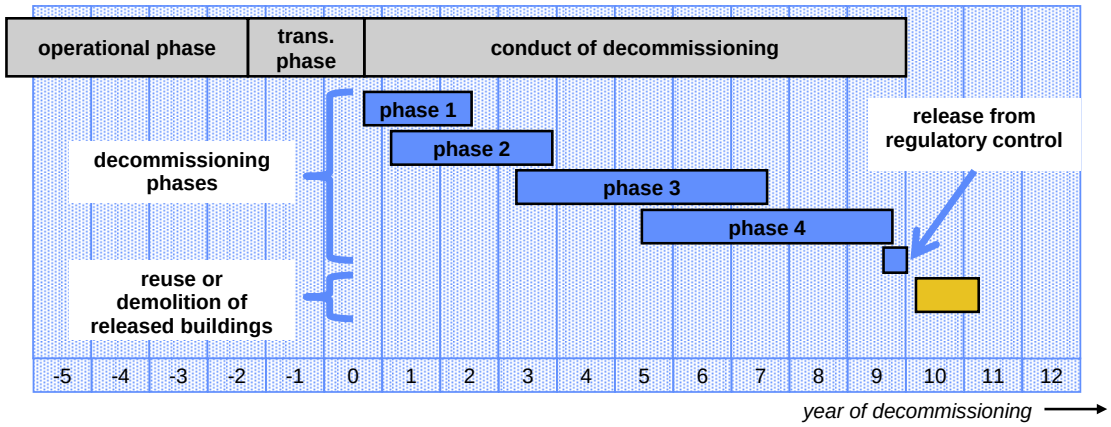
An overview of selected aspects of this international approach to decommissioning safety assessment, developed by both projects, is presented in this paper. In the preparation of this overview the relation between a safety assessment for decommissioning and a decommissioning plan is briefly discussed in Section 2. The general multi-step safety assessment methodology, proposed by the DeSa Project, is described in Section 3 and the evolution of safety assessments for decommissioning for multiphase decommissioning projects is explained in Section 4.

2 AN OVERVIEW OF SAFETY ASSESSMENTS AND DECOMMISSIONING PLAN

Following IAEA requirements and guides [3, 6], the safety assessment for decommissioning shall support the final decommissioning plan and therefore need to be incorporated into the final decommissioning plan or be part of a series of supporting documents presenting the safety arguments, depending on the complexity of the project.

For large, complex and long term projects a multiphase approach is often applied (ref. Figure 1). Experience feedback shows that this multiphase approach can be applied whatever are the decommissioning strategy, the type of nuclear facility, the licensing process and the time schedule of the project. Each phase reflects different scope of decommissioning actions. The benefit of this multiphase approach is that the details of the first phase (e.g. phase 1) are elaborated in sufficient detail to allow granting a license or regulatory approval for that phase, while the details of subsequent phases are still under development. As such, first decommissioning activities can start immediately after the first license / approval is granted, while the operator can continue in parallel with detailed planning of the work of the subsequent phases. In addition, such a multiphase approach provides with more flexibility in

planning and responding to new situations that may arise (new information, developments in technology, recent experiences from previously implemented phases). Such changes in the plan are easier to be done before a license / approval is issued for the subsequent phases.



Transition phase	Activities for preparation of the decommissioning, including • removal of spent fuel • system decontamination • removal and disposal of radioactive media generated during operation
Phase 1	First dismantling of contaminated components to generate free space for the later dismantling activities, including • equipment airlock and air-recirculation system (modification / replacement) • flooding tanks • external parts of the control rod guide thimbles and drives • accumulator In parallel: set up of infrastructure needed for later dismantling activities
Phase 2	Dismantling of large components, including • pipes and main coolant pumps of the primary coolant loops • steam generators
Phase 3	Dismantling of activated systems and components, including • reactor vessel internals • reactor vessel • biological shielding • concrete cross beams • rack from the former spent fuel pool
Phase 4	Dismantling of remaining systems and components • crane • refuelling platform • ventilation system • water treatment facility
Release from regulatory control	Clearance of the buildings and of the site
Afterwards	Reuse or demolition of the released buildings

Figure 1 Example of a multiphase decommissioning project for a NPP [5]

For a multiphase project the assessment of safety follows the process of planning of decommissioning actions for each phase. Practice has shown that two different types of safety assessment need to be performed to demonstrate safety:

1. Overarching Safety Assessment (OSA)
   The OSA addresses the safety of all phases of a decommissioning project to demonstrate that, despite the individual phases, safety for the overall project is

ensured. Accordingly, the OSA must not be as detailed as the safety assessment related to the individual phases.

2. Final Safety Assessment (FSA)
For each phase a final safety assessment of sufficient detail has to be performed before commencement of the decommissioning actions related to the phases to demonstrate that safety is ensured in detail.

Regardless of the type of the safety assessment, it needs to follow a systematic, logical and transparent methodology, considering inter alia starting and endpoints for each phase and clear end-state for the decommissioning project as a whole. Section 3 explains the main steps of this methodology.

3 GENERAL METHODOLOGY FOR DECOMMISSIONING SAFETY ASSESSMENT

Based on the practices and experiences from the IAEA Member States, a methodology for preparation of a safety assessments for decommissioning of facilities using radioactive material was developed during the course of the DeSa project [3], [4].

Main purpose of safety assessment is to identify hazards during normal decommissioning operations and during potential accidental conditions that may occur, and then to identify engineered and administrative control measures thatprevent, eliminate or mitigate hazards and their consequences, so reducing residual risk in accordance with the safety criteria and demonstrating them to be as low as reasonably achievable (ALARA). Although developed with strong focus on nuclear and radiological hazardsand their consequences for workers and the public, the methodology also allows consideration of the conventional hazards, which tend – especially as decommissioning project progresses – to be of higher importance for workers than the nuclear and radiological hazards.

Figure 2 presents the main steps of the iterative methodology for safety assessments for decommissioning, as described in [3], [4]:

1. Identification of the safety assessment framework

   This initial step of the safety assessment process serves to identify the conditions, which set the outer frame for the conduct of the safety assessment. Therefore, within this step all the regulatory conditions, safety requirements and criteria to be taken into account during decommissioning need to be identified and described. During the later evaluation step a compliance of the safety assessment results against these safety requirements and criteria has to be performed. Accordingly, due consideration needs to be given to summarize the requirements and criteria correctly and completely.
   During this step the major decommissioning actions and corresponding project phases, that will be subject to the safety assessment, need to be summarized as well(if any), including end points of the individual phases and the final end-state of the overall decommissioning project. This step also needs to describe the safety assessment methodology that will be applied and to explain the output which will be produced by the safety assessment.

2. Description of the facility and decommissioning activities

   Within this step a description of the facility and of the decommissioning actions is prepared. The description of the facility needs to cover those aspects of the facility, including the site, which are required as inputs for performing the safety assessment. As such, information on climate, site hydrology or surrounding population need to be provided, same as aspects of the design of the facility, including safety relevant systems, structures and components and the radiological inventory of the facility. With respect to existing facility documentations, this description may contain a summary of the relevant information with links to more detailed information in existing

documents.
Concerning the decommissioning actions, all planed actions within a givenproject phase, that are subject to assessment, need to be described. The description should be as detailed as necessary to serve the safety assessment. This description may also comprise a summary of the planned decommissioning actions with additional links to relevant documents with more detailed descriptions of the planned decommissioning actions.

3. Conduct of the hazard identification and screening

   Within this step existing and future hazards (both radiological and non-radiological), which might affect workers, members of the public and the environment during planned decommissioning actions and under accident conditions that could arise, need to be identified. All reasonably foreseeable initiating events and accident scenarios that might activate hazards, need to be identified for the assessment.
   Following the identification of the hazards, the initiating events and the accident scenarios, a first screening assessment of the hazards and scenario should be performed to identify those hazards and scenarios imposing significant threats to safety, so they need to be assessed in more details in the next step of the safety assessment.
   Depending on the complexity of the facility and the associated hazards, the screening might result in an extensive list of hazards and scenarios or in a limited list, which allows a conservative assessment of the safety of the planned decommissioning activities.

4. Conduct of the hazard evaluation

   Based on the outcomes of the previous step a detailed analysis of the relevant hazards and scenarios is performed. For each hazard and its scenarios the safety impact with regard to the planned decommissioning action, but also with regard to any faults and accident scenarios, is analyzed. Both the normal (planned) actions and accidents are analyzed regarding their consequences for workers, the public and the environment. As such, workers doses and the doses to the public from radioactive effluents are determined.
   The necessary safety functions needed to ensure safety are identified during the analyses. Based on the analysis of the consequences from normal and abnormal/accident scenarios, the requirements for the safety functions are specified and the engineered and administrative safety measures are preliminarily identified to provide the needed safety functions. Detailed identification of the safety measures is done in the following steps of the safety assessment process.
   The analysis is usually based on deterministic approaches, but depending on the complexity of a specific decommissioning project, the application of probabilistic approaches might be appropriate too.

5. Conduct of an engineering analysis

   Within this step previously identified engineered safety measure sare analyzed with regard to their technical design and properties. A compliance of the safety relevant systems, structures and components (SSCs) with appropriate engineering codes and standards, commensurate with the importance of the safety functions (e.g. the unmitigated consequences in case of their failure) is assessed. It is also assessed if existing SSCs are suitable and sufficient to provide the safety functions as assumed in the hazard analysis and if they will achieve the required reduction of doses and risks to an appropriate level of confidence.

6. Evaluation of results and identification of controls measures

   The safety assessment serves to demonstrate compliance with regulatory requirements and to identify those control measures necessary to ensure compliance and that risks have been reduced appropriately, so decommissioning can be carried out safely. Therefore, the results of the safety assessment will normally be adjusted

by the application of safety measures, until the regulatory criteria and requirements are met and risks are ALARA.
Within this step the role of the control measures, already identified and preliminarily specified, is confirmed and further elaborated. This step covers sensitivity analyses to identify and assess those parameters and values with the highest impacts on assessment results. If the outcome is particularly sensitive to an input parameter or assumption, direct efforts are needed towards reducing the uncertainties and repeating that part of the safety assessment.
The outcome of this step is the collection of all safety assessment results, expressed in entities reflecting the regulatory criteria and requirements, the relevant hazards and scenarios and the associated safety measures.

7. Compliance of the safety assessment results with regulatory requirements and criteria

   If the results of the safety assessment do not demonstrate compliance with safety requirements or criteria, the assessment should be revised in accordance with the framework shown in Figure 2. The results should be used to identify proposed amendments to the existing decommissioning strategy, plan or actions, as well as engineered measures and protective safety measures, and, where appropriate, to identify additional safety measures to ensure compliance with the safety requirements and criteria. The treatment or reduction of uncertainties should be reviewed and, where necessary, revised. If the decommissioning plan is revised, the safety assessment should be reviewed or revised as necessary to evaluate the revisions to the decommissioning plan.

8. Conduct of an independent review by the operator

   An independent review should be conducted by or on behalf of the operator, prior to finalizing the safety assessment and before submitting it for regulatory review. The operator's independent review should ensure inter alia that the input data and assumptions used are valid, that the assessment accurately reflects the actual state of the facility and the intended decommissioning actions, and that the safety measures derived from the safety assessment are adequate for the decommissioning actions.
   It is common understanding that the independent review should not be substituted by the regulatory review, which serves to verify that the safety assessment meets applicable regulatory requirements, as well as to verify that the safety assessment supplies adequate information to support the requirements for preparation for decommissioning. The outcomes of the regulatory review form part of the regulatory process to decide on the decommissioning actions proposed by the operator.

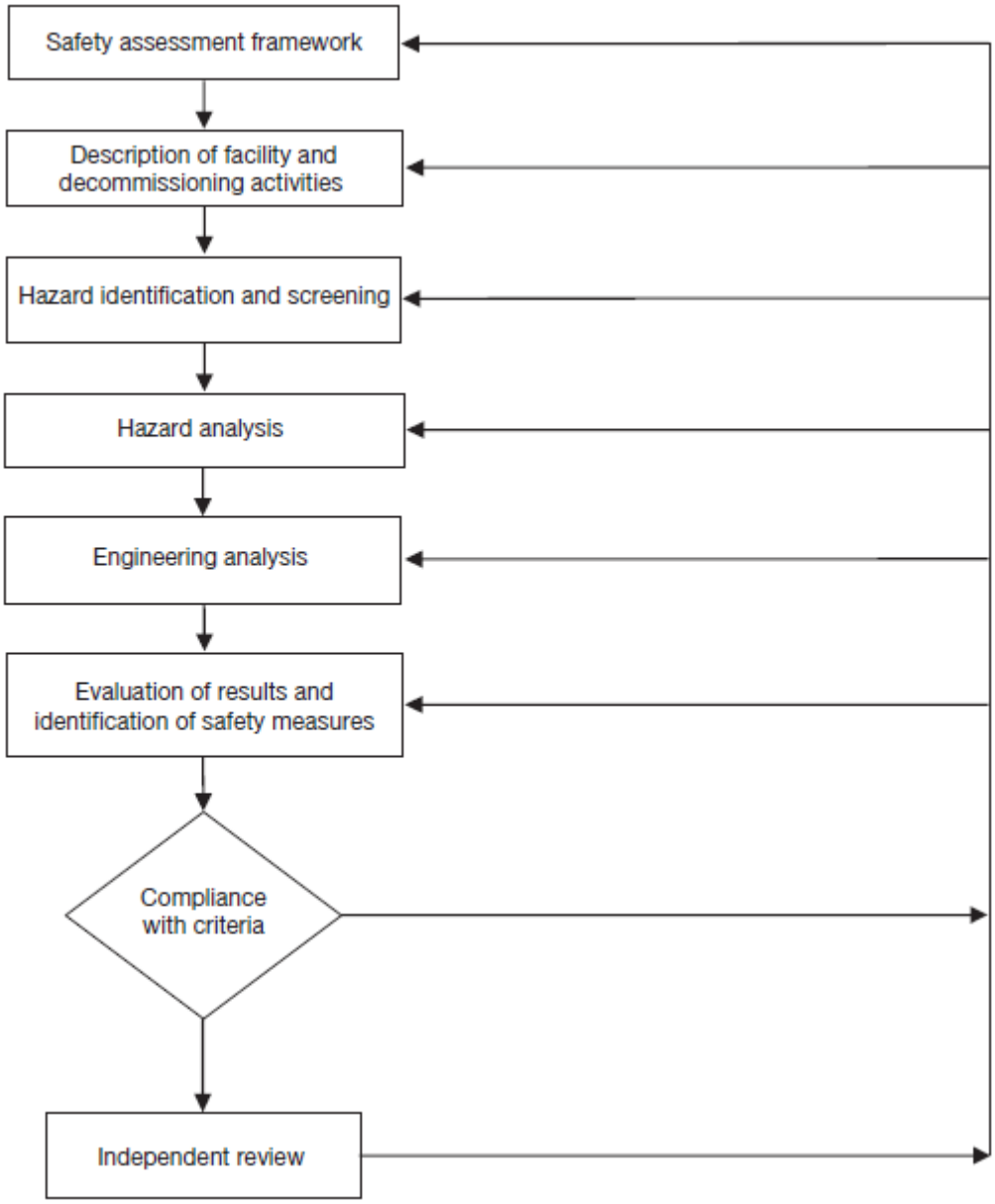


Figure 2 Main steps of the methodology for safety assessments for decommissioning [3]

Depending on the outcomes of the individual steps of the safety assessment process a return to previous steps is necessary to adjust assumptions or calculation methods or even to restart with modified plans for the intended decommissioning actions. As such, the methodology described provides an iterative system, which usually will be processed several times until all criteria are met and the independent review confirms correctness and high quality of results.

It is important to recognize, that only after successfully passing the independent review, the results of a safety assessment and the related decommissioning plan should be submitted to the regulatory body.

The methodology explained provides a general frame for a systematic safety assessment. The individual steps within the methodology allow a wide range of specific approaches, calculation and assessment methods. For example, a deterministic approach to safety assessment is often appropriate to deal with the hazards and related radiological consequences, to identify safety measures as layers of protection to afford defense in depth; however, a probabilistic approach might also be utilized in a complementary manner.

It is best practice to adjust the level of detail of a safety assessment to keep it proportionate to the hazards for both normal and accident scenarios, which are associated with the

planned decommissioning actions. This concept is internationally referred as graded approach and can be easily applied to each step of the safety assessment methodology. All steps of the process may be subject to grading. For example, a national regulations may require compliance of effluents either with the regulation tabled limits for the released radioactivity in Bq/a or alternatively with a 1 mSv/a dose criterion for members of the public; as the second criterion requires a significant effort to demonstrate compliance for a less complex nuclear facility, the application of the tabled limits may be possible and appropriate in accordance with the graded approach concept. Further details and illustrations on the application of the graded approach for safety assessment for decommissioning can be found in Volume III of the reference [4].

4 EVOLUTION OF SAFETY ASSESSMENTS DURING CONDUCT OF DECOMMISSIONING

As already mentioned in Section 2, for a multiphase decommissioning project an overarching safety assessment (OSA) and phase related final safety assessments (FSA) are needed.

Overarching Safety Assessment

The OSA is focused on the demonstration that the overall decommissioning project can be performed safely. Then, final (i.e. detailed) safety assessments for each phase are developed with the overall objective to identify which related safety measures are necessary.The OSA and the related final decommissioning plan for the decommissioning project are expected to provide the following key information:

- the decommissioning strategy and end-state,
- the main phases and associated safety issues,
- the associated time schedule,
- the waste management plan.

Experience shows that the content and extent of the OSA supporting the final decommissioning plan is focused upon the identification and justification of the main safety issues of the decommissioning project. Inter alia this objective is to provide to the regulatory body the set of technical information, which are necessary to issue the decommissioning license, such as the justification of the decommissioning strategy, the identification of the main phases, the associated planning, the main safety issues and the decommissioning objectives and criteria associated with. The identification of the main safety issues of each phase of a decommissioning project will help the regulatory body to manage the licensing process by issuing one single license with milestones, which may be subject to specific authorizations or to a set of licenses. It will help the regulatory body to establish license conditions, which the operator will have to comply with.

The OSA is the starting point for the development of the FSAs to support each phase. It provides references to the final safety assessment related to an individual phase. This practice is generally endorsed by operators themselves who consider that it is the only way to keep up to date the global view of the decommissioning project.

The OSA could be maintained as a “living report” and be updated after each phase has been completed or when discrepancies, having an impact on safety, are identified during the development of the safety assessment for each phase. The consistency of the FSA for each phase should be checked based on the OSA. It’s good practice for the operator to keep the OSA up to date.

As mentioned earlier, a multiphase approach is beneficial for the development of the FSAs. It allows the operator to incorporate new data, e.g. updated techniques, lessons learnt from previous phases, and with that developing a more realistic safety assessment. This approach is illustrated by the Figure 3, which summarizes the main aspects developed above and provides an example of the way to implement an entire decommissioning project, when a

phased approach is proposed. Here a link is made between the development of the safety documentations (left side of the diagram) and the phased approach (right side of the diagram). Illustration of what kind of development, evolution and update of the safety documentations should be undertaken is also provided.

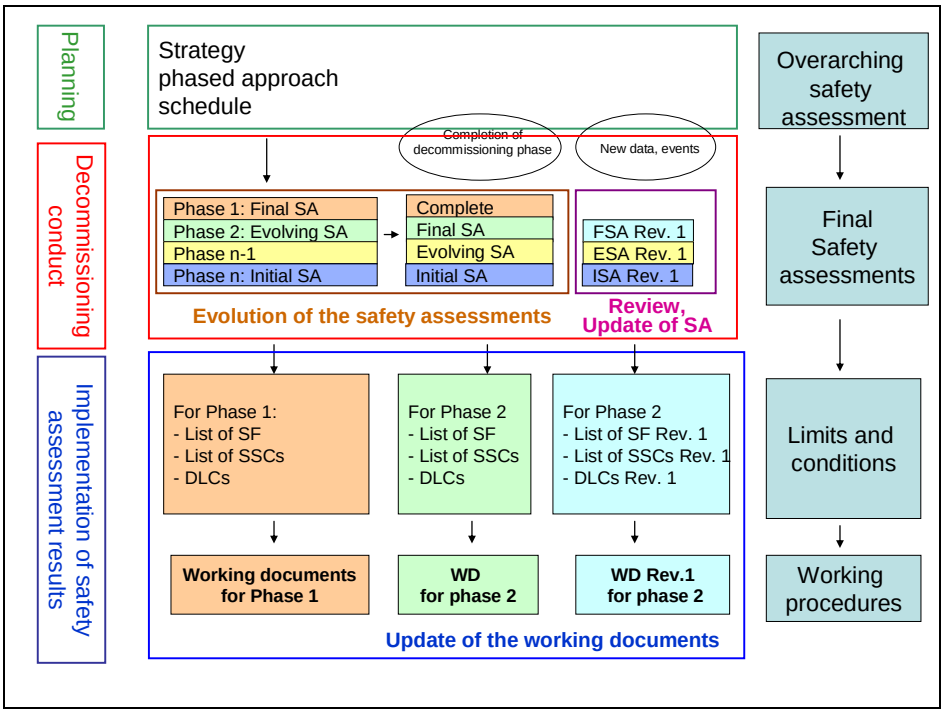


Figure 3 Application of safety assessment in a multiphase decommissioning project [5]

Based on the outcomes from the overarching safety assessment, which is developed to cover all the phases of the project, the operator develops detailed safety assessments for each phase:

- to manage the evolution of the decommissioning project and to deal with the specific issues associated with each phase,
- to keep up to date the safety assessment for the complete decommissioning project such that it reflects the modifications occurring during the decommissioning process.

Final Safety Assessment

As explained previously, for each phase of a decommissioning project a FSA must be available on time. The level of detail of these FSAs is comparable to the safety assessment related to the final decommissioning plan as recommended in [3] and briefly explained in Section 3.

Central outcomes of the FSA are the safety measures (either engineered or administrative) and the decommissioning limits and conditions. These form the starting point for the development of the decommissioning documents required for implementation of the decommissioning project. The decommissioning documents comprise inter alia operating rules and working documents such as work instructions and manuals and drive the daily work activities. Accordingly, they need review and revision as the phases change or final safety assessments require revisions.

As the FSA for a phase depends on the work details and vice versa, the work details depend on the evaluation of related safety aspects, the work details for a given phase and the associated FSA will not be developed independently. Development of the scope and details of a phase and related FSA assessment will follow an iterative development process.

In order to avoid stop and go in the decommissioning project, the evolution of the safety assessment must be performed progressively, taking into account all the safety, radiation protection and waste management issues, but also all the organizational aspects of the decommissioning (modification of the facility, training of personnel, staff management, etc.).

The evolution of the safety assessments towards the FSAs follows an iterative and continuous process starting from initial safety assessment and ending with a final safety assessment. The initial safety assessment is taken from the overarching safety assessment. The final safety assessment is based upon the initial safety assessment and is the one used to prepare the working documentation. Objectives of the evolution process are not only to effectively develop the final safety assessment, but also to provide feedback on the safety during detailed planning of the decommissioning actions within the phase. As such, evolving safety assessments may be helpful in optimizing working methodologies, depending upon the complexity of the hazards and magnitude of the consequences associated with the phase. Vice versa, the safety assessments (initial, evolved or final) are supported by technical studies. The main objectives of these technical studies are to confirm the feasibiity of the techniques choosen and to consolidated, when necessary, the radiological inventory of the SSC's to be dismantled during each phase.

Figure 4 shows the evolution process of the safety assessment for a multiphase project.

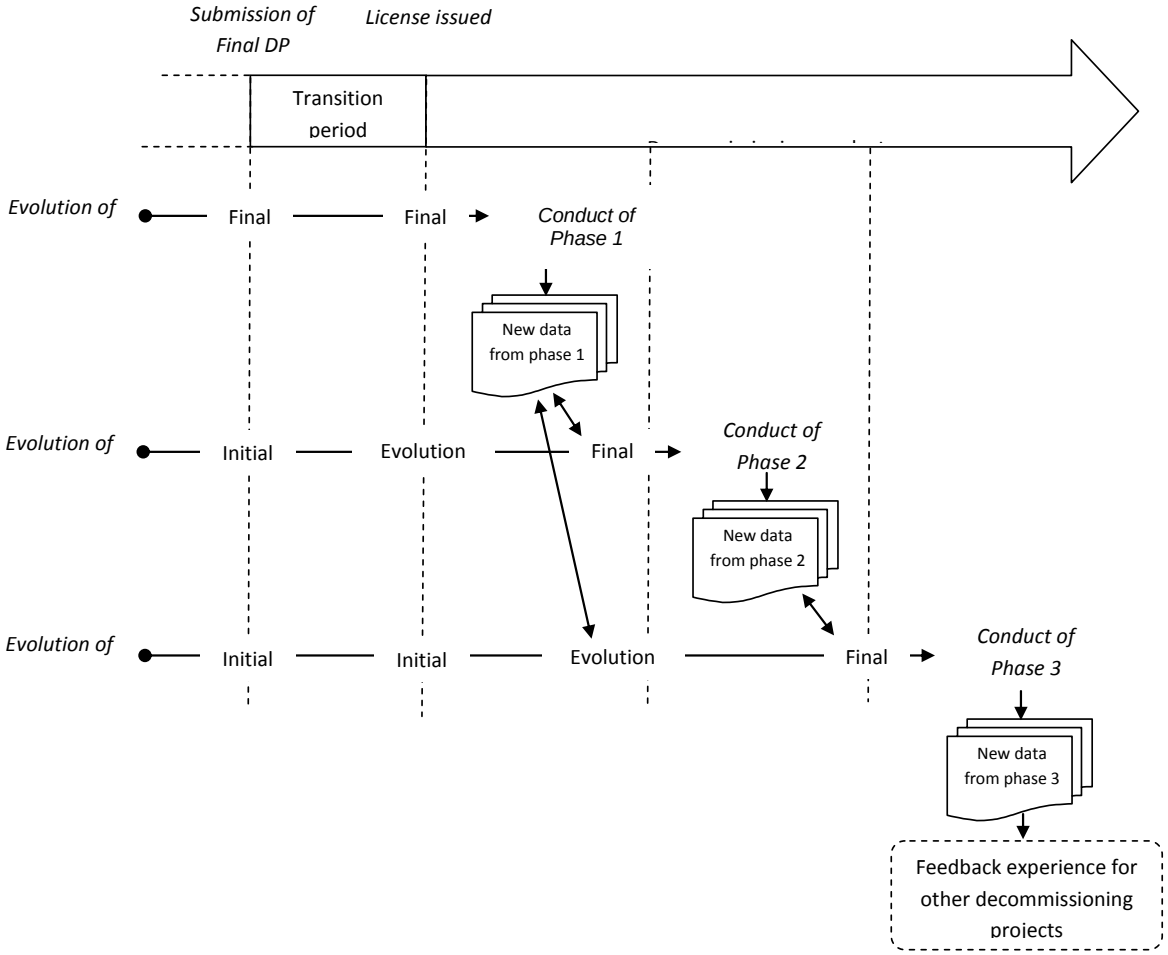


Figure 4 Illustration of the evolution of safety assessments for a 3-phase decommissioning project [5]
(*DP – Decommissioning Plan, SA – Safety Assessment*)

Figure 4 illustrates that for different phases the evolution of the final safety assessment can start at different times. It shows in addition that new data, which can be collected from experience feedback, events and/or incidents, progress in dismantling operations, may allow a better knowledge of the radiological inventory in the facility, etc. These new data may be

considered relevant for the conduct of the upcoming phases and then taken into account in the development of the related safety assessments.

As already illustrated by Figure 3, typically the FSA for the first phase needs to be available before start of the decommissioning work of phase 1, while at this time the FSA for phase 2 is not ready, but is in a reasonably mature status, termed evolving safety assessment for phase 2. During conduct of phase 1 the evolving safety assessment for phase 2 will be developed to become the final safety assessment for phase 2 and to become available before start of the decommissioning work of phase 2. Depending on the national regulatory system it is convenient that the OSA and the FSA for the first phase are prepared at the end of operation and during the transition period of the facility, i.e. before the first license for decommissioning is granted.

The Figure 3 shows a transition period from the permanent shutdown up to the start of the decommissioning actions. It's generaly during this transition period that the review of the Final Decommissioning Plan is performed by the regulatory body. Nevertheless, the preparatory works for decommissioning which could be done during this transition period are in practice performed under the conditions of the operational license.

In addition, it can be observed that:

- the implementation of a phase approach is also applied when phases runn in parallel;
- whatever is the planning and schedule of a phase approach, the end-state of each phase have to be defined clearly to allow the decision making process to move from one phase to an other one.

5 CONCLUSIONS

The two IAEA international projects DeSa (2004 – 2007) and FaSa (2008 – 2011) resulted in the internationally accepted methodologies for safety assessment for the decommissioning of facilities using radioactive material. The IAEA Safety Guide WS-G-5.2 summarizes the methodology, developed by the DeSa Project, on how to perform a safety assessment for decommissioning and how to review its results. The FaSa Project provided more details on the evolution of the safety assessment during facility lifetime and on the implementation of safety assessment results.

The core of the safety assessment for decommissioning is based on

- clarification of the assessment framework,
- first screening of hazards and scenarios associated with the decommissioning project,
- detailed safety analysis of those hazards and scenarios, representing significant threats to safety,
- identification of safety functions and related engineered and administrative safety measures
- compliance check to verify that regulatory criteria and requirements are fulfilled, and
- conduct of an independent review, performed as a part of the operator's process.

The methodology to assess and demonstrate safety is subject to a graded approach, but the effort for its assessment has to be appropriate for the hazards and the safety threats related to the individual decommissioning project.

In case of a multiphase decommissioning project, it turns out, that the safety assessment methodology is applied repeatedly for the different projects phases and with different level of details. The evolution process of a safety assessment supports the flexibility of large and complex decommissioning projects, which is one of the main reasons for a multiphase approach.

The number of more than 100 participants in both DeSa and FaSa projects shows that there has been a high interest in sharing experiences on how to perform a safety assessment for decommissioning, but it also indicates that the recommendations and guidance elaborated on safety assessment for decommissioning have been extracted from a variety of practices and experiences in the IAEA Member States.
Information provided in this paper is based on the outcomes of both IAEA projects. The authors like to express their gratitude to all the participants of these projects and to recommend to the reader the references [4] and [5] for more details.

6 REFERENCES

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