IAEA International Project

Use of Safety Assessment Results in Planning and Implementation of Decommissioning of Facilities Using Radioactive Material

(FaSa Project)

Annex Report on the FaSa Project Test Cases

Annex 4 – The Mining and Milling Processing Facility Test Case

(Working Material)

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FOREWORD

Annex 4 presents the results achieved by the working group on the Mining and Mineral Processing Facility Test Case (MMPF TC). It addresses aspects of the application of the safety assessment methodology, as proposed during the DeSa project, and aspects of the use of safety assessment results in planning and implementation of decommissioning during decommissioning of mining and milling processing facilities.

The IAEA would like to express its gratitude to all the member of the MMPF TC Working Group, who contributed to the development and review of this Annex 4 and providing information on their specific decommissioning projects, and, in particular, to the chairman of the working group, A. Cadden (U.K.).
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1 INTRODUCTION

BACKGROUND

Evaluation and demonstration of safety is an essential component of the successful planning, performance and completion of decommissioning of facilities that contain a radioactive inventory.

Recognizing the need for exchange of information and experience, to allow consolidation of best practice and lessons learned in these areas, the International Atomic Energy Agency (IAEA) launched in 2005 the project on Evaluation and Demonstration of Safety of Decommissioning of Nuclear Facilities (DeSa Project). This 3 years project developed a harmonized methodology for the evaluation and demonstration of safety during decommissioning, and this was illustrated by developing test cases. The test cases covered a nuclear power plant, a small research reactor and a nuclear laboratory.

As a follow up of the DeSa Project and following a proposal by the members of the DeSa Project the FaSa Project was launched on 17 November 2008 and performed until November 2011. The outcomes of the FaSa Project are documented in the main volume of this publication.

Part of the FaSa Project was a trial application of the DeSa methodology on safety assessments (and of the new FaSa methodology) for the decommissioning of mining and mineral processing facilities to demonstrate, that the methodology is applicable for this type of facilities and to document related experiences.

The Annex 4 has been produced by the Mining and Mineral Processing Facility Test Case Working Group (MMPF TC WG), using the materials provided by the working group members. The WG meetings were organized as part of the four annual meetings of the FaSa Project (2008-2011), and on one additional occasion, where a limited number of working group members participated. In addition, individual work was done by several working group members between the meetings. All the figures and tables, presented in this Annex, has been provided or developed by the members of the MMPF TC WG of the FaSa Project.

SCOPE AND OBJECTIVES

Annex 4 describes the outcomes of the Mining and Mineral Processing Facility Test Case Working Group (MMPF TC WG). At the beginning the working group intended to apply the DesSa methodology and the new FaSa methodology for the decommissioning of the milling and mineral processing facility. In doing so, the MMPF TC WG intended to verify and illustrate the applicability of both methodologies for MMPFs.

During the first year of conduct it turned out that no real project on the decommissioning of a MMPF was available to provide sufficient information to perform such safety assessments. Moreover, the MMPF TC WG recognized that aspects of nuclear safety are by far not the main issue to be considered when planning and assessing decommissioning projects of MMPFs.

As a consequence the objectives of the working group have been changed:

- to transform information on a safety assessment related to the decommissioning of a MMPF into the safety assessment format defined by the DeSa project [2] and to
evaluate whether the DeSa methodology on safety assessment is applicable to MMPFs; and

- to collect experiences on safety assessments in national decommissioning projects related to mining and mineral processing facilities.

The objectives of the DeSa methodology same as those of the FaSa methodology are related to the safety assessment related to the decommissioning of facilities but not on aspects on remediation of sites. Accordingly, the MMPF TC WG does not focus on the rehabilitation of landscapes, especially on tailing ponds etc. although a majority of publications does address such aspects instead of decommissioning.

STRUCTURE
Annex 4 is structured as follows:

- This chapter contains the introduction to the Annex 4.
- Chapter 2 contains the results of a transformation of safety related information from a real decommissioning project in the field of a milling and mineral processing facility into the format of a safety assessment according to the approach of the DeSa project.
- Chapter 3 provides a compilation on safety assessment related experiences from national projects on the decommissioning of milling and mineral processing facilities. The experiences were collected by the members of the MMPF TC WG and structured to the extent possible following a structure, also prepared by the working group.
- Chapter 4 summarizes the experiences from the observations of the members of the working group and from recent projects on the decommissioning of milling and mineral processing facilities and draws conclusions on safety assessments, especially on the applicability of the DeSa and FaSa methodologies.
2 EXAMPLE ON THE APPLICATION OF THE DESA METHODOLOGY

INTRODUCTORY NOTE

After screening the descriptions of several projects related to the decommissioning and remediation of sites with MMPF, the MMPF TC WG selected a national example from North America on the decommissioning of a milling and mineral processing facility site with several facilities as the base for the transformation of safety related information into the format used within the test cases of the DeSa project. From the MMPF TC WG’s point of view this example provided the most complete information available; however, it still showed limitations for achieving the objective of the verification and illustration of the applicability of safety assessment methodologies as proposed by the DeSa project and IAEA Safety Standards Series WS-G-5.2 and the FaSa Project:

1. The example is an operating site that is progressively decommissioning facilities on the site that have reached the end of their life or usefulness. The ideal site would not be operating and the entire site would be decommissioned.

2. A safety assessment has not been performed for the facilities to be decommissioned. Instead, for the site a preliminary risk assessment was performed using Failure Mode and Effects Analysis (FMEA) methodology to determine the priority of individual projects and has presented preliminary decommissioning plans for each facility. A detailed long term safety assessment will be performed for each facility and for the entire site in the future to obtain regulatory approval to decommission the entire site and to reach the end-state.

3. The end-state for the decommissioned site has not been determined nor plans developed to achieve an end state at this time.

In spite of these limitations, the information available, especially from the Failure Mode and Effects Analysis methodology and the preliminary decommissioning plans were transformed into the format of the test cases of the DeSa project.

2.1 Introduction

2.1.1 Objectives

The objective of this example is to take an actual mining and mineral processing decommissioning project to illustrate the application of the DeSa methodology on safety assessment for decommissioning [2], and in particular the FaSa instructions on the use of safety assessment results in decommissioning.

An overview of the general safety assessment methodology, developed by the DeSa project [2] and incorporated in [1], and on the safety assessment for multiphase decommissioning projects as developed within the FaSa Project to a typical safety assessment is presented in Fig. 2 and Fig. 3.
FIG. 2. Safety assessment methodology for decommissioning ([1]).

FIG. 3. General concept of the evolution of safety assessments for decommissioning and the implementation of their results.
The following sections and sub-sections are based on available information from the planning of the decommissioning of a real site with several milling and mineral processing facilities; the planning was based on a preliminary risk assessment; a safety assessment as proposed in [1], [2] was intended for long term aspects associated with the end state of the decommissioning project. To the extent possible safety related information from the preliminary risk assessment was considered within the specific sections / sub-sections on safety assessment; in case relevant information is missing, this is indicated accordingly or alternatively, some generic explanations are placed, which were based on the experiences of the MMPF TC WG members.

2.1.2 Structure

The structure of this chapter 2 is based on the structure of the test case reports of the DeSa project, especially of annex I, part B of the IAEA Safety Report Series No. 77 [2], and is detailed below:

2.1. Introduction
2.2. Safety Assessment Framework
2.3. Description of the Facility and Decommissioning Activities
2.4. Hazard Analysis: Identification and Screening
2.5. Hazard Analysis: Evaluation
2.6. Preliminary Risk Assessment
2.7. Engineering Analysis
2.8. Evaluation of Results and Safety Measures
2.9. Graded Approach
2.10. Confidence Building in the Safety Assessment
2.11. Summary, including Lessons Learned

Within this structure, section 2.6 considers that for the site of the test case a preliminary risk assessment was performed to prioritize the different decommissioning projects. Such a section is not part of the test cases of the DeSa project; moreover, such an assessment step is not foreseen as part of the safety assessment methodology for decommissioning proposed by the DeSa project in [2] and IAEA Safety Standards Series No. WS-G-5.2 [1] or in the main volume of this publication, but the MMPF TC WG felt information on the performed preliminary risk assessment highly valuable as the risk assessment provides further insights into the planning of decommissioning for a site with mining and mineral processing facilities and into the assessment of uncertainties, which may affect the objectives of a decommissioning project.

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1 The annex I of the IAEA Safety Report Series No. 77 is available in electronic format; for further details on the download of the annex I please refer to the IAEA home page.
2.2 Safety Assessment Framework

2.2.1 Context of safety assessment

According to the IAEA Safety Reports Series N. 77 ([2]) and IAEA Safety Standards Series WS-G-5.2 ([1]) as part of the safety assessment framework the context of the safety assessment should be addressed:

- “The context of the safety assessment involves determining whether the safety assessment is consistent with:
  (1) The description of the facility;
  (2) The decommissioning strategy;
  (3) Decommissioning activities;
  (4) Plans and strategies for the management of radioactive waste.” ([1]).

- “The safety assessment forms part of a decommissioning plan, as described in Section 2.2. The safety assessment is carried out in the context of that plan, and, therefore, the scope of the safety assessment needs to be linked and to be consistent with the scope of the project decommissioning plan as a whole. In some situations, the starting point for the safety assessment may be well defined, for example, at the end of operation of a facility for which comprehensive records are still available. In other situations, the condition of the facility may be unclear, and it may be necessary, as part of the overall decommissioning plan, to include an initial information/documentation gathering phase prior to performing the decommissioning of the facility.” ([2]).

For the selected example the safety assessment is based on the preliminary decommissioning plan. This preliminary decommissioning plan is based on a preliminary risk assessment; the assumptions for and outcomes from the preliminary risk assessment need to be considered in the safety assessment, too. As part of this sub-section, the assumptions and relevant outcomes need to be listed; due to the limitations of the members of the MMPF TC WG not detailed list was prepared.

2.2.2 Scope of the assessment

Decommissioning of the site has taken place over a number of years as new phases of mining have taken place. For the selected example a safety assessment has to be performed considering each of the facilities and especially interdependencies between them. This safety assessment has to consider among others all decommissioning activities foreseen in the decommissioning plan. Up to now, only a preliminary risk assessment was performed, using the Failure Mode and Effects Analysis (FMEA) methodology. The preliminary risk assessment considered following facilities and their intended main decommissioning activities, laid down in a preliminary decommissioning plan:

- Decommissioning of underground mine (Conceptual Closure Plan – Planning Phase)
  - all fresh air and exhaust raises will be filled with waste rocks and sealed with concrete bulkheads; covered with soil and revegetated;
  - portal cover will be removed; filled with waste rocks; profiled and covered with soil and revegetated;
  - mine allowed to flood naturally.
- Decommissioning of surface mines (e.g. ponds)
  - monitor water quality in the ponds; once water quality meets regulatory requirements, breach the dike to be return the area to the lake;
  - revegetate dike abutments;
- Decommissioning of mineral processing plant (milling facility)
  - water treatment will be reconfigured for decommissioning to occur at a later date in order to treat waste water generated during decommissioning of onsite facilities;
  - equipment and building materials will be cleaned and salvaged where practical;
  - unsalvageable material and equipment will be buried in a landfill or placed in the in-pit tailings management facility (TMF) or underground mine;
  - mill foundations will be broken up and covered up with soil and revegetated; any contaminated concrete would be excavated and disposed of in the in-pit TMF;
  - any contaminated soil around the processing facilities will be disposed in the in-pit TMF; remaining areas will be revegetated;
  - the ore pads will be excavated and material will be placed in the in-pit TMF; the area will be covered with soil and revegetated.
- Decommissioning of waste rock piles
  - geochemical source term characterization;
  - based on characterization, option analysis for remediation;
  - profile, slope for runoff control, compact, place soil and revegetate;
  - toe seepage from the pile will be pumped to the mill for treatment during the transition period until full revegetation is established.
- Decommissioning of tailings management facilities (in-pit and above ground)
  - A) In-pit TMF (IPTMF)
    - thaw frozen layers; pump water off the surface; leave tailings to desiccate; build up layer of waste rock to assist with consolidation of tailings; place an impermeable layer; place a drainage blanket over the impermeable layer; cover with soil and revegetate;
    - continue to pump and treat the raise water until consolidation is completed;
    - water level will be allowed to return to natural levels.
  - B) Above ground TMF (AGTMF)
    - geochemical source term characterization;
    - update hydrological model;
    - cover analysis and design, perform pathways and ecological risk assessments;
    - compact and cover; revegetate. May place an impermeable layer on top.
- Decommissioning ancillary facilities/equipment
- radiological risk will generally be negligible so equipment will be dismantled and salvaged where possible;
- road and airstrip will be profiled, plowed and revegetated.

The scope of the later safety assessment according to [2] or [1] has to be the same.

2.2.3 Objectives of the assessment

The objectives of safety assessments for an MMPF typically are:

(a) to demonstrate safety of workers, the public, and the environment during the planned decommissioning activities and to show compliance with regulatory requirements and criteria;

(b) to confirm the existing or suggest new safety related systems and controls;

These objectives can be illustrated only partially for the selected example due to the following limitations:

(a) Related to objective (a)

The impact to the public and the environment from decommissioning activities themselves at a MMPF, particularly for the example of the test case, is minimal. Also, because of a well characterized, known and low level radiation sources, the exposure of workers is easily controlled without extensive analysis. For a MMPF, most of the safety assessment is focused on impact of radiological and non-radiological elements on the public and environment in the long-term post-decommissioning period. Non-radiological elements often determine the decommissioning requirements.

(b) Related to objective (b)

Because the risk assessment was only preliminary, it was not possible to confirm the existing or to suggest new safety-related systems and controls.

2.2.4 Timeframes

The site began operation in 1974. The site continues to mine an underground ore body, process the ore at an existing mill and deposit the tailings in an in-pit tailings management facility. Some parts of the site have been decommissioned or have been undergoing decommissioning while others will be decommissioned progressively such as mined-out open pits and associated waste rock piles.

Details on the timeframe for decommissioning of the selected example are not known, but in general have to be addressed as a very long duration of a decommissioning project might result in scenarios with relevant consequences for the safety.

2.2.5 End point of the decommissioning phases

The end points of the decommissioning phases are different for each of the various facilities at the site. The final end-state for the ultimate decommissioning of the entire site will be determined by performing a detailed long term safety assessment to demonstrate an acceptable impact on the environment and the public from decommissioned facilities. The safety assessment and the decommissioning / remediation plans will be approved by the regulatory bodies and monitoring plans put in place to demonstrate when the end point is
achieved. Once the final-state is achieved, the site will be transferred to institutional control with restricted use of certain areas, such as the tailings facilities.

2.2.6 Requirements and criteria

For decommissioning of the MMPF, the exposure to workers performing the decommissioning activities has to be monitored and maintained below the regulatory limits. The regulatory requirements and criteria for the decommissioning activities will be addressed by the detailed, post-decommissioning / long term safety assessment for the entire site that will analyze both radiological and radiological impacts to the environment and ultimately the public.

2.2.7 Assessment outputs

Within the selected example no safety assessment for decommissioning was performed. But, the decommissioning plan consists of using the FMEA methodology to analyze the risk for the full site to determine the priority of decommissioning projects on the sites and outlining some preliminary plans for decommissioning each facility.

Prior to decommissioning of any facility of the MMPF a safety assessment will be performed that evaluates the impact to workers, the members of the public and the environment from decommissioning activities and the post-decommissioned facilities and to demonstrate compliance of the decommissioning activities with regulatory requirements and criteria.

2.2.8 Safety assessment approach

Within the selected example no safety assessment was performed. But, the approach typically taken for a safety assessment of decommissioning activities in a MMPF is to develop safety, health, environmental and quality procedures that meet the corporate safety, health, environmental and quality policy and is consistent with ISO14000 ([3]); review safety and environmental requirements, objectives and criteria and perform hazard and risk assessments.

Safety assessment would normally consider:

- consequences to the workers, the public and the environment from decommissioning activities under both normal operating and abnormal conditions, including radiation dose rates;
- operational limits and conditions, which are directly related to the work carried out during decommissioning; and
- updated operating limits and conditions documentation, and the working procedures, including both physical and procedural designations, which reflect the revised operating limits and conditions documentation, including key compliance activities.

2.2.9 Existing safety assessments

Often, the safety assessment for decommissioning will refer to parts of the safety assessment for operation of a facility; in case of multi-facility site cross references to the safety assessment of other facilities at the site, which might be under decommissioning or still under operation, are likely. References are done to benefit from assessment results / assessment
work already done in the frame of the safety assessment referred to; this approach is effective and appropriate as long as the referenced safety assessment is still valid and the parts used within the safety assessment for decommissioning are correct and properly integrated.

For the selected example up to now no safety assessment has been prepared, but a preliminary risk assessment was performed addressing some safety relevant aspects. Accordingly, when preparing a safety assessment according to [2] and [1] reference to the preliminary risk assessment can be expected as some of the outcomes of the preliminary risk assessment will be used within the safety assessment.

2.2.10 Safety management measures

The first element in a typical decommissioning project is to assume that a management system is in place for the decommissioning project that includes: organizational structure for decommissioning with clear responsibilities and authorities, change control procedures, work control procedures, maintenance and testing procedures, personal protective equipment, training and testing programs, trained personnel, radiation protection programs and procedures, occupational safety programs and emergency scenario programs, quality assurance program, as well as procedures for documentation and record keeping. It is further assumed that these safety measures will remain in place until decommissioning is completed. In the selected example decommissioning of facilities on an operational site will use the managerial systems currently in place and consider the elements above as required for the projects. Decommissioning and remediation of a mined-out pit (i.e. pond) or waste rock pile is not nearly as complex or requires as many processes / analyses as decommissioning a nuclear power plant or other nuclear facilities.

The second element of a typical project consists of how to translate the results of the safety assessments into operating conditions, procedures, or how to decide on the use of additional engineering systems, or on the implementation of mitigating measures, such as managerial controls to avoid unacceptable impacts to the workers, public and the environment. In the selected example, the impact to the public and the environment from decommissioning activities is typically negligible. The safety assessments for a MMPF will normally concentrate on the long term impact of the entire decommissioned site on the public and on the environment.

2.3 Description of the Facility and Decommissioning Activities

2.3.1 Site description and local infrastructure

The uranium mining and processing site is in a remote location. The site is situated by a large lake. Population is sparse with the nearest community located approximately 30 kilometers away.

The climate is typical of a continental sub-arctic region:

- Summers are short and rather cool, even though daily temperatures can reach above 30°C on occasion. Mean daily maximum temperatures of the warmest months are around 20°C and only three months on average have mean daily temperature of 10°C or more.

- The winters are cold and dry with mean daily temperature for the coldest month below minus 20°C. Winter daily temperatures can reach below minus 40°C on occasion.
- Freezing of surrounding lakes, in most years, begins in November and breakup occurs around the middle of May. The average frost-free period is approximately 90 days.
- Average annual total precipitation for the region is approximately 450 mm, of which 70% falls as rain, more than half occurring from June to September. Snow may occur in all months but rarely falls in July or August.

There is road access to the site for trucking in supplies and shipping out yellowcake product. There is also an airstrip and a camp at the site for fly in / fly out operation.

2.3.2 Safety related structures, systems and components

Following safety related structures, systems and components (SSC) exist at the different facilities of the site needed for operation:

- Underground mine
  - ventilation system (fresh air and exhaust raises, air heating system, and associated fans);
  - monitoring (radon and dust);
  - mine dewatering system.

- Surface mine
  - water treatment system;
  - monitoring.

- Mineral processing plant (including ore pads, mineral processing building, effluent treatment plants, and equipment)
  - ventilation system (air heating system and associated fans);
  - monitoring (radiation, radon and dust);
  - fire protection/suppression system;
  - distributed control system;
  - filtration systems (air scrubbers);
  - water treatment system.

- Waste rock piles
  - monitoring (chemical and infiltration).

- In-pit tailings management facility (IPTMF)
  - raise water system;
  - monitoring;
  - pump and treat system.

- Above ground tailings management facility (AGTMF)
  - monitoring (radiation, chemical, infiltration and dust);
  - pump and treat system for seepage.
It has to be noted, that within a report on the safety assessment for decommissioning, only those SSC have to be listed, which are needed to ensure a safe decommissioning. Such a list will be based on the safety assessment performed for decommissioning.

As within this selected example no such safety assessment was performed, but a preliminary risk assessment is available only, the presented list does consider those SSC relevant for operation. Typically, the SSC for decommissioning is a sub-set of those SSC for operation, but additional SSC than those for operation might be needed also, depending on the outcomes of the safety assessment.

2.3.3 Radioactive inventory

ACTIVATION AND CONTAMINATION OF DIFFERENT COMPONENTS OF THE MILLING FACILITY

Neutron activation of systems, structures and components does not occur in mining and mineral processing facilities. Also, the level of radioactivity is associated with residual contamination of equipment materials after draining and flushing media / material and from tailings and waste rock so is much lower than in other nuclear facilities. The level of radioactive contamination of materials is measured by scanning, which determines whether it can be salvaged or requires disposal.

Material is normally not shipped off site or salvaged if the surface contamination is greater than 0.4 Bq/cm² but disposed at the site. Table 1 presents the disposal paths of material generated during operation and decommissioning at the site.

<table>
<thead>
<tr>
<th>Equipment/Process/Area</th>
<th>Waste Category</th>
<th>Ultimate Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore Pads</td>
<td>Low level Waste</td>
<td>IPTMF</td>
</tr>
<tr>
<td>Mill (Scoop, Conveyor, Crusher, Grinder)</td>
<td>Low level Waste</td>
<td>Disassemble and bury; IPTMF; mine</td>
</tr>
<tr>
<td>Leaching Equipment</td>
<td>Low level Waste</td>
<td>Mine; IPTMF</td>
</tr>
<tr>
<td>Solvent extraction equipment</td>
<td>Low level Waste</td>
<td>Mine; IPTMF</td>
</tr>
<tr>
<td>Remainder of equipment</td>
<td>Low level Waste</td>
<td>Disassemble and bury; borrow pits; mine</td>
</tr>
</tbody>
</table>

DOSE RATES

No information available.

2.3.4 Operational History

OVERVIEW ON OPERATION

The original uranium deposit was discovered in 1968 under a lake. Draining of the lake was completed in 1974 and mining of the pit commenced shortly thereafter. Mining of the ore was
completed in 1984. Three additional deposits were found immediately off the shore of a large lake near the original deposit. All three required dikes to be constructed to allow dewatering of each area to access the ore. The first zone was mined from November 1985 to February 1991. The other two zones were mined from late 1995 to early 1997. A deep deposit was discovered in the area in 1980. An underground mine was developed with ore extraction starting in 1994 and is ongoing.

The mill to process all the ore bodies was constructed in the early 1970’s. The first ore was milled starting in June 1975 and continues today.

An above ground tailings management facility (AGTMF) was constructed in the early 1970’s to contain any tailings from the processing of the original deposit. The AGTMF was formed by constructing a dam at each end of a nearby valley. The dams were raised periodically during milling of the ore from the original deposit, which continued from 1974 to 1985. The facility contains about 6.5 million tons of tailings over 53 hectares with a maximum height of 23.5 meters. There are layers and pockets of frozen tailings within the AGTMF.

In 1985, once the mining of the original deposit was completed, the open pit was converted into an in-pit tailings management facility (IPTMF) with a pervious surround (porous rock and sand layer around the outside of the pit). The initial tailings were filtered, placed and spread in the facility. Starting in 1986, tailings, as a thickened slurry, were piped to the IPTMF and deposited in the facility to form a beach (sub-aerial deposition). This process was continued from 1987 to 1999. One of the challenges of depositing the tailings sub-aerially was that lenses of frozen tailings were created during winter deposition. In 1999, deep injection of tailings was started to prevent the formation of lenses of frozen tailings and also to use the heat contained within the tailings to thaw some of the frozen tailings. This practice continues to date.

The in-pit tailings management facility currently contains about 6.7 million tons of tailings. The facility was recently expanded to contain an additional 850,000 tons of tailings representing a little more than three years of production.

ACCIDENTS AND IRREGULARITIES

One of the irregularities that occurred during operation of this site that will impact decommissioning is historically the ore was placed directly on the ground beside the mill, thus contaminating soil in this area of the site. During decommissioning, this soil will be excavated and placed in the IPTMF.

The current practice is to construct ore pads to temporarily store uranium ore.

PRE-DECOMMISSIONING ACTIVITIES

Pre-decommissioning activities include:

- activities to terminate the operations such as: flush, drain and empty pipes and tanks (e.g., reagent and process tanks);
- remove and dispose of organic from the solvent extraction process;
- transfer of equipment from closed parts of the site to the operations.
2.3.5 Decommissioning activities and techniques

DECOMMISSIONING ACTIVITIES

Currently, only preliminary plans for the decommissioning are available. Following is a summary of these plans; the final decommissioning plan of each facility will be based on a detailed safety assessment for each:

- **Underground mine**
  Decommissioning activities will consist of dismantling any underground equipment that can be salvaged. Next, openings will be sealed and profiled to conform to the surrounding geography and the areas revegetated.

- **Surface mines**
  Once water quality in the ponds in the surface mines meet regulatory limits, the dikes will be dismantled to turn the area back to the lake. The small abutments that remain will be revegetated.

- **Mineral processing plant**
  The plant includes ore pads, mineral processing building, effluent treatment plants, and equipment. The equipment and buildings will be dismantled and decontaminated where needed for salvage. The concrete foundation will be demolished. Any contaminated soil will be excavated and placed in the IPTMF. Equipment and materials that cannot be salvaged will be placed in the mine, the IPTMF or in borrow pits on site and buried. The plant area and areas that were excavated will be covered with soil and revegetated.

- **Waste rock piles**
  Following demonstration of an acceptable impact on the environment, the waste rock piles will be profiled to control runoff, compacted, covered with soil and revegetated to minimize infiltration and conform to the local geography.

- **IPTMF**
  Waste rock layers will be progressively built up to assist with consolidation to squeeze out pore water and reduce the permeability of the tailings. The raise system will continue to be pumped and the water treated until consolidation reaches a predicted level. The raise system will be dismantled, sealed, profiled and revegetated. A drainage layer will be placed on top of the waste rock layer, followed by a soil cover that will be revegetated.

- **AGTMF**
  The AGTMF will be profiled to control runoff, compacted to minimize infiltration, covered with soil and revegetated to control infiltration and to conform to the local geography.

- **Ancillary facilities / equipment**
  All equipment will be dismantled. Disturbed areas will be profiled to conform with the local geography and revegetated.

DECOMMISSIONING TECHNIQUES

Based on the preliminary decommissioning plans the following techniques will be used for decommissioning of the individual facilities of the site:
- Underground mine
  The techniques will involve dismantling equipment, sealing openings with concrete bulkheads and remediating disturbed areas.

- Surface mines
  Dismantling of dikes and remediating disturbed areas will be the techniques required.

- Mineral processing plant and ancillary facilities
  Decommissioning techniques will require dismantling or demolishing, decontamination where salvage is possible, earthwork / construction and remediation.

- Waste rock piles and AGTMF
  The techniques will consist of civil engineering, earthwork / construction and remediation.

- IPTMF
  Techniques will consist of dismantling equipment, civil engineering, earthwork / construction and remediation.

SAFETY AND PROTECTIVE MEASURES
The following are the safety and protective measures that will be incorporated, based on the preliminary decommissioning plans for the facilities.

- Underground mine
  When workers are in the mine, the ventilation system will be maintained, radon and dust monitoring will be performed and individuals will carry personal dosimeter badges.

- Surface mines
  Water quality in the ponds will be monitored until it meets regulatory guidelines.

- Waste rock piles
  Prior to and following remediation, the infiltration rate and seepage water quality will be monitored to confirm that rates and quality meet predictions. Seepage will be treated as required to meet regulatory guidelines.

- Mineral processing plant and ancillary facilities
  Radiation monitoring will be performed to use to develop work plans. Time on task, shielding or work procedures, personal protective equipment (PPE) and dust suppression will be used, if required, to control the radiation dose to decommissioning workers, where required.

- IPTMF
  Radiation and radon monitoring, time on task limitations, shielding, work procedures, personal protective equipment (PPE) and dust suppression will be used if required to control the radiation dose to decommissioning workers.

- AGTMF
  Radiation and radon monitoring, dust suppression will be performed during decommissioning work and PPE used, if required.
SUMMARY ON ACTIVITIES, TECHNIQUES AND SAFETY / PROTECTIVE MEASURES

The preliminary decommissioning activities, techniques and safety and protective measures are summarized in Table 2:

**TABLE 2. PRELIMINARY DECOMMISSIONING ACTIVITIES, TECHNIQUES AND SAFETY AND PROTECTIVE MEASURES**

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Decommissioning activities</th>
<th>Techniques</th>
<th>Safety and protective Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground mines</td>
<td>Dismantling; sealing opening; profiling and revegetation</td>
<td>Construct concrete bulkheads; dismantling; remediation</td>
<td>Radon and dust monitoring in mine; individual monitoring (badges) when in mine</td>
</tr>
<tr>
<td>Surface mines</td>
<td>Dismantling dikes; revegetation of abutments;</td>
<td>Dismantling; remediation</td>
<td>Water quality monitoring</td>
</tr>
<tr>
<td>Waste rock piles</td>
<td>Profiling; compacting; covering; revegetation</td>
<td>Civil engineering earth work/construction; remediation</td>
<td>Infiltration monitoring; seepage monitoring</td>
</tr>
<tr>
<td>Mineral processing plant</td>
<td>Excavating; dismantling; landfill; Decontaminating; demolishing; covering; revegetating</td>
<td>Dismantling; demolition; Decontamination; remediation</td>
<td>Radiation monitoring; time on tasks; PPE; dust suppression;</td>
</tr>
<tr>
<td>Tailings management facilities (In-pit and surface)</td>
<td>Surface TMF: profiling; compacting; covering; revegetation In-pit TMF: covering with waste rock; consolidation; pump and treat; drainage layer; soil cover; and revegetation</td>
<td>Surface TMF: civil engineering; earth work/ construction; remediation In-pit TMF: civil engineering earth work/construction; remediation</td>
<td>Surface TMF: dust suppression; radiation &amp; radon monitoring; individual monitoring; PPE; infiltration monitoring; seepage monitoring In-pit TMF: time on task; dust suppression; radon monitoring; individual monitoring; PPE</td>
</tr>
<tr>
<td>Ancillary facilities/equipment</td>
<td>Dismantling; profiling and revegetation;</td>
<td>Civil engineering earth work/ construction; dismantling; remediation</td>
<td></td>
</tr>
</tbody>
</table>
2.3.6 Waste management

WASTE MANAGEMENT
Waste rocks piles and tailings are consolidated and contained in-situ. The waste could include equipment that could not be salvaged, which would be disposed of in a borrow pit, TMF or within the mine.

CLEARANCE
A small amount of material could be cleared for reuse. This would be material that was not exposed to uranium bearing solutions or where radiation scanning showed it is not contaminated.

2.3.7 Supporting facilities
Unlike other nuclear installations, there are typically no supporting facilities required e.g. to process radioactive waste.

2.3.8 End-state
The end state is to leave the facility in a safe, stable and sustainable condition, suitable for institutional control with restricted use in some areas, such as the tailings facilities.

An environmental impact assessment is needed to define the end state. This would normally comprise of a pathways analysis and ecological risk assessment for the post-decommissioned site. Appropriate monitoring would be established based on the environmental impact assessment, which would demonstrate the achievement of the end state.

The end-state of the individual facilities at the site is sketched below:
- Underground mine
  All openings will be sealed, the mine allowed to flood naturally and the surface areas of the mine contoured to conform to the local geography and revegetated.
- Surface mines
  The open pit mines have been developed within the boundaries of the lake are to be returned to the lake when water quality regulatory objectives are met.
- Mineral processing plant
  Clearance criteria for the related facilities can be applied based on the regulatory framework in order that these facilities/equipment/materials can be reused or disposed of appropriately.
- Waste rock piles
  These piles will be profiled to control erosion and run-off, compacted, covered with layer of soil and revegetated to minimize water infiltration and contaminant transport to the environment.
- AGTMF
  The slopes will be reprofiled to control erosion and run-off. The tailings will be compacted, covered with a soil layer and revegetated to minimize water infiltration and contaminant transport to the environment.
- **IPTMF**
  The tailings will be consolidated with a waste rock layer and covered with drainage and soil layers. Contaminant releases from the consolidated tailings will be limited by diffusion control of any remaining pore water from the low permeability tailings and the high porosity of the surrounding pervious surround and local geology to allow groundwater to bypass the tailings. The raise water system (i.e., pore water collection system) will be sealed, covered with soil and revegetated.

- **Ancillary facilities/equipment**
  These facilities include transportation routes/access roads, power lines, sedimentation ponds, borrow pits, water supply pumps, and pipelines. Clearance criteria of these facilities can be applied based on the regulatory framework in order that these facilities/equipment/materials can be dismantled, reused or disposed of appropriately. Where appropriate, e.g., in the case of transportation routes/access roads, these facilities will be reprofiled and revegetated.

The end-state of a fully decommissioned site will typically be determined by the regulatory bodies. Normally, according to the national regulations this type of decommissioned site would be transferred to institutional control with restricted land use for some areas, such as the tailings facilities.

2.4 Hazard Analysis

As already explained earlier, for the selected example no safety assessment was performed. Moreover, a preliminary risk assessment was performed to prioritize the individual decommissioning projects which need to be conducted at the site.

Within that preliminary risk assessment, risk is understood as the effect of uncertainties on the objectives of a project [3], especially on its success, and thus is different from the risk as defined in IAEAs Glossary [4]. Within the preliminary risk assessment the impact of decommissioning on the environment, financial performance of the operating organization and interested parties’ support to the project was qualitatively evaluated. For further details on the performed preliminary risk assessment, please refer to section 2.6

A Hazard Analysis in the sense of the safety assessment methodology proposed by the DeSa project [2] or by IAEA Safety Standards Series No. WS-G-5.2 [1] was not performed within the risk assessment as the radiological inventory and any associated scenarios during decommissioning are of less impact to workers and the environment. Nevertheless, aspects of a radioactive inventory and radiological consequences, mainly on long term, are considered in the preliminary risk assessment.

2.4.1 Hazard identification

*Not performed.*

2.4.2 Approaches to hazard identification

*Not performed.*
2.4.3 Preliminary hazard analysis and screening

According to the safety assessment methodology the hazard analysis would result in a list of hazards and associated scenarios, which need a first evaluation to identify those hazards and associated scenarios, which result in significant consequences in terms of the regulatory criteria and requirements to be met and which need further more detailed assessment.

As for the selected example no hazard identification was performed the MMPF TC WG decided to provide some typical outcomes of a preliminary hazard analysis and screening for a MMPF to illustrate the concept of that process step within the safety assessment methodology. Accordingly, the following preliminary analysis of the hazards and associated scenarios is based on the experiences of the members of the MMPF TC WG.

PRELIMINARY ANALYSIS FOR WORKERS UNDER NORMAL CONDITIONS

Typical decommissioning activities will involve dismantling of equipment where solutions and solids containing radioactive elements have been emptied and flushed, covering waste rock or tailings and demolishing buildings or foundations.

Thus, only low levels of residual radiation will be encountered during decommissioning of uranium MMPF. The impact to workers from decommissioning activities is typically performed by scanning the area, developing detailed decommissioning plans and procedures and using time on task or personal protection equipment (PPE), if required, to control radiation exposures.

Persons working in radiation areas will carry personal radiation dosimeters to monitor their exposures. Industrial hazards are evaluated as part of the decommissioning work planning and job hazard assessment prior to performing the activities.

PRELIMINARY ANALYSIS FOR MEMBERS OF THE PUBLIC UNDER NORMAL CONDITIONS

Due to the nature of the decommissioning activities outlined in previous sub-section there are no radiological consequences to the public to be expected.

PRELIMINARY ANALYSIS FOR WORKERS UNDER ACCIDENT CONDITIONS

Accidents will be industrial in nature rather than radiological.

PRELIMINARY ANALYSIS FOR MEMBERS OF THE PUBLIC UNDER ACCIDENT CONDITIONS

Due to the nature of the decommissioning activities outlined in previous sub-section, there are no accident scenarios with significant radiological consequences to the public to be expected.

2.5 Hazard Analysis and Evaluation

According to the safety assessment methodology proposed by the DeSa project [2] and the IAEA Safety Standards Series WS-G-5.2 [1] for the most important hazards and scenarios, identified as part of the hazard identification, a more detailed assessment has to be performed. The results of the detailed assessment need to be presented in the following sub-sections.
As a hazard analysis and evaluation was not performed for the selected example, no specific information is available.

From the MMPF TC WG’s experience often the process step “Hazard Analysis and Evaluation” is merged with the previous process step “Hazard Analysis” in case of MMPFs. This is due to the low radioactive inventory and the limited set of scenarios which might result to relevant consequences for workers and the public.

2.6 Preliminary Risk Assessment

Not part of the safety assessment methodology proposed by the DeSa project [2] or by IAEA Safety Series No. WS-G-5.2 [1] or by the main volume of this publication, for the full site of the selected example a preliminary risk assessment was performed. Approach and results are summarized in the following sub-sections.

2.6.1 Approach of the risk assessment

Following is an overview on the approach of the preliminary risk assessment performed to prioritize the individual decommissioning projects at the site.

RISK-BASED ASSESSMENT

A risk assessment approach known as Failure Mode and Effects Analysis (FMEA) was used to develop a broader understanding of all of the uncertainties, risks, and consequences associated with reclamation of various parts of the site and to establish decommissioning project priorities. FMEA is a procedure for analysis of potential failure modes within a system for classification by severity or determination of the effect of failures on the system. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. Failure causes are any errors or defects in process, design, or item, especially those that affect the customer, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. This consequence is determined by weighing the factors of a clean environment, supportive community and financial performance (i.e. cost / benefit analysis).

Although an FMEA typically occurs early in the design process, the technique can also serve well as an analysis tool throughout the life of a process. An FMEA produces qualitative, systematic lists that include the failure modes, the effects of each failure, and additional actions that may be necessary. Generally, when analyzing impacts the probable worst-case scenario is assumed and analysts would determine whether existing environmental protection measures are adequate.

It is important that focusing on one risk component, such as seepage from a waste rock pile, doesn't lead to other components being overlooked. The FMEA methodology allows a balanced evaluation of the risks associated with various components of a system. It constitutes an enabling mechanism with which to identify the multiple paths of system failures. Indeed, a requisite for an effective risk assessment process is to identify all conceivable failure modes of a system.
FAILURE MODE AND EFFECTS ANALYSIS APPROACH

Fundamental to FMEA is a well-defined system(s). The following guidelines were adopted for spatial, functional and temporal boundaries of the FMEA:

- The FMEA would be bounded spatially to incorporate specific onsite areas and the other directly connected site components, for example, ponds and waste rock piles. Note: Offsite impacts are considered in other pathway analysis, outside the FMEA.
- The temporal scope of the FMEA was not limited, but two phases were defined:
  - current condition – no reclamation completed or, in some cases, no further reclamation; and
  - reclamation complete – the period after the area has been reclaimed.
- The FMEA was restricted to portions of the site that were not presently involved in active production.

A risk assessment matrix, refer to Fig. 2.3, would be used for determination of the overall qualitative risk. The consequence, i.e. the severity, and the likelihood would be rated based on the judgment of the subject matter experts. The risk assessment was limited to consider clean environment, financial performance and supportive community risk matrices.

The FMEA process, as it was applied in the development of the planning document used for the selected example can be summarized as follows:

- For each facility or area of the mine site, the assessment team was asked to develop a list of failure modes and associated consequences and rate the overall likelihood of the event.
- The severity of the consequence for each measure of success (Clean Environment, Financial Performance and Supportive Community) was then estimated.
- The likelihood was determined.
- The risk level for each measure of success was then read from the matrix.

These estimates were discussed by the assessment team and all values were held open to adjustment until consensus was reached.
FIG. 2.3. Example of a Risk Assessment Matrix to Evaluate Risks.

OTHER FACTORS
In addition to risk, the priority of projects or sub-projects was assessed based on three other factors:

1. Factor “Size”
   The primary objective in this regard was to schedule large projects one at a time, such that personnel and equipment would be readily available.

2. Factor “Site Synergy”
   Some projects may be synergistic with other projects of a similar nature and therefore might be done at the same time, barring the issue of project size, as discussed above.

3. Factor “Immediate Returns”
   These are projects where a small effort would quickly remove a known liability and result in some tangible environmental or social benefit.

The above factors were taken into account by assigning scores to each project in regard to how well it addressed a given factor. A rating scale of 1 to 5 was used, where 5 represented the highest score and 1 the lowest. In this case, the major projects were broken down into several smaller components that could be completed on an incremental basis. In the rating of each individual sub-project, it was assumed that all required precedents for the project were complete. For example, in rating revegetation activities on a waste rock pile, it was assumed that all slope-flattening or covering had been completed before rating a project for hydroseeding.
Several reclamation activities are quite well defined, but would not be performed for several years due to a dependence on other reclamation activities. It was decided to leave these activities unrated for ‘other factors’ at present as the sequence has already been determined.

2.6.2 Results of the FMEA as part of the preliminary risk assessment

The outcomes of the FMEA evaluation are summarized in the FMEA Risk Register, presented as a selection of the risks effects and outcomes in Fig. 4. A total of 85 failure modes were considered, discussed and rated.

The results shown in Fig. 4 were summarized by plotting all failure modes with risk ratings above the tolerable threshold on Fig. 5 and Fig. 6. Fig. 5 summarizes failure modes prior to reclamation, while Fig. 6 summarizes modes of failure following reclamation/decommissioning. The summary nomenclature used in Fig. 2.4 and Fig. 2.5 includes a letter to indicate the category of failure consequence (E- environmental, F- financial and S- stakeholder) and a number that indicates the facility, and the failure mode.

For example, S1.15 is identified as a medium high risk failure mode (‘tolerable with strong management’) in Fig. 5. In this case, S indicates “stakeholder” consequences, “1.1” indicates the AGTMF in its current condition and 5 indicates the specific failure mode. The stakeholder consequence for this failure mode is identified as moderate (one or more of: “Brief regional negative attention; prolonged local negative attention; unsupportive stakeholders; criminal action threatened; regulatory stop work order; or temporary operational shutdown”). The likelihood of this consequence is identified as quite likely (expected to occur several times during the lifetime of facility (e.g. ~1:3 or 10 - 30% chance of occurrence/year)). The specific failure mode is: “AGTMF – Increased infiltration at the surface causing increased seepage to the lake,” and the effect of this failure mode is: “May result in increased Contaminants of Potential Concern (COPC) to the lake”.

In summary, the FMEA analysis showed the following:

- No failure modes in the high risk category (Intolerable) were identified. This is an important finding, as it indicates that no acute issues exist and it allows some flexibility, with input from stakeholders, to address the schedule in a measured and orderly fashion;
- Fig. 5 shows a total of six failure modes that rated in the “tolerable with strong management” or medium-high risk category. Two of these were related to the AGTMF and two were related to the downstream lake system. Two of the waste rock piles received one rating each in this category. This suggests that efforts might be focused primarily on these four facilities to reduce risk levels most efficiently;
- In the “Managed” category of Fig. 5, 16 modes were related to the AGTMF, 12 to one Waste Rock Pile (WRP), 4 to a second waste rock pile and 2 to the downstream lake system. This confirms that the AGTMF might be the priority area to be addressed at the site, and also shows that the two waste rock piles and the downstream lake system might be addressed as the next level of priority;
- Other facilities that rated several “mentions” in the “Managed” category of Fig. 5 included the borrow areas, mineralized waste piles, low level radioactive waste facility and the one open pit pond;
- Fig. 6 shows that only two post decommissioning failure modes were rated as medium-high risks (Tolerable with strong management). The number of modes in the
“Managed” category was also lower than for the pre-decommissioned state. This result suggests that the aggregate effects of decommissioning activities will be to reduce the overall risk level; and

- The majority of failure modes in Fig. 6 show a financial consequence. This financial consequence is due to uncertainty over the final regulatory acceptability of any decommissioning measure undertaken prior to completion of a full decommissioning environmental assessment for the entire site. It is the view of the company and the local stakeholders that facilities on the operational site might be remediated progressively as they reach the end of the life or usefulness. The risk to the company is that the remediated sites may not be acceptable to future regulators when the entire site is fully decommissioned. This is an area of concern that will require ongoing dialogue to ensure a level of regulatory certainty for the corporation with respect to reclamation goals, objectives and criteria prior to active reclamation activities proceeding.

While the FMEA exercise proved valuable in understanding risks based on the current level of knowledge, additional work is either being planned or is currently ongoing to better understand risks associated with reclamation activities. Detailed safety assessments will be performed in the future to support decommissioning activities and the post-decommissioning end state.
<table>
<thead>
<tr>
<th>Area</th>
<th>ID1</th>
<th>ID2</th>
<th>ID3</th>
<th>FMEA Criticality</th>
<th>Failure Mode Event</th>
<th>Effect</th>
<th>Effect Likelihood</th>
<th>Environmental Likelihood</th>
<th>Financial Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGTMF</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Wildlife intrusion into tailings</td>
<td>Metal and radiation dose to burrowing animals</td>
<td>Very Likely</td>
<td>Insignificant</td>
<td>Managed</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Minor Dam Failure (no release)</td>
<td>Loss of confidence in dam - need to remediate</td>
<td>Unlikely</td>
<td>Insignificant</td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Blockage of seepage collection system</td>
<td>Effect is to raise piezometric level resulting more GW seepage and</td>
<td>Somewhat Likely</td>
<td>Moderate</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Wildlife grazing on tailings (both moose and geese)</td>
<td>Metal and radiation dose to grazing animals</td>
<td>Very Likely</td>
<td>Insignificant</td>
<td>Managed</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Increased infiltration at the surface causing increased seepage to Lake</td>
<td>May result in increased COPC loading to Lake</td>
<td>Somewhat Likely</td>
<td>Moderate</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Vegetation on dam face</td>
<td>Interferes with inspections</td>
<td>Very Likely</td>
<td>Insignificant</td>
<td>Managed</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Increased community desire for relocation</td>
<td>Large cost and delay to defray the concern</td>
<td>Unlikely</td>
<td>Insignificant</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Major Dam Failure</td>
<td>Uncontrolled release of tailings solids</td>
<td>Very Unlikely</td>
<td>Major</td>
<td>Managed</td>
</tr>
<tr>
<td>AGTMF After Reclamation</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Thaw compensation fill does not prevent depressions</td>
<td>Need to bring in more fill - delays in acceptance into IC</td>
<td>Somewhat Likely</td>
<td>Insignificant</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Plan does not meet future regulatory objectives</td>
<td>Additional cost and delay to IC</td>
<td>Quite Likely</td>
<td>Minor</td>
<td>Managed</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Implemented reclamation does not meet technical criteria</td>
<td>Additional cost and delay to IC</td>
<td>Unlikely</td>
<td>Minor</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Change in perceived land use (before IC acceptance)</td>
<td>Additional cost and delay to IC</td>
<td>Very Likely</td>
<td>Insignificant</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>Potential loss of use of LPR or disposal area</td>
<td>Cost to find and develop a new disposal area</td>
<td>Somewhat Likely</td>
<td>Insignificant</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Waste Rock Pile</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Riprap of perimeter containment ditch</td>
<td>Uncontrolled release of COPCs and cost to repair</td>
<td>Quite Likely</td>
<td>Minor</td>
<td>Managed</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Blowing of waste rock dust into surrounding area</td>
<td>Transport of solids to local area</td>
<td>Unlikely</td>
<td>Insignificant</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td>On-going load to GW water due to high infiltration</td>
<td>Continued loading to GW environment</td>
<td>Very Likely</td>
<td>Minor</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Increased pressure to relocate to pit</td>
<td>Increased cost and delays to overall completion</td>
<td>Quite Likely</td>
<td>Unlikely</td>
<td>Tolerable</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td>Increased surface water overtopping and discharge</td>
<td>Increased loadings to fusion, inc Reg concerns, impact to TOS</td>
<td>Quite Likely</td>
<td>Minor</td>
<td>Managed</td>
</tr>
</tbody>
</table>

FIG. 4. Excerpt from the FMEA Risk Register for the Selected Example.
FIG. 5. FMEA Results for Decommissioning Activities of the Selected Example.
FIG. 6. FMEA Results for the Period after Completion of Decommissioning of the Site.
2.7 Engineering Analysis

No information on a specific engineering analysis is reported to the working group.

2.8 Evaluation of Results and Identification of Controls

No information on the evaluation of results and identification of controls is reported to the working group.

From the experience of the working group members it is likely that most of the controls during decommissioning will be those already in place during operation of a MMPF; this is e.g. the work instructions, personal protective equipment already used during maintenance and repair. This is mainly due to the low radiological inventory after media and material have been drained and removed.

2.9 Graded approach

The application of the graded approach not only simplifies the analysis but also combines several steps in the safety assessment, e.g. “Hazard Analysis” and “Hazard Analysis and Evaluation”.

The graded approach typically is used in decommissioning plans for uranium mines and mineral processing facilities. Detailed analysis of the radiation risk to workers is not performed because only low levels of residual radiation exist and engineering measures or decommissioning procedures can be used to optimize exposures.

2.10 Confidence Building in the Safety Assessment

2.10.1 Quality management system

The company has a corporate quality management program that is based, in part, on ISO 9001 and is the basis for a quality management program at the site.

QUALITY MANAGEMENT WITH REGARD TO THE DEVELOPMENT OF THE SAFETY ASSESSMENT

Quality management needs to be applied consistently with the corporate quality management program in development of the detailed post-decommissioning safety assessment for the entire site. A standard approach has to be developed for performing the safety assessment and evaluating the impacts from decommissioned facilities.

QUALITY MANAGEMENT WITH REGARD TO THE DECOMMISSIONING OF THE MMPF

As part of the development of the facility specific decommissioning plans, the operating site would develop quality assurance and safety plans and the implementation procedures. These plans and procedures would be updated, as necessary.
2.10.2 Independent review and approval process

Following internationally accepted good practice the safety assessment for decommissioning needs to be subject to an independent review, which is performed on behalf of the operator by experts, not involved in the preparation of the safety assessment. As outlined in [2] and [1] the outcomes of the independent review might result in a revision of the safety assessment and the associated decommissioning plan. Only after passing successfully the independent review the safety assessment can be submitted to the regulatory body.

In case of the selected example, no safety assessment has been performed up to now; accordingly, no information on an independent review does exist. Concerning the preliminary risk assessment, which has to be subject to an independent review, too, the assessment outcomes were subject to an expert discussion before they were used further on.

2.10 Summary and Lessons Learned

This MMPF TC WG developed this chapter 2 in order to determine the applicability of the safety assessment methodology proposed by the DeSa project and the IAEA Safety Standards Series No. WS-G-5.2 to these types of facilities; and to illustrate how a safety assessment is used to assess options and perform risk analyses and assessments.

For these objectives the MMPF TC WG selected a real site with milling and mineral processing facilities, for which to some extent safety related information on decommissioning activities were available. The MMPF TC WG transformed this information into the format of a safety assessment as defined for the test cases of the DeSa project [2]. During transformation of the information the MMPF TC WG recognized certain challenges associated with the example, including:

1. The site is an operating site and is at an initial phase of planning for decommissioning of onsite facilities that are no longer operating.
2. Although a preliminary risk assessment, covering also aspects of a safety assessment, has been performed, a formal safety assessment in the IAEA traditional sense has not been done at this stage. However, a detailed long term safety assessment for the period after completion of the decommissioning of the site is typical for mining and mineral processing facilities and will be performed to finally decommission this entire site.
3. The isolation of this site versus a more densely populated site could impact the level of safety assessment required.
4. The climate conditions of the selected example may not be applicable to other mining and mineral processing facilities or sites.
5. The end state requirement of the entire site has yet to be agreed upon with the regulatory bodies.

The following lessons learned were identified by the working group:

1. The safety assessment methodology is sufficient open and flexible to be applied to many different types of projects. Using the “graded approach” helps to match the
level of rigor and analyses commensurate with the level of hazards, especially of a milling and mineral processing facility.

2. For mining and milling processing facilities, while the safety assessment methodology can be used, the steps are not as detailed or rigorous as expected at other types of fuel cycle facilities (e.g. dose calculations). However, this is in keeping with the graded approach and due to the well characterized radiation source and low level of radiation typically found at MMPFs.

3. At operational mining and mineral processing facilities the application of monitoring, knowledge and experience of past and current performance, ongoing processes, activities and operations, and good safety measures simplifies the need for elaborate hazard analysis. As a result, analysis performed by the operating organization to develop decommissioning plans (e.g. measurement of radiation field, development of decommissioning plans, including optimization, and monitoring and comparison to regulatory limits to control workers exposure) is typically simplified and the need for complex modeling is unnecessary.

The decommissioning activities deal with dismantling of equipment that has been drained and flushed to remove any solutions or solids containing radioactivity, covering tailings or waste rock or demolishing buildings. Workers performing these activities are only exposed to low level residual radiation from contaminated materials, tailings or waste rock that is easily characterized and controlled.

4. The risk associated with decommissioning will be predominately associated with non-radiological hazards, which could be found in the construction or mining industry. Radiological hazards are more associated with low level of radiation in the environment over a long period of time.
3 COMPILATION ON SAFETY ASSESSMENTS IN NATIONAL DECOMMISSIONING PROJECTS

In the following sections information related to safety assessments for decommissioning from national decommissioning projects of mining and mineral processing facilities are presented. The information is based on information available to the MMPF TC WG members i.e. by own knowledge/experience, by publications or by private communications.

As already mentioned in chapter 1 the members of the MMPF TC WG were facing significant challenges in getting access to examples which address aspect of decommissioning facilities (i.e. buildings, structures, systems or equipment) and not only aspects of remediation of the site of a mining and mineral processing facility, e.g. on the remediation of a tailing pond or of a waste rock dams. As a consequence the working group accessed several national examples but only three of them provided sufficient information to illustrate some aspects of a safety assessment for decommissioning.

The structure of the presentation of the three examples follows the individual steps of the safety assessment methodology as proposed by the DeSa project [2] and incorporated in the IAEA Safety Standards Series No. WS-G-5.2 - Safety Assessment during Decommissioning [1]. The structure takes also into account additional aspects which are of interest from a point of view of the FaSa methodology.

For some aspects, not all examples provide the information the working group was interested in. In such cases the note “no information available” is placed in the relevant sub-section. It is important to note, that in such a case, the missing information might be interpreted as “the working group does not have access to the full set of information” or “the information is not documented, but the aspect was considered in the decommissioning project” or “information is not documented as the aspect was not considered in the decommissioning project”.

3.1 Example of a Mining and Milling Site

3.1.1 Safety assessment framework
- Ensure the safety of the public and the environment, with, in particular, certification of the safety of all the mine structures as well as the perennial safety of the restored sites.
- Applying the optimization principle to make all the residual impacts as low as reasonably possible (in particular the radiological impact).
- Limit the consumption of space and therefore the surface of the land.
- Succeed in the integration in the landscape and the possible development of a certain activities on the restored sites by taking into consideration the wishes of the local organizations after joint meetings with them and the administration.

2 With respect to aspects of remediation several documented examples can be found worldwide, e.g. in the IAEA Technical Reports Series No. 362 [5].
3.1.2 Description of facility and activities

BACKGROUND INFORMATION
- Location: Europe
- Type: mining and milling site.
- Facilities to be decommissioned:
  - complete site.

PRODUCTION HISTORY
In 1974, with the energy crisis and the decision to use nuclear energy to produce the major part of the country’s electricity supply, the valorization study of deposits was started and these reserves were estimated to be 18 500 tons of uranium contained in the ore.

In mid-1975, the first site installations were constructed (offices, stores, workshop, change room) and in September the digging of the access to the main deposit was started. This involved surveying the deposit more accurately, so as to prove the reserves by boreholes, defining the methods for working and ore extraction, carrying a pilot plant study of the treatment process developed in the laboratory. These objectives were reached at the start of 1978 and the work was then accelerated with the beginning of yellow cake production in early 1981. In April 1979, the authorities issued the construction license for the ore processing plant and its operation was authorized in September 1980. The first kilogram of uranium, as yellow cake, was produced on 16 April 1981. In 1993, the recoverable underground mine reserves were still in the order of 4500 tons of uranium, but their characteristics and the very poor economic environment did not allow maintaining the production rate; this was then progressively reduced and all production was definitively stopped in April 1997.

DECOMMISSIONING PLANNING
- Final end state: Unrestricted release of the site.

DESCRIPTION OF ACTIVITIES FOR DECOMMISSIONING

No information available.

3.1.3 Hazard Identification and screening

RADIOLOGICAL INVENTORY

No information available.

IDENTIFICATION AND SCREENING

No information available.
3.1.4 Hazard Analysis

PATHWAY ASSESSMENT
No information available.

DOSE CALCULATIONS
No information available.

RISK ASSESSMENT
No information available.

PROTECTION MEASURES
No information available.

3.1.5 Engineering analysis

DECOMMISSIONING IMPLEMENTATION
Following implementation related aspects were mentioned in the available information on the decommissioning project:
  - Work plans
    - Studies concerning tailings storage facilities: geo-technical stability of the building up of tailing containers, geo-mechanical stability (erosion resistance) and geochemical stability of coverings, geochemical change of tailings.
    - Studies regarding the underground mine: the main study concerns the site's hydrogeology which allow forecasting the phenomena resulting from the rising of water levels during mine flooding. This study required drawing a complete inventory of the water inflows into the underground mine and their characterization.
    - A pilot test covering about one third of a tailings pond was conducted to measure the radiological efficiency of a 1 m thick layer of non compacted waste rock: radon emission measurements were made directly over the tailings and after covering and compared with measurements made over the waste rock dump.
  - Environmental Monitoring
    Pre-shutdown studies benefited from the data provided by the environment monitoring network which was installed at the beginning of the mine production.
  - Revision of environmental monitoring plans.

3.1.6 Evaluation of results and identification of controls
No information available.
3.1.7 Compliance with requirements

No information available.

3.1.8 Limits, conditions and controls specification

No information available.

3.1.9 Termination

The new radiological impact assessment methodology for impoundments of uranium mill tailings after reclamation allows demonstrate the ability of the repository to ensure protection for people, taking into account the current legislation. The limit of 1 mSv appears to be met.

3.2 Example on a Uranium Conversion Site

3.2.1 Safety assessment framework

No information available, but refer also to section 2.2.7.

3.2.2 Description of facility and activities

BACKGROUND INFORMATION

- Location: North America.
- Type: facilities for uranium conversion.
- Facilities to be decommissioned:
  - the facility is intended for reclamation, i.e. the restoration of mined land to its original contour, use or condition.

PRODUCTION HISTORY

The facility was engaged in different operations in different areas of the site, including:

- the recovery of uranium by concentration and purification processes,
- the conversion of concentrated and purified uranium ore into UF6 between the years of 1970 and 1993, and
- the reduction of UF6 into UF4 from February 1987 until 1993.

The facility ceased production in 1993 and submitted a preliminary plan for completion of decommissioning.

DECOMMISSIONING PLANNING

- The preliminary plan for completion of decommissioning indicated that decommissioning the facility would include construction of an on-site disposal cell to isolate the decommissioning waste.
- All of the waste materials will be disposed on-site. The facility’s proposed approach would result in the dismantlement of facility equipment and structures, removal of
sludges, impoundments, buried wastes and impacted soils, and placement of resulting waste materials in an engineered disposal cell.

- Drainages that exit the fenced institutional controlled area of the facility to the west contain some residual radioactive materials from historic releases. However, doses from exposure to these materials without restrictions are not distinguishable from background. As a result, the facility plans no further cleaning in these drainages.

- The facility conducted site characterization and decommissioning planning activities in order to develop a decommissioning plan for the facility site.

- In addition, the facility submitted information in support of an environmental impact statement which was initiated by the regulatory body.

- Final end state: restricted property to a state organization for long term care and maintenance.

DESCRIPTION OF ACTIVITIES FOR DECOMMISSIONING
Following detailed activities have been foreseen:

- Construction of an above-grade, engineered disposal cell on the facility site for permanent disposition of the decommissioning and reclamation wastes.

- Removal of sludges and sediments from the ponds and lagoons, excavation of buried low-level wastes, removal of stored soils and debris, and placement of these materials into the disposal cell.

- Dismantlement of process equipment, followed by recovery of gross quantities of contained uranium.

- Size reduction/compaction of process equipment, piping and structural materials (including scrap metal, empty drums, and packaged wastes that will accumulate prior to decommissioning) to satisfy disposal requirements for maximum void volume.

- Dismantlement/demolition of structures excepting the new facilities administrative office building and the storm water impoundment.

- Demolition of concrete floors, foundations and storage pads and asphalt or concrete paved roadways outside the footprint of the cell.

- Removal of clay liners and/or contaminated soils from under impoundments.

- Excavation of underground utilities, contaminated sand backfill from utility trenches and building foundation areas and more highly contaminated soils under the cell footprint.

- Excavation of contaminated soils lying outside the footprint of the disposal cell that exceed site-specific radiological cleanup criteria.

- Handling and treatment of produced ground water and storm water during cell construction.

- Placement of all decommissioning wastes into the on-site disposal cell, followed by capping and closure of the cell.

- Re-grading the site, backfilling of excavations to the finished grade, and re-vegetation.
- Establishment of a fenced institutional control area around the cell, installation of additional monitoring wells as necessary, and initiation of a long-term site monitoring plan.

3.2.3 Hazard Identification and screening

RADIOLOGICAL INVENTORY

The contamination at the facility is a result of uranium processing activities that took place during the operation of the plant. Throughout the operating life of the plant, on-going evaluations of the impact of plant operations, including airborne and liquid discharges, and soil and groundwater sampling, occurred.

In the vicinity of the process buildings, process impoundments and uranium handling areas, concentrations of uranium in the soils exceed background and in many areas exceed the proposed soil cleanup criterion. Uranium in soil at concentrations above 1.3 Bq/g (35 pCi/g) is found to a maximum depth of about 9.45m (31 feet) beneath the process area. In addition, a few areas of limited extent are impacted by thorium-230 and/or radium-226. Soils containing thorium or radium in excess of the proposed limits are confined to areas where raffinate sludge was managed.

Groundwater beneath portions of the facility site is impacted by uranium from past leaks and spills. The vertical extent of the groundwater impact is limited by an almost impervious sandstone layer.

IDENTIFICATION AND SCREENING

No information available

3.2.4 Hazard Analysis

PATHWAY ASSESSMENT

The exposure scenario, representing a residential farmer, is comprised of direct exposure to external radiation and inhalation and ingestion of radioactive material to an individual who lives on the site and ingests food grown on the site.

DOSE CALCULATIONS

Inside the fenced institutional controlled area and using derived concentration guideline levels (DCGLs) for radium, thorium, and uranium the dose to a person carrying out authorized activities is estimated to be less than 0.02 mSv/y. For a resident farmer intruder inside the fenced institutional controlled area (equivalent to loss of institutional control scenario) the dose will be 0.54 mSv/y, the facility site radium benchmark dose. The dose rate to the industrial worker and the resident farmer would be approximately 20% of the radium benchmark dose or 0.004 mSv/y and 0.11 mSv/y, respectively.

The dose to a member of the public from contamination that is presently in the drainages that exit the institutional controlled area and cross states owned property is less than 0.002 mSv/y.
RISK ASSESSMENT

No information available.

PROTECTION MEASURES

A radiation safety program describing measures to protect workers, the public, and the environment will be maintained and followed during decommissioning and reclamation. In recognition that the amount of radioactivity and therefore associated hazards will be reduced as the project progresses, the radiation safety program may be modified commensurate with the activities being performed. The facility’s operator will review and approve the radiation safety program, and any revisions that are made during the project. Any such adjustment to the requirements of the radiation safety program has to be made in accordance with document control procedures.

3.2.5 Engineering analysis

DECOMMISSIONING IMPLEMENTATION

In conjunction with the overall sequence and water management strategy the anticipated construction sequence for the disposal is outlined below:

1. setup of the soil stockpiling and washing area (if necessary) in the yellowcake storage pad;
2. removal of sediment and underlying sub-soils from the emergency basin, north ditch, and sanitary lagoon. These materials would require temporary stockpiling;
3. removal of contaminated soils from the footprint of the disposal cell, particularly where the lined area will be. This would include excavation of utility trenches and removal of piping and conduit under the cell footprint. These soils would require temporary stockpiling;
4. backfilling and compaction of excavations under cell footprint;
5. preparation of the lined area within the disposal cell. Placement of layer materials within the lined area of the disposal cell;
6. cleaning and removal of and temporary stockpiling of synthetic liners from raffinate sludge ponds;
7. excavation of remaining liner soils and sub-soils;
8. preparation of remaining areas of the disposal cell for fill placement;
9. removal of structural materials, and placement in the disposal cell;
10. excavation of remaining contaminated soils, with disposal cell footprint adjusted to the east and south as necessary (based on contaminated soil volume); and
11. cover construction.

3.2.6 Evaluation of results and identification of controls

No information available.
3.2.7 Compliance with requirements
The dose rate to the industrial worker and the resident farmer would be approximately 20% of the radium benchmark dose or 0.004 mSv/y and 0.11 mSv/y, respectively.
The dose to a member of the public from contamination that is presently in the drainages that exit the institutional controlled area and cross states owned property is less than 0.002 mSv/y.

3.2.8 Limits, conditions and controls specification
No information available.

3.2.9 Termination
- After the removal of systems and equipment, structures, and soils and sediments, the site will be restored by backfilling (if necessary), grading and seeding with vegetation.
- The operator will establish and fence the institutionally controlled area to limit unauthorized access. Activities within the institutional controlled area are only those authorized by the regulatory body or its contractors, such as monitoring or maintenance.
- Final radiological survey to demonstrate that the end state has been met

3.3 Example on a Hydrometallurgical Site
3.3.1 Safety assessment framework
No information available except on dose limits; for the later please refer to sub-section 3.3.4.

3.3.2 Description of facility and activities
BACKGROUND INFORMATION
- Site: Europe.
- Type: site with hydrometallurgical facilities (incl. a milling facility) for uranium processing.
- Facilities to be decommissioned:
  - old hydrometallurgical plant (already decommissioned);
  - new hydrometallurgical plant;
  - on-site waste piles and spilled tailing.
PRODUCTION HISTORY
The facility began production in 1947 as a hydrometallurgical plant for processing uranium ores and regeneration of ion-exchange resins from in situ leaching technology. The facility was in operation between 1947 and 1990, processing some 10 million tons of ore from various uranium deposits, using different techniques for hydrometallurgical extraction of the
uranium ores.

The mill used a variety of chemical reagents for extracting the uranium, including:

- sulphuric acid;
- carbonates and bicarbonates;
- manganese ore, potassium permanganate or nitrates as oxidizers of the uranium;
- organic substances as flocculants;
- lime;
- kerosene; and
- other reagents necessary for the production of ‘yellow cake’.

An ore enrichment facility operated at the site between 1957 and 1964.

The main pollutant around the villages of the facility during this time was ore dust due to lack of facilities capable of capturing it. The environment was polluted with radionuclides, heavy and nonferrous metals by particulate waste. Therefore, the ore enrichment plant was shut down and decommissioned in 1964.

The old plant was already decommissioned resulting in radioactive waste remaining at the site. The new plant, buildings, ponds and the ground itself are waiting for decommissioning and remediation.

DECOMMISSIONING PLANNING

- Final end state: The intention is to achieve unrestricted release, but may be revised during decommissioning conduct. Relevant criteria are laid down in the national regulations for remediation actions of uranium mining sites.
- Removal of contaminated material to tailings pond (low level radioactive waste facility).
- Restoration of the site with clean material.
- Construction of a surface water drainage system.
- Revegetation.

DESCRIPTION OF ACTIVITIES FOR DECOMMISSIONING

Following decommissioning activities were or are foreseen:

Related to the old plant (already decommissioned)

1. Demolition and decommissioning undertaken between 2000-2003, consisting of:
   - dismantling of machinery, equipment, pipelines, ventilation systems and more;
   - decontamination (cleaning) of radioactivity less contaminated equipment; and
   - disposal in the trenches in the new tailing pond of highly contaminated containers, pipelines and other facilities.
2. Demolition of buildings by blasting.
3. Deposition of demolition waste in the tailings pond (not done yet).
Related to the new plant

1. Complete mineral processing and leaching systems. The stripping system and other ancillary systems (such as tungsten recovery circuit) to recover uranium from the resin was installed but never used.

2. The equipment and building was decontaminated and have been left in situ

3. It is planned to:
   - dismantle, clean, and reuse equipment;
   - demolish buildings using traditional methods;
   - if possible materials would be cleaned for reuse; and
   - radioactive waste, if any, would be disposed in the tailings pond (low level waste disposal facility).

Related to other buildings

1. Administration building
   - radiological survey undertaken;
   - levels of contamination detected are below legislated limits (<300nGy/h); and
   - potential for presence of radon gas (measured at 56Bq/m³ outside the administration building).

2. Other buildings used for non-uranium milling.

3.3.3 Hazard Identification and screening

RADIOLOGICAL INVENTORY

Mostly no information is available related to the radiological inventory of the buildings and the equipment itself except that for the administrative building, which is mentioned in previous sub-section 3.3.2. Information on the radiological situation at the site itself is available; although this information is mainly relevant for the remediation of the ground, including the tailing ponds, and thus is not subject of this Annex 4, the information is summarized below as the contaminations represent a significant radiation source even for the decommissioning of the buildings.

- Scattered uranium ore
  The ore stockpile and adjacent areas is the largest source of this type of contamination. The waste dump area is contaminated by pieces of ore. Radiation parameters of this type of pollution vary widely: gamma dose rate of individual pieces exceeds 20 µSv/h, but the average is between 1.5 – 2.0 µSv/h. The measured beta contamination from ore is in the range of 30 and 1500 β/cm². The values of the activity of uranium-238 and radium-226 in samples are 5 to 50 times higher than the average normal values of the rocks in the area.

- Scattered tailings from processing ore after the partial extraction of uranium
  Before building a tailing dam, tailings were deposited in a gully to a nearby river. This dump is heavily eroded. Tailings are characterized by strong gamma rays, with
measured readings up to 7 – 8 µSv/h, and an average is 1.5 – 3.5 µSv/h. Tailings material from the alkaline leaching method have a lower gamma radiation dose rate (1.5 – 2.0 µSv/h) than those from acid leaching method (3.5 – 7.0 µSv/h).

- *Radiochemical pollution from spills and leakage of solutions and ion-exchange resins*  
  This radioactive contamination is localised and occupies an area of approximately 1500 m². It includes pollution caused by contaminated machinery and equipment placed throughout the site. Radiation characteristics of these contaminants are very varied, but in general they have relatively low gamma dose rate (1,0 – 2.0 µSv/h). The measured beta contamination ranges between 50 Bq/cm² and 5000 Bq/cm².

- *Construction waste from the old factory*  
  After demolition of the old plant hereby generated contaminated waste remained on-site. It was proposed to deposit this material into the tailings pond. Gamma dose rate of this material varies from 0 to 1.3 µSv/h.

**IDENTIFICATION AND SCREENING**

*No information available*

**3.3.4 Hazard Analysis**

**PATHWAY ASSESSMENT**

Not assessed in detail, but recognized dust generation to be the most probable release method, potentially leading to inhalation and, possibly, ingestion. Radon and daughter products were and will be measured during conduct of decommissioning work.

**DOSE CALCULATIONS**

Principal sources of radiological exposure:

- *Radon and radon progenies*  
  Measured values of radon and its progenies in the region of the facility give reason to expect that the radiation exposure of workers will vary widely - from "background" for working outdoors or in the new plant, to over 2 working level months (WLM) in some buildings (for example the chemical laboratory). After the first stage of decommissioning, the majority of buildings with very high and high risk were and will be demolished.

- *Long-lived natural radionuclides in air*  
  The expected long-lived radionuclides are: uranium-238, uranium-234, thorium-230, radium-226, lead 210 and polonium-210. The study of such pollutants has been performed using aerosol sampler filters. Measurement results show that 2/3 of the radiological risk for inhalation is from nuclides of Uranium-Radium chain.

- *Grading of radiological hazards*  
  Radiological sources at the site are complex, varying significantly within the site, and are from naturally occurring radioactive material (NORM).

Apart from places near uranium concentrates, external exposure is determined mainly by gamma dose rate. The measured values show that gamma doses can exceed 5 mSv per year for 2000 hours exposure.
In other places the main radiological source depends on the specific relationship between external exposure, concentration of radon progenies and long-lived radionuclides. Total impact of radiation sources lead to annual effective dose over 5 mSv for workers, i.e. within the limit for Category B personnel. In the national regulations there exists category A (radiation workers) up to 20 mSv; category B (other personnel working on nuclear facilities) up to 6 mSv; and the public up to 1 mSv.

RISK ASSESSMENT

The site was classified as a site with very high radiological risk compared to other mining and milling facilities according to the methods used in the country.

PROTECTION MEASURES

Following protection measures to for workers during conduct of the decommissioning measures are foreseen

- boundaries of contaminated area are delimited;
- authorised pathways for movements within the site are designated to limit exposure;
- use of check points to assess contamination of vehicles, and clean them as necessary; contaminated water is sent to the tailings pond (no water treatment at present);
- check points for workers;
- workers use
  - individual dosimeters;
  - PPE such as overalls, filter masks etc.;
- establishing written safe working procedures;
- training of workers;
- medical control of workers; and
- daily monitoring of clothes.

3.3.5 Engineering analysis

DECOMMISSIONING IMPLEMENTATION

- Work plans
  - some written safe working procedures e.g. on emergency plan, radiation protection exist; it is planned to develop further written procedures for other activities, such as cutting.
- Environmental monitoring comprising
  - water sampling (surface and ground);
  - soil sampling;
- air sampling (Ra, dust).
- Revision of work plans and environmental monitoring plans as required.

3.3.6 Evaluation of results and identification of controls

_No information available_

3.3.7 Compliance with requirements

_No information available_

3.3.8 Limits, conditions and controls specification

_No information available_

3.3.9 Termination

Termination will cover following aspects:

- Final radiological survey to demonstrate that the end state has been met
- Environmental Monitoring in case of restricted release
Summary and Conclusions on Safety Assessment in Decommissioning Projects of Milling and Mineral Processing Facilities

Evaluation and demonstration of safety is an essential component of the successful planning, performance and completion of decommissioning of facilities that contain a radioactive inventory. This has been highlighted by the international safety standards on decommissioning of nuclear power plants, research reactors, fuel cycle facilities and medical, industrial and research facilities.

A decommissioning project is usually executed using a phased approach, for example, where the decommissioning of the various facilities is completed progressively in different phases following termination of operations at the site.

The safety assessment methodology used in the test cases of the DeSa project and the FaSa Project for nuclear power plants, research reactors, fuel fabrication facilities and nuclear laboratories addresses the radiological risks expected to occur during decommissioning processes. Non-radiological hazards are identified but the assessment and control are normally outside of the nuclear safety assessment scope of the IAEA’s safety assessment methodology and dealt with separately, except they will result in nuclear or radiological consequences. The safety assessment used normally covers radiological risks to workers, the general public and the environment for normal and abnormal conditions that occur during decommissioning activities.

Summary on Experiences from Decommissioning Projects

The working group of the Mining and Mineral Processing Facility Test Case has faced particular challenges, primarily due to the lack of data associated with decommissioning of mining and mineral processing facilities. A substantial body of information was available but related to the closure and remediation of parts of mine sites, such as the tailings dams, pit lakes and waste rock dumps; the information available for these facilities almost exclusively relates to safety assessment of the end state, and in particular the safety assessment of long term exposures to very low levels of radiation. Mainly no information was found relating to safety assessment relating to the decommissioning of mill buildings and individual mineral processing facilities. As a consequence only four national examples with safety assessment related information were found, one of them presented in more detail in chapter 2, three of them summarized in chapter 3.

The working group recognized and concluded that radiological aspects of the decommissioning of milling and mineral processing facilities (safety assessment of personnel, the public and the environment) need to be considered but are not of the same scale as, for example, in a nuclear power plant:

- There is no neutron activation of materials to produce high level isotopes – as a consequence radiation sources are well characterized and known.
- Typically equipment will be drained off of solutions and emptied of solids containing radioactive elements and flushed before decommissioning activities start. Thus only low levels of residual radiation from contaminated materials are present and are easily to be quantified.
The decommissioning activities themselves involve dismantling equipment and buildings, covering waste rock and tailings facilities and disposing of materials. None of these activities create risk to the public or the environment for either normal or abnormal conditions. The radiation exposures of workers involved in the activities need to be managed but are easily controlled due to the typical low levels of radiation. The protection often those protection measures available from operation of the facilities which are still appropriate to ensure safety during decommissioning.

A typical safety assessment for an uranium milling and mineral processing facility is more concerned with identifying and optimizing decommissioning plans for mines, waste rock piles and tailings facilities to minimize the post-decommissioning impact of radiological and non-radiological elements on the environment and the public in the long term. Even though both radiological and non-radiological elements are analyzed, often the non-radiological elements are the primary driver for control measures.

The most complete example of a practical decommissioning project in chapter 2 allowed illustrating some aspects on the application of the DeSa methodology and the FaSa methodology. However this example also has several limitations for achieving the objective of a full illustration of the applicability of both methodologies:

1. It is an operating site that is progressively decommissioning facilities on the site that have reached the end of their life or usefulness. The ideal site for a full illustration would not be operating and the entire site would be decommissioned.

2. A safety assessment has not been performed for the facilities to be decommissioned. The site has performed a preliminary risk assessment using the Failure Mode and Effects Analysis (FMEA) methodology to determine the priority of projects and has presented preliminary decommissioning plans for each facility. A detailed post-decommissioning safety assessment will be performed for each facility and for the entire site in the future to obtain regulatory approval to decommission the entire site.

3. The end state for the decommissioned site has not been determined nor plans developed to achieve an end state at this time.

In spite of these limitations, the information available from the FMEA methodology and the preliminary decommissioning plans was incorporated into the illustration in chapter 2; in addition, a sub-section was prepared to inform on the risk assessment as the risk assessment provides insights in the project risks associated with the decommissioning of the site of the selected example. All facilities requiring progressive reclamation on the site were considered in the original preliminary safety assessment but this Test Case only presents a selection of the facilities in the decommissioning plan.

CONCLUSIONS ON THE APPLICABILITY OF DESA AND FASA SAFETY ASSESSMENT METHODOLOGY

Regarding the radiological hazards, experiences and examples have shown that it is possible to replace significant pieces of safety assessment performed for other nuclear facilities than mining and mineral processing facilities by application of individual and working area monitoring, good process knowledge and good safety measures. As a result, analysis (e.g. measurement of residual radiation fields, development of decommissioning plans and procedures and comparison of radiation monitoring data to regulatory limits to control
workers exposure for optimization) performed for milling and mineral processing facilities is simpler than for other nuclear facilities and the need for complex radiation dose modelling is usually not needed.

The working group considers that the application of the DeSa methodology to MMPF is appropriate when considering the graded approach – the safety assessment for decommissioning of MMPF needs to be commensurate with the hazards present. For instance, not all steps of the safety assessment methodology need to be performed but can be combined or need to be performed with the same scrutiny as for a nuclear power plant. Also, typical protection measure for workers are those already in place from operation and used e.g. during maintenance and repair work.

The working group’s experiences and the examples indicate also that the three phases of the FaSa methodology (Planning, Conduct and Termination) are also applicable. A strong focus is laid on the aspect of termination which is the long term assessment of environmental aspects associated with the intended end-state of the decommissioning of a full site of mining and mineral processing facilities.

Concluding, the working group recognized that safety assessment as proposed by the IAEA in the IAEA Safety Reports Series No. 77 and recommended in the IAEA Safety Standards Series No. WS-G-5.2 is applicable for mining and mineral processing facilities, but with a clear consideration of the graded approach to ensure, that safety assessments are commensurate with the low radiological hazards.
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