NIS

Siempelkamp
NIS Ingenieurgesellschaft

# TECHNICAL DOCUMENT

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**Decommissioning cost estimate**
**Update 2023**

[redacted]

**Client:** **Ministerie van Infrastructuur**
**en Waterstaat (IenW)**

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## Executive summary


Contractors

The Dodewaard NPP (KCD) shut down in 1997 is in the safe enclosure (SE) since 1st July 2005. The duration of this phase is planned for 40 years. Siempelkamp NIS Ingenieurgesellschaft mbH (NIS) prepared several preliminary decommissioning plans (PDP) and the relating cost calculations for the owning and operating company B.V. Gemeenschappelijke Kernenergiecentrale Nederland (GKN), last in 2021.

At the moment, the transfer of KCD towards the government is negotiated and expected in 2023. To determine the adequate price, the Ministerie van Infrastructuur en Waterstaat (IenW) assigned NIS to update the previous decommissioning cost calculation.

NIS is involved in planning and cost estimation for the decommissioning of nuclear facilities for almost 40 years. As an independent expert NIS prepares the decommissioning planning and cost estimates for the German nuclear power plants (NPP) and nuclear research facilities still in operation or already shutdown.

Moreover, NIS is involved in projects out of Germany. In the Netherlands, NIS has also prepared the latest decommissioning planning and cost estimates for the NPP in Borssele as well as the reactor in Delft and the PALLAS reactor in the construction phase at the moment.

For the KCD NIS provided various decommissioning studies and cost estimates since 1994 considering different strategies, scenarios and planning. The present study refers to the last PDP issued in 2021. It describes the NIS methodology to develop decommissioning costs and the corresponding results.

Masses to be handled

According to the last PDP, a total decommissioning mass of **71.322,8 Mg** is determined, which has to be dismantled. **967 Mg** has to be packed in **2.170 containers** and sent to COVRA implying a storage volume of **2.817 m³** there. The content of the 20 ft. container can be released after 50 years decay storage reducing the required repository volume for final disposal to **1.679 m³** accordingly.

Planning / scheduling

With reference to the last PDP, the planning for decommissioning starts in 2041 as the SE phase ends in June 2045. In following the plant is completely dismantled. “Green field” is reached in 2055. So, the total project duration is at about **14 years**.

Costs

The costs are calculated considering the price and cost increases in the past two years observed in current nuclear decommissioning projects as well as detected by statistical agencies. Furthermore, COVRA and container costs are updated according current price and fee tables.

The total cost is calculated to **269 Million €**.

Uncertainties

Obviously, uncertainties need to be considered in decommissioning projects. The corresponding cost estimates should reflect the potential impact in financial terms. For a 50%-confidence level 4,5% contingency rate is recommended to add on total costs.

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## General acronyms

| | |
|---|---|
| AACEI | Association for the Advancement Cost Engineering International |
| ANVS | Dutch authority for nuclear safety and radiation protection (Autoriteit Nucleaire Veiligheid en Stralingsbescherming) |
| CALCOM | Calculation and cost management (NIS database application) |
| CBS | Statistics Netherlands (Centraal Bureau voor de Statistiek) |
| CORA | Component registration and analysis (NIS database application) |
| COVRA | Dutch nuclear waste processing and storage facility (Centrale organisatie voor radioactief afval) |
| DIS | Dodewaard Information System |
| KCD | Dodewaard NPP (Kerncentrale Dodewaard) |
| NIS | Siempelkamp NIS Ingenieurgesellschaft mbH |
| NPP | Nuclear power plant |
| SE | Safe enclosure |
| PDP | Preliminary decommissioning plan |
| RPV | Reactor pressure vessel |
| WBS | Work breakdown structure |
| WP | Working package |

# 1 Introduction

The Dodewaard NPP (KCD) shut down in 1997 is in the safe enclosure (SE) since 1st July 2005. The duration of this phase is planned for 40 years. Siempelkamp NIS Ingenieurgesellschaft mbH (NIS) prepared several preliminary decommissioning plans (PDP) and the relating cost calculations for the owning and operating company B.V. Gemeenschappelijke Kernenergiecentrale Nederland (GKN), last in 2021.

At the moment, the transfer of KCD towards the government is negotiated is expected in 2023. To determine the adequate price, the Ministerie van Infrastructuur en Waterstaat (IenW) assigned NIS to update the previous decommissioning cost calculation.

NIS is involved in planning and cost estimation for the decommissioning of nuclear facilities for almost 40 years. As an independent expert NIS prepares the decommissioning planning and cost estimates for the German nuclear power plants (NPP) and nuclear research facilities still in operation or already shutdown.

Moreover, NIS is involved in projects out of Germany. In the Netherlands, NIS has also prepared the latest decommissioning planning and cost estimates for the NPP in Borssele as well as the reactor in Delft and the PALLAS reactor in the construction phase at the moment.

For the KCD NIS provided various decommissioning studies and cost estimates since 1994 considering different strategies, scenarios and planning. The present study refers to last PDP issued in 2021 [1]. It describes the NIS methodology to develop decommissioning costs and the corresponding results considering cost and price increases observed in the past two years. In particular, following issues are revised:

- Boundary conditions for costs
- Wages / hourly rates of the staff
- Decommissioning equipment costs
- Container costs
- COVRA fees
- Price escalation of all other cost items to the price level 01/2023.

In general, the NIS approach for the performance of the decommissioning cost calculations relies on the four steps

- Mass analysis
- Creation of a work breakdown structure (WBS)
- Time scheduling of the decommissioning project
- Cost calculation.

These four steps are performed with the NIS database applications CORA (**CO**mponent **R**egistration and **A**nalysis) and CALCOM (**CAL**culation and **CO**st **M**anagement) to create a cost calculation model delivering the results. The following chapters of this report describe this approach in sequence of the four steps.

Finally, uncertainties are presented and calculated according to [2].

# 2 Mass analysis

In the first step of the mass analysis the inventory of the NPP is registered. Second, a waste management concept is applied to country and site-specific purposes considering particularly radiological assessments of the decommissioning masses. Finally, the results of the mass analysis like waste amounts, number of required containers and storage volumes are provided.

## 2.1 Inventory

The inventory of the KCD is registered in the Dodewaard Information System (DIS) as well as in the application CORA. According to the last PDP update a **total mass** of **71.323 Mg** has to be dismantled or demolished to reach green field conditions at the end of the decommissioning project. More details concerning the inventory are provided in the PDP 2021 [1]. Table 2-1 gives an overview.

**Summary of KCD masses**

| Description | Mass [Mg] |
|---|---|
| **Plant inventory** | **6.233** |
| Primary mass | 5.435 |
| Tertiary/additional mass | 798 |
| **Building structures** | **65.090** |
| KCD buildings | 64.250 |
| New buildings | 840 |
| **Total** | **71.323** |

Table 2-1: Summary of KCD masses to be dismantled or demolished

## 2.2 Waste management concept

During decommissioning of a nuclear facility, a large amount of components, structures and other residuals etc. with very different physical, chemical and radiological properties have to be treated, conditioned and packaged. In general, the objectives of all of the treatments are either:

- Conditioning and packaging of radioactive waste for final repository (COVRA)
- Release of non-radioactive material for industrial recycling, if necessary a decontamination treatment can be processed before
- Preparation of non-radioactive waste for conventional repository.

The following waste treatments are planned in the PDP 2021 and consequently considered for the present update of the cost calculation:

- Cutting / disassembling
    - Not all dismantled components have the optimum dimensions for treatment and conditioning. The dimensions of the dismantled parts have to fulfill the permissible dimensions for packaging and transportation. Internal surfaces should be accessible for decontamination and measurement equipment.
- Decontamination of components and equipment
    - Decontamination of components and equipment is performed to reduce the quantity (in kg) of radioactive waste. Fractions with contamination that is hard to remove will normally not be decontaminated at all. Fractions with loose contamination will be decontaminated and most of them are expected to be ready for free release after decontamination.

    - Most contamination is linked to the internal surface of the components that have been in contact with radioactive fluids. Another portion is at the external surface of equipment in the controlled area. Such contaminated surfaces are dealt with decontamination techniques such as:

      a) Mechanical decontamination: sandblasting (corundum), steel blasting, grinding, brushing

      b) Wet decontamination: high pressure washing

- Super-compaction
    - Super-compaction is done to reduce the volume of radioactive waste, to get a better filling grade of the waste packages and consequently to reduce the number of required packages. The installation of a mobile super-compactor in the turbine hall is assumed for KCD decommissioning.
- Packaging
    - Radioactive waste will be packed in suitable waste packages. The packages must fulfil the waste acceptance criteria of the destination facility (i.e. COVRA) and additional the requirements for transportation on public roads as well as for shielding of the personnel. Depending on the kind of waste and package an internal basket are used as well as spacers to fix especially pellets from super-compaction.
- Cementation
    - Most types of waste and packages require an immobilization of the material inside the package. The package is filled with liquid concrete to get a monolithic block. Before closing the package, a waiting period for drying and hardening has to be considered.
- Incineration
    - For efficiency reasons combustible waste is super-compacted onsite.
- Liquid waste treatment
    - Liquid waste is collected in a storage tank. The contaminated liquids are transported to COVRA using 60-l drums for further treatment. Non-contaminated liquids are measured and discharged to the river.
- Preparation for decay storage at COVRA
    - Radioactive waste releasable after 50 years decay can be sent to COVRA for storage during this period. The considered components and materials are separated from the waste for final storage and prepared for accurate measurements. The measurements are documented and include the required quality assurance. COVRA delivers appropriate 20 ft. containers for the transport.

For the packaging of the remaining radioactive waste following containers are considered corresponding to the PDP 2021 [1]:

- 90-l drum (press drum for super-compaction)
- 60-l drum (for transport of liquid waste to COVRA)
- 200-l drum
- 400-l drum
- MOSAIK Type II container
- KONRAD Type II container
- 20 ft container (50 years decay storage).

## 2.3 Waste management results

The waste management concept for the PDP 2021 is implemented in CORA. There, the calculation of the waste management results relies on the assignment of the so-called distribution factors to the registered inventory components. A distribution factor indicates the planned treatment of the component concerning waste management aspects (see section 2.2). As it is difficult to consider each component individually concerning its specific properties, a set of distribution factors is often used for several components. So, the percentages of the distribution represent average values and do not need to be applicable to the single component, but to the group.

The considered packages (see section 2.2) are linked with the distribution factor, here with the waste objective. The number of required packages derives from the filling rates of the containers defined in CORA dependent on the waste material, particularly on the density or activity.

Furthermore, the waste management concept implemented in CORA includes the so-called secondary masses. Secondary masses are additional radioactive waste generated during dismantling, decontamination or waste treatment activities, such as protective clothes, gloves, residuals and liquids from decontamination, foils, water from hygienic areas and other consumables. In CORA a percentage surcharge is linked to the components depending on planned dismantling and waste treatment activities. So, the waste management results include slightly higher masses than the total mass of the inventory.

Table 2-2 shows the mass distribution of the KCD inventory according the planned objective without building structures and secondary waste. Table 2-3 provides the masses and packages for final disposal as well as the corresponding storage volume including secondary waste.

**Mass distribution according to planned objective**

| Destination | Mass [Mg]*) | | Percentage |
|---|---|---|---|
| Cleared material<br>(e.g. unrestricted release / reuse / landfill) | | 5.150 | 83% |
| thereof after decontamination | 754 | | |
| COVRA | | 1.082 | 17% |
| thereof release after 50 years decay storage | *396* | | |
| **Total** | | **6.233** | **100%** |

**) Without building structures and secondary waste*

Table 2-2: Mass distribution per objective

**Masses and packages for final repository**

| Container type | Packed mass [Mg] | Number of packages | COVRA volume [m³] | Repository volume [m³] |
|---|---|---|---|---|
| 200-l / 400-l drum | 420 | 2.056 | 1.195 | 1.195 |
| KONRAD Type II | 526 | 96 | 445 | 445 |
| KONRAD Type II / 180mm NC | 16 | 5 | 23 | 23 |
| MOSAIK Type II / 60mm Fe | 6 | 12 | 16 | 16 |
| 20 ft. container (decay storage) | 396 | 30 | 1.138 | |
| **Total** | **1.363** | **2.200** | **2.817** | **1.679** |

Table 2-3: Container type, packed mass, number of containers and storage volumes

# 3 Work breakdown structure (WBS)

## 3.1 General

The WBS includes all activities necessary for the decommissioning project and to reach "green field". These tasks include planning, licensing, preparation, nuclear dismantling, decontamination, clearance, conventional dismantling, waste processing, disposal, and operation tasks. All these tasks are arranged hierarchically and implemented to the NIS database application CALCOM preparing calculations in a bottom up principle.

The following working packages (WPs) represent the first level of the WBS in the PDP 2021 [1].

- WP 01: Pre-decommissioning actions
- WP 02: Licensing procedure
- WP 03: Preparatory work
- WP 04: Dismantling controlled area (contaminated)
- WP 05: Dismantling RPV internals
- WP 06: Dismantling RPV
- WP 07: Dismantling drywell
- WP 08: Dismantling biological shield
- WP 09: Dismantling remaining systems and components (contaminated)
- WP 10: Clearance of building structures
- WP 11: Waste processing, transport, storage and disposal
- WP 12: Conventional demolition
- WP 13: Site restoration and landscaping
- WP 14: Asbestos removal
- WP 15: Project management, engineering and site support
- WP 16: Site security, surveillance and maintenance
- WP 17: Authorities.

## 3.2 Content of the WPs

The content of the WPs is defined by the assignment of several activities. The costs for the WPs and consequently the total decommissioning costs are summed up by bottom-up principle. In following the content of the WPs is summarized to justify the concluding cost assessment in chapter 5.

### 3.2.1 WP 01: Pre-decommissioning actions

WP 01 contains pre- and project planning activities as well as verification of the technical and radiological plant data. Main tasks are the contract placement with the main contractor and the final decommissioning project set-up.

The activities start in due time before the end of safe enclosure period.

### 3.2.2 WP 02: Licensing procedure

WP 02 includes the preparation of the documents required for the application of the licenses for the decommissioning project. Beside the decommissioning license, there are construction and demolition as well as waste water release licenses to be applied for.

It is assumed that licenses are issued in due time and delays are avoided.

### 3.2.3 WP 03: Preparatory work

WP 03 contains tasks of the preparation of the site for the subsequent decommissioning activities. These are the following tasks:

- Installation of new offices in the control and former visitor room
- Installation of mechanical and electrical workshops in the waste building
- Erection of new free release building and entrance buffer
- Modification and installation of new entrance to the controlled area
- Modification and installation of new sanitary area
- Installation of health physics equipment
- Modification / Installation of electrical equipment
- Modification / Installation of ventilation system
- Preparation of waste treatment areas as well as installation of equipment and facilities for decontamination, cutting, super-compaction, immobilization/cementation and free release measurements
- Preparation of transport routes inside the buildings
- Modification of buildings (e.g. enlarging of openings);
- Installation of handling and lifting devices.

Preparatory work on site starts immediately after license approval.

### 3.2.4 WP 04: Dismantling controlled area (contaminated)

WP 04 covers the dismantling of components and equipment in the controlled area (reactor building, waste building, auxiliary building, ventilation building, turbine building). Electrical equipment, ventilation systems and steel construction are dismantled later during WP 09 (see section 3.2.9) as they are still required at first.

Planning and preparation work as well as attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) is included beside the dismantling work itself.

### 3.2.5 WP 05: Dismantling RPV internals

WP 05 covers the removal of the internals of the reactor pressure vessel (RPV). It includes the planning and installation of the remote-controlled dismantling equipment as the dry dismantling from top to bottom. The pieces are packaged in situ into appropriate containers. Attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) are considered.

### 3.2.6 WP 06: Dismantling RPV

WP 06 includes the dismantling, cutting and packaging of the RPV. It is carried out under dry conditions while the drywell internals are dismantled. The RPV is cut from top to bottom in defined rings. Before the RPV rings are cut, the surrounding equipment inside the drywell is removed. The costs for the removal of the drywell components are considered in WP 07 (see section 3.2.7). Attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) are considered.

### 3.2.7 WP 07: Dismantling drywell

WP 07 covers the dismantling of the drywell internals and the drywell wall. It is carried out from top to bottom together with the dismantling of the RPV (see section 3.2.6). Attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) are considered.

### 3.2.8 WP 08: Dismantling biological shield

WP 08 considers the dismantling of the activated part of the biological shield. The non-activated part is demolished conventionally during WP 12 “Conventional demolition (see section 3.2.12). The biological shield is cut in pieces suitable for KONRAD-containers under dry conditions remote controlled. Activation calculations indicate that a separation of steel from concrete is not reasonable. Attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) are considered.

### 3.2.9 WP 09: Dismantling remaining systems and components (contaminated)

WP 09 covers the dismantling of the remaining systems and components after the previous removing of the other contaminated and activated parts of the plant. Corresponding to WP 04 “Dismantling controlled area (contaminated)” (see section 3.2.4) mainly the remaining electrical equipment, ventilation systems and steel constructions are included. According to other WP, attendant measures (supervision, radiation protection, internal transport, accompanying decontamination) are considered.

### 3.2.10 WP 10: Clearance of building structures

The WP 10 includes the decontamination of the building structures after the removal of the suspected radioactive inventory as well as clearance measurements to prove compliance with the release limits. After the official clearance procedures, the respective area and finally the whole site is released from nuclear regulations. Subsequent activities can be carried out conventionally.

### 3.2.11 WP 11: Waste processing, transport, storage and disposal

WP 11 covers the handling and treatment of the dismantled material as well as the conditioning and packaging of the radioactive waste according to the waste management concept referring section 2.2. Furthermore, it contains the costs for the required containers and the corresponding external costs for COVRA.

### 3.2.12 WP 12: Conventional demolition

WP 12 covers the conventional demolition of the KCD buildings, the removal of foundation piles and the external treatment of concrete rubble.

### 3.2.13 WP 13: Site restoration, cleanup and landscaping

WP 13 includes the restoration of the site and the refilling of the pits after the conventional demolition of the buildings. The decommissioning project is completed when achieving “green field“.

### 3.2.14 WP 14: Asbestos removal

WP 14 covers the removal of the asbestos inventory accurately investigated previously. Asbestos is located in contaminated as well as in conventional installations or building structures.

### 3.2.15 WP 15: Project management, engineering and site support

WP 15 covers generally required functions and services regarding management, engineering and site support of the KCD decommissioning project. These are briefly summarized:

- Administration
- Finance and accountancy
- Personnel management
- Technical project management
- Project controlling
- Quality assurance
- Documentation
- Support services, IT, procurement.

### 3.2.16 WP 16: Site security, surveillance and maintenance

WP 16 covers generally required functions and services regarding the operation of the site during decommissioning of the KCD. These are briefly summarized:

- Plant operation
- Operation consumables and utilities
- Radiation protection management
- Maintenance
- Security.

### 3.2.17 WP 17: Authorities

WP 17 contains the expenses for authorities during the decommissioning project. WP 02 “Licensing procedure” includes the licensee costs (see section 3.2.2).

# 4 Time scheduling

The activities described in chapter 3 are arranged in the hierarchical WBS. By combining them under consideration of their dependencies, the duration and the sequence of complete decommissioning project is determined.

The KCD decommissioning project is scheduled in the NIS database application CALCOM for the PDP 2021. Figure 4-1 gives an overview in terms of a time frame determined by the generic sequence of the project described in following.

- At first the planning and licensing has to be performed in order to receive the decommissioning licence as well as other licenses required for the dismantling of the plant.
- In parallel, the planning of the new buildings and new installations starts. The erection of new buildings begins when the decommissioning license is granted.
- Before the dismantling starts the treatment areas and transport routes for the dismantled components are prepared.
- At first, contaminated equipment is removed to get space for the remote-controlled equipment for the dismantling of the activated parts.
- When the remote-controlled equipment is installed, the dismantling of the RPV internals starts immediately followed by the dismantling of the RPV and the internals of the drywell.
- The next step is the dismantling of the biological shield and the remaining systems in the controlled area which are not needed anymore.
- In parallel, the dismantling of the systems in the turbine building and in the rest of the controlled area is performed.
- The dismantled activated parts (e.g. RPV internals and RPV) are packed directly into appropriate containers. The dismantled contaminated components are transported to the new installed treatment area in the turbine building for further treatment, packaging or release after measurements.
- When all installations are removed, the building structure is decontaminated and released for conventional demolition.
- At the end of the project the buildings are demolished and the complete site is restored (including removing of the piles).

The PDP divides the KCD decommissioning project into 5 steps. Table 4-1 provides an overview of the corresponding dates and duration.

**Main milestones / duration steps**

| Milestone / step | Start [Month/year] | End [Month/year] | Duration [Years] |
|---|---|---|---|
| Step 1: Start project to end of SE | 07/2041 | 06/2045 | 4,0 |
| Step 2: to end of preparatory work | 06/2045 | 12/2046 | 1,4 |
| Step 3: to end of biological shield | 12/2046 | 09/2051 | 4,7 |
| Step 4: to building structures cleared | 09/2051 | 09/2053 | 2,0 |
| Step 5: to "green field" | 09/2053 | 05/2055 | 1,6 |
| **Total:** | **07/2041** | **05/2055** | **13,9** |

Table 4-1: Main milestones and step duration

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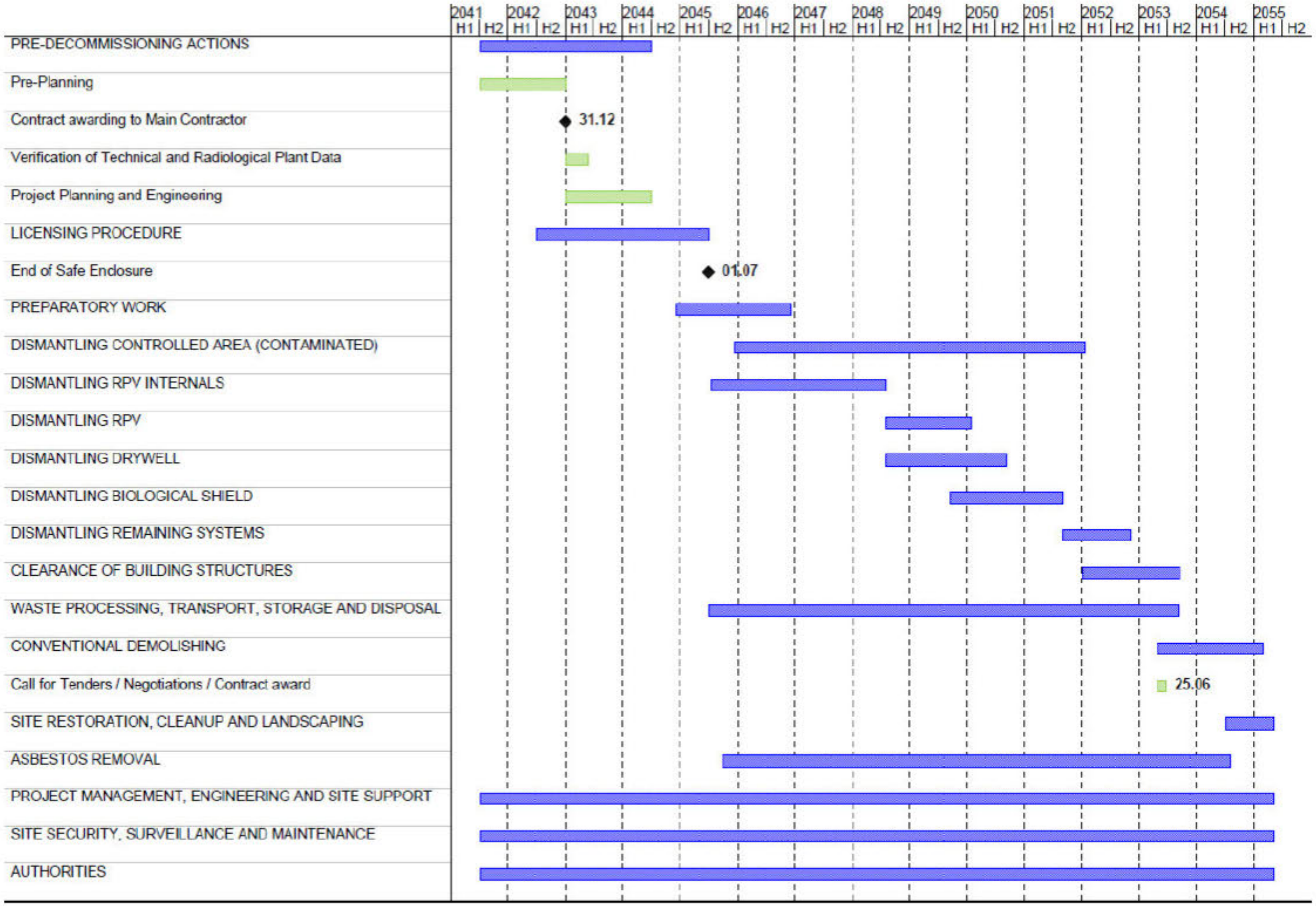
Figure 4-1: KCD decommissioning schedule (overview)



# 5 Cost calculation

Cost factors are assigned to each particular task arranged in the WBS to calculate the decommissioning costs of KCD. For this purpose, several assumptions are made for the PDP 2021 [1] and are implemented into the NIS database application CALCOM. Finally, the cost calculation is carried out in a bottom-up principle.

With reference to the PDP 2021 following updates are implemented into CALCOM to calculate the KCD decommissioning cost update 2023:

- Wages / hourly rates of the staff
- Decommissioning equipment costs
- Container costs
- COVRA fees
- Price escalation of all other cost items to the price level 01/2023.

The following section 5.1 summarizes the assumptions made. Section 5.2 provides the related results of the present study.

## 5.1 Assumptions

The following assumptions are made for the present study:

- The goal of the decontamination and dismantling activities is to reach green field.
- Non-radioactive concrete rubble is reused or sent to a landfill.
- The present study is based on the equipment and materials database developed for KCD (DIS).
- The radiation exposure is kept ALARA. In any case, the radiation exposure per person is limited to 20 mSv per year. This is the current Dutch dose limit for workers occupationally exposed to radiation.
- All materials in the controlled area are supposed as being radioactive, unless measurements indicate that the contamination is below the clearance levels. All materials in the controlled area that cannot be released will be treated as radioactive waste.
- The mass specific clearance levels are those specified in the Dutch radiation protection regulations [3], e.g. 0,1 Bq/g for Co-60, Eu-152 and Eu-154.
- As the Dutch regulations do not contain surface specific clearance levels, those from the German “Strahlenschutzverordnung” (radiation protection ordinance [4]) are considered e.g. 1 Bq/cm² for Co-60, Eu-152 and for Eu-154.
- Price basis of the cost calculation is 01/2023. All costs given are without value added tax.
- The calculation is performed as a best estimate strategy. Risks and contingencies are not included.
- Planning and execution work is performed by two external main contractors (one for the nuclear part and one for the conventional part) each in a frame of a single contract. The staff is assigned to the individual tasks considering the required qualification. The personnel costs are calculated considering hourly rates listed in Table 5-1. The qualifications refer to the PDP 2021. The corresponding rates are updated to price level 01/2023 according to current wages applicable for the Netherlands provided by COVRA.

### Qualification and wages staff

| Qualification | Wages [€/h] |
|---|---|
| **Decommissioning** | |
| Project manager | [redacted] |
| Engineer / on-site manager | |
| Administrator / accountant | |
| HP technician | |
| Foreman | |
| Craftsman | |
| Worker | |
| Security guard (site security) * | |
| **Conventional building demolition** | |
| Planner / work organizer | |
| Foreman | |
| Craftsman | |
| Crane operator | |
| Worker | |

** incl. increases for public holidays, overtime and call after stand by*

Table 5-1: Wages for different staff qualifications

- The costs for containers are shown in Table 5-2. The corresponding COVRA costs including transport and storage provides Table 5-3. Both refer to the PDP 2021 and are updated according to current price lists of the manufacturer and COVRA.

### Empty package costs

| Container type | Costs [€] |
|---|---|
| 90-l Press drum | [redacted] |
| 200-l drum / 400-l drum | |
| KONRAD Type II | |
| KONRAD Type II / 180 mm NC | |
| MOSAIK Type II / 60 mm Fe (Type B (U)) | |
| 20 ft. container (50 years decay storage) | |

*1) COVRA fee table*

*2) Price table German manufacturer*

**) included in COVRA costs*

Table 5-2: Costs for waste packages / containers

### COVRA costs

| Container type | Costs [€] |
|---|---|
| 200-l / 400-l drum, with a surface dose rate <= 0,2 mSv/h | [redacted] |
| MOSAIK-container | |
| KONRAD-container Type II, with a surface dose rate <= 0,2 mSv/h | |
| 20 ft. container (50 years decay storage incl. container) | |

Table 5-3: Costs for transport, interim storage at COVRA and disposal

- The cost calculation includes investment costs for the special equipment listed in Table 5-4. These costs are updated considering gained experiences and planning from current decommissioning projects.

## List of investments

| No. | Description | Costs [€] | Associated WP |
|---|---|---|---|
| 1 | New free release measurement building | [redacted] | 3 |
| 2 | Clearance Measurement Facility incl. other measuring equipment | | 3 |
| 3 | Storage areas / Internal transport equipment (fork lifts, lattice boxes, etc.) | | 3 |
| 4 | Entrance Controlled Area and HP equipment | | 3 |
| 5 | Modification Ventilation system | | 3 |
| 6 | Modification Sewage water treatment (incl. Waste water release line) | | 3 |
| 7 | Modification Hot Shower water treatment | | 3 |
| 8 | Lifting devices (incl. handling ropes of Reactor- and Turbine building crane) | | 3 |
| 9 | Modification electrical installations (incl. cranes) and pressurized air supply | | 3 |
| 10 | Modification / Equipment electr. and mechanical work shops | | 3 |
| 11 | Modification / Equipment offices | | 3 |
| 12 | Modification / Equipment of radiological laboratory | | 3 |
| 13 | Packaging Station (cementation) | | 3 |
| 14 | Decontamination equipment (decontamination area) | | 3 |
| 15 | Cutting devices (Cutting area: band saw, shredder, etc.) | | 3 |
| 16 | Super-compaction station | | 3 |
| 17 | Cutting and Manipulator equipment RPV Internals (incl. Drywell Internals) | | 5 |
| 18 | Cutting and Handling RPV (incl. Drywell) | | 5 |
| 19 | Cutting and Handling Biol. Shield | | 8 |
| 20 | Dismantling equipment (tools, scaffolds, portable filters, tents, etc.) | | 3 |
| 21 | Dismantling equipment for large components (TB) | | 4 |
| 22 | Dismantling equipment for large components (WB) | | 4 |
| 23 | Equipment for building and site decontamination | | 10 |
| | **Total** | | |

Table 5-4: Investment costs

## Specific cost factors

| Factor | Value |
|---|---|
| Consumable costs complex dismantling | [redacted] |
| Consumable costs demolition | |
| Consumable costs regular dismantling | |
| Consumable costs remote controlled dismantling | |
| Consumable costs RPV-Internals remote controlled dismantling | |
| Consumable costs surface abrasion | |
| Consumables Blasting Decontamination | |
| Consumables Cutting | |
| Consumables Immobilization | |
| Consumables Release Measurement | |
| Consumables Shredding | |
| Consumables Super-compaction | |
| Liquid waste treatment at COVRA (Liquid Class II per standard 60-l drum) | |
| Refilling ground | |
| Remove and treatment of ground material (incl. Transport) | |
| Selling Alu scrap | |
| Selling Copper scrap | |
| Selling Lead scrap | |
| Transport and treatment of concrete rubble (conventional) | |
| Transport and treatment of steel (conventional) | |

Table 5-5: Specific cost factors (€/kg, €/m³, etc.)

- Table 5-5 gives an overview of further specific cost factors considered and updated to current price level.
- The costs for plant operation are calculated according the yearly amounts referring Table 5-6 after the end of SE. These cost rates are reduced considering the completion of defined working steps. With regard to the others, these rates refer to the PDP 2021 and are increased to price level 01/2023 according to appropriate price indices provided by Statistics Netherlands (CBS) as well as in accordance to gained experiences and planning from current decommissioning projects.

**Operation and administration costs (non-personnel) after end of SE**

| Factor | Value |
|---|---|
| Authorities | [redacted] |
| Consumable Maintenance (Civil) | [redacted] |
| Consumable Maintenance (Electr.) | [redacted] |
| Consumable Maintenance (Mech.) | [redacted] |
| Consumable Workshop (Mech./Electr./Civil) | [redacted] |
| Education / Staff training | [redacted] |
| Fire Protection Sytems Maintenance | [redacted] |
| Insurance | [redacted] |
| IT Hardware (External contractors) | [redacted] |
| IT Hardware (GKN) | [redacted] |
| IT-Hardware Maintenance (External contractors) | [redacted] |
| IT-Hardware Maintenance (GKN) | [redacted] |
| IT-Software (External contractors) | [redacted] |
| IT-Software (GKN) | [redacted] |
| Laundry (External Service) | [redacted] |
| Mail, Communication (External contractors) | [redacted] |
| Mail, Communication (GKN) | [redacted] |
| Medical Service | [redacted] |
| Office Material (External contractors) | [redacted] |
| Office Material (GKN) | [redacted] |
| Provision Electricity (Assumption: 1 MW/h incl. Heating) | [redacted] |
| Provision Water (Assumption: 2.000 m³/year) | [redacted] |
| Provision Water (Connection to net) | [redacted] |
| Rad. Laboratory | [redacted] |
| Recurring Safety Checks (Electr.) | [redacted] |
| Recurring Safety Checks (Mech.) | [redacted] |

Table 5-6: Specific cost factors [€/year]

- The asbestos inventory in the KCD installations is considered (see section 3.2.14). The related removal costs are updated by a recent COVRA quote considering the expected increase in labor cost for this specialist work and the expected stricter regulations.
- The costs for the decommissioning license are increased according to a current ANVS quote and to a current COVRA quote for the technical support organization [redacted] are considered for regulator supervision till the end of the project.

## 5.2 Results

The total costs of the KCD decommissioning amounts to **269 Million €** according to the price level 01/2023. The costs per WP are given in Table 5-7 and the total costs per year and working package in Table 5-8. Figure 5-1 shows the yearly total costs.

### Costs per working package

| Working package | Costs [k€] |
|---|---|
| 01 PRE-DECOMMISSIONING ACTIONS | [redacted] |
| 02 LICENSING PROCEDURE | [redacted] |
| 03 PREPARATORY WORK | [redacted] |
| 04 DISMANTLING CONTROLLED AREA (CONTAMINATED) | [redacted] |
| 05 DISMANTLING RPV INTERNALS | [redacted] |
| 06 DISMANTLING RPV | [redacted] |
| 07 DISMANTLING DRYWELL | [redacted] |
| 08 DISMANTLING BIOLOGICAL SHIELD | [redacted] |
| 09 DISMANTLING REMAINING SYSTEMS | [redacted] |
| 10 CLEARANCE OF BUILDING STRUCTURES | [redacted] |
| 11 WASTE PROCESSING, TRANSPORT, STORAGE AND DISPOSAL | [redacted] |
| 12 CONVENTIONAL DEMOLISHING | [redacted] |
| 13 SITE RESTORATION, CLEANUP AND LANDSCAPING | [redacted] |
| 14 ASBESTOS REMOVAL | [redacted] |
| 15 PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT | [redacted] |
| 16 SITE SECURITY, SURVEILLANCE AND MAINTENANCE | [redacted] |
| 17 AUTHORITIES | [redacted] |
| **Total** | **269.452** |

Table 5-7: Total costs per WP

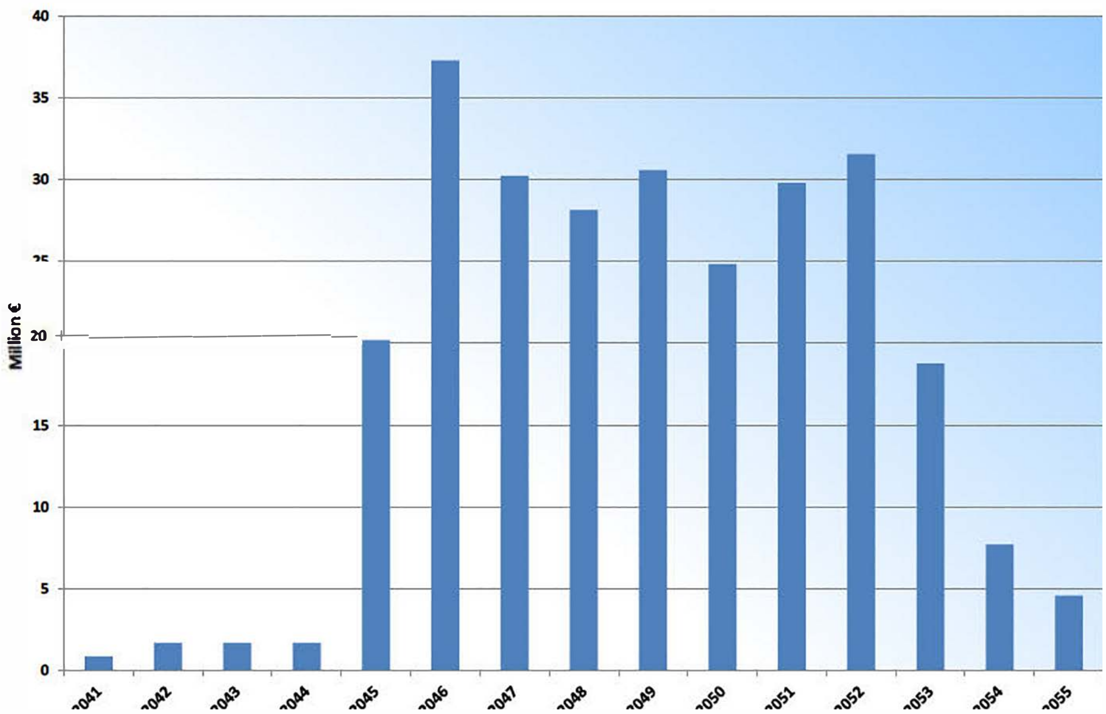



Figure 5-1: Total costs per year

Table 5-8: Total costs per WP and year

## Costs per working package and year

| Working package | Costs [k€] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sum | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 |
| 01 PRE-DECOMMISSIONING ACTIONS | [redacted] | | | | | | | | | | | | | | | |
| 02 LICENSING PROCEDURE | | | | | | | | | | | | | | | | |
| 03 PREPARATORY WORK | | | | | | | | | | | | | | | | |
| 04 DISMANTLING CONTROLLED AREA (CONTAMINATED) | | | | | | | | | | | | | | | | |
| 05 DISMANTLING RPV INTERNALS | | | | | | | | | | | | | | | | |
| 06 DISMANTLING RPV | | | | | | | | | | | | | | | | |
| 07 DISMANTLING DRYWELL | | | | | | | | | | | | | | | | |
| 08 DISMANTLING BIOLOGICAL SHIELD | | | | | | | | | | | | | | | | |
| 09 DISMANTLING REMAINING SYSTEMS | | | | | | | | | | | | | | | | |
| 10 CLEARANCE OF BUILDING STRUCTURES | | | | | | | | | | | | | | | | |
| 11 WASTE PROCESSING, TRANSPORT, STORAGE AND DISPOSAL | | | | | | | | | | | | | | | | |
| 12 CONVENTIONAL DEMOLISHING | | | | | | | | | | | | | | | | |
| 13 SITE RESTORATION, CLEANUP AND LANDSCAPING | | | | | | | | | | | | | | | | |
| 14 ASBESTOS REMOVAL | | | | | | | | | | | | | | | | |
| 15 PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT | | | | | | | | | | | | | | | | |
| 16 SITE SECURITY, SURVEILLANCE AND MAINTENANCE | | | | | | | | | | | | | | | | |
| 17 AUTHORITIES | | | | | | | | | | | | | | | | |
| **Total (nominal costs price level 01/2023)** | **269.452** | [redacted] | | | | | | | | | | | | | | |

# 6 Uncertainties

The cost calculation for a decommissioning project over some decades in future depends on certain assumptions defined in section 5.1. Obviously, every assumption contains an uncertainty impacting the results.

## 6.1 Overview

The costs for the KCD decommissioning are calculated according to "best engineering judgement" without contingencies for future risks or uncertainties representing best estimate or likely costs respectively. However, it is recognized that several uncertainties remain, i.e.:

- Physical inventory
- Radiological inventory
- Project duration
- Manpower requirements
- Dismantling efficiency
- Price escalation, wages, external services and provisions
- Decontamination and release of building structures.

### 6.1.1 Physical inventory

The inventory registration is certainly subject to tolerances. For the registered masses of the main components (e.g. parts of the RPV and the internals) about +/- 10% are expected. For other groups of components seem to be higher ranges. The masses of activated parts refer to activation calculations and were verified by sampling. However, deviations have to be considered.

The masses of the main components are derived from original drawings. So, only minor deviations should be expected.

The activation calculation of the biological shield was followed-up by a huge sampling program. However, there remains the uncertainty of some scatters particularly in the drywell influencing the activated mass. The deviation of the mass of the biological shield itself should be lower as it was derived from drawings.

Concerning contaminated systems and equipment the DIS completely provides information on contamination in the systems including the corresponding masses. The DIS was developed by a group of physicists and health physicists supported by lab technicians performing the gamma spectroscopy.

Building masses as well as masses of stairs, platforms and other structures are derived from original drawings. Therefore, the uncertainty seems to be less.

The possible deviation of inventory masses affects the amount of waste, repository volume and the related costs consequently.

### 6.1.2 Radiological inventory

The amount of radioactive waste relies on the assumed distribution according to the waste management concept. An increase of activation due to an updated calculation could be considered by containers with additional shielding. A reduction could be considered by increasing the load of the planned number of containers.

An increase of components for release decreases the number of required containers and vice versa.

### 6.1.3 Project duration

The duration of the decommissioning and dismantling project will be affected by some optimization opportunities but also by several risks for delay, e.g.:

- Availability of licenses
- Required equipment e.g. for remote-controlled dismantling is not ready for use in time
- Longer periods for maintenance and repair of the equipment
- Occurrence of further unexpected technical problems.

Time extensions lead to cost increases especially in operation, administration, maintenance and project management tasks.

### 6.1.4 Manpower requirements

The decommissioning project is divided in several tasks. To calculate the costs, the personnel is linked to each task considering the required qualification. The amount of required personnel of staff can have a tolerance affecting project duration and costs consequently.

### 6.1.5 Dismantling efficiency

With respect to the cost, all participants in the decommissioning projects are interested in optimizing the working efficiency. This concerns dismantling and decontamination efficiency, as well as operation and administration tasks to be optimized. An increasing efficiency reduces the decommissioning costs.

### 6.1.6 Price escalation, wages, external services and provisions

Generally, personnel costs represent the biggest part of the total decommissioning costs. These costs depend on the estimated amount of work, the related qualifications and the corresponding wages or hourly rates. The corresponding rates are updated to price level 01/2023 according to current wages applicable for the Netherlands provided by COVRA.

The costs for external services and provisions are update according to gained experiences and planning from current decommissioning projects. However, significant differences in supply prices are observed.

### 6.1.7 COVRA costs

The COVRA costs are calculated by multiplication of the estimated radioactive waste [kg] and the current mass specific COVRA fee [€/kg]. For the considered COVRA fee [€/kg] there are chances for lower fees per kg as well as risks for higher fees per kg.

As the considered COVRA fees [€/kg] rely on current costs considering a relative low level of waste packages in comparison to decommissioning periods, a reduction of the COVRA fee [€/kg] due to a depression of the fix costs seems to be feasible.

However, there remains a high uncertainty in COVRA costs as they include disposal expenditures for much later decades.

### 6.1.8 Decontamination and release of building structures

In Germany, an increase in efforts for the decontamination of the concrete surfaces and for the following release procedure has been recognized in recent years. Although this aspect is considered in that working field, an uncertainty for additional working expenditures remains. It cannot be ruled out that at some location radioactivity has penetrated deeper into the building structure due to cracks as assumed.

## 6.2 Calculation of estimating uncertainty

It is obvious that uncertainties need to be considered in decommissioning projects. Additionally, the corresponding cost estimates should reflect the potential impact in financial terms. In 2017 OECD/NEA published a guideline addressing uncertainties in cost estimates for the decommissioning of nuclear facilities [2]. According to this report an uncertainty calculation in financial terms is established within the decommissioning project scope defined and presented in the previous chapters and sections. It follows the recommendation in the mentioned guideline [2].

The uncertainty is determined on the basis of the so called “likely costs” corresponding to the results presented in Table 5-7. The estimating uncertainty is calculated by using a probabilistic Monte Carlo analysis tool (Oracle Crystal Ball). The triangular distribution is applied as probability distribution. The required minimum and maximum values are defined by the expected accuracy range (variation in below and above ranges).

The selection of these ranges relies on the uncertainty classification model provided by the Association for the Advancement of Cost Engineering International (AACEI) presented in Table 6-1. For the estimate of the 17 WPs class 4 is selected. Depending on gained experiences as well as on confidence to current decommissioning planning the ranges are adjusted within the limits of this estimate class.

Table 6-2 shows the input data for the estimating uncertainty analysis.

**AACEI uncertainty classification**

| Estimate class | End usage / typcial purpose of estimate | Methodology / typical estimating method | Expected accuracy range low | | Expected accuracy range high | |
|---|---|---|---|---|---|---|
| Class 5 | Concept screening | Capacity factored, parametric models, judgement or analogy | -20% | -50% | 30% | 100% |
| Class 4 | Study or fes bility study | Equipment factored or parametric models | -15% | -30% | 20% | 50% |
| Class 3 | Budget authorization or control | Semi detailed unit costs with assembly level line items | -10% | -20% | 10% | 30% |
| Class 2 | Control or bid/tender | Detailed unit cost with forced detailed take-off | -5% | -15% | 5% | 20% |
| Class 1 | Check estimate or bid/tender | Detailed unit costs with detailed take-off | -3% | -10% | 3% | 15% |

Table 6-1: AACEI uncertainty classification

## Estimating uncertainty input data

| Working package | Best estimate / likely costs [k€] | % below | % above |
|---|---|---|---|
| 01 PRE-DECOMMISSIONING ACTIONS | [redacted] | -20% | 30% |
| 02 LICENSING PROCEDURE | | -15% | 20% |
| 03 PREPARATORY WORK | | -25% | 25% |
| 04 DISMANTLING CONTROLLED AREA (CONTAMINATED) | | -30% | 30% |
| 05 DISMANTLING RPV INTERNALS | | -25% | 25% |
| 06 DISMANTLING RPV | | -25% | 25% |
| 07 DISMANTLING DRYWELL | | -25% | 25% |
| 08 DISMANTLING BIOLOGICAL SHIELD | | -25% | 25% |
| 09 DISMANTLING REMAINING SYSTEMS | | -30% | 30% |
| 10 CLEARANCE OF BUILDING STRUCTURES | | -25% | 25% |
| 11 WASTE PROCESSING, TRANSPORT, STORAGE AND DISPOSAL | | -20% | 50% |
| 12 CONVENTIONAL DEMOLISHING | | -20% | 30% |
| 13 SITE RESTORATION, CLEANUP AND LANDSCAPING | | -15% | 20% |
| 14 ASBESTOS REMOVAL | | -15% | 20% |
| 15 PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT | | -15% | 30% |
| 16 SITE SECURITY, SURVEILLANCE AND MAINTENANCE | | -15% | 30% |
| 17 AUTHORITIES | | -15% | 20% |
| **Total** | **269.452** | | |

Table 6-2: Estimating uncertainty input data

Running the Monte Carlo analysis yields the following output:

- Probability distribution (Figure 6-1)
- Cumulative probability distribution (Figure 6-2)
- Accompanying statistical data (Table 6-3).

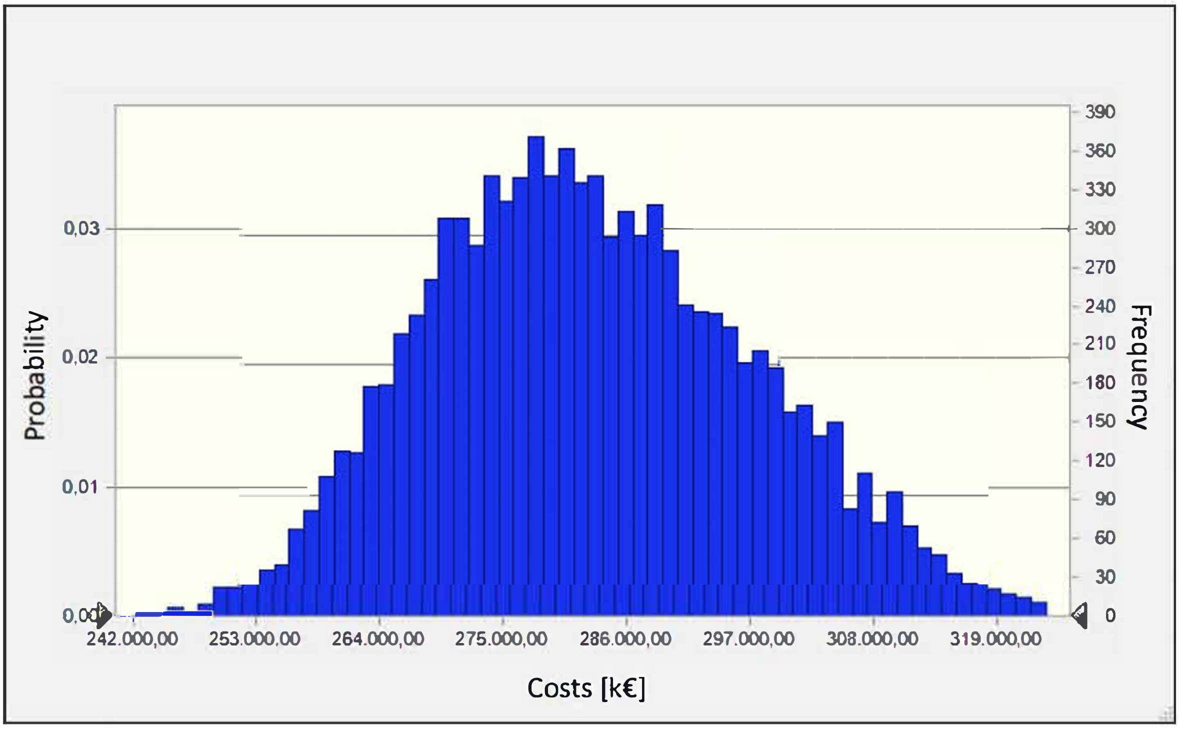



Figure 6-1: Probability distribution / frequency scale

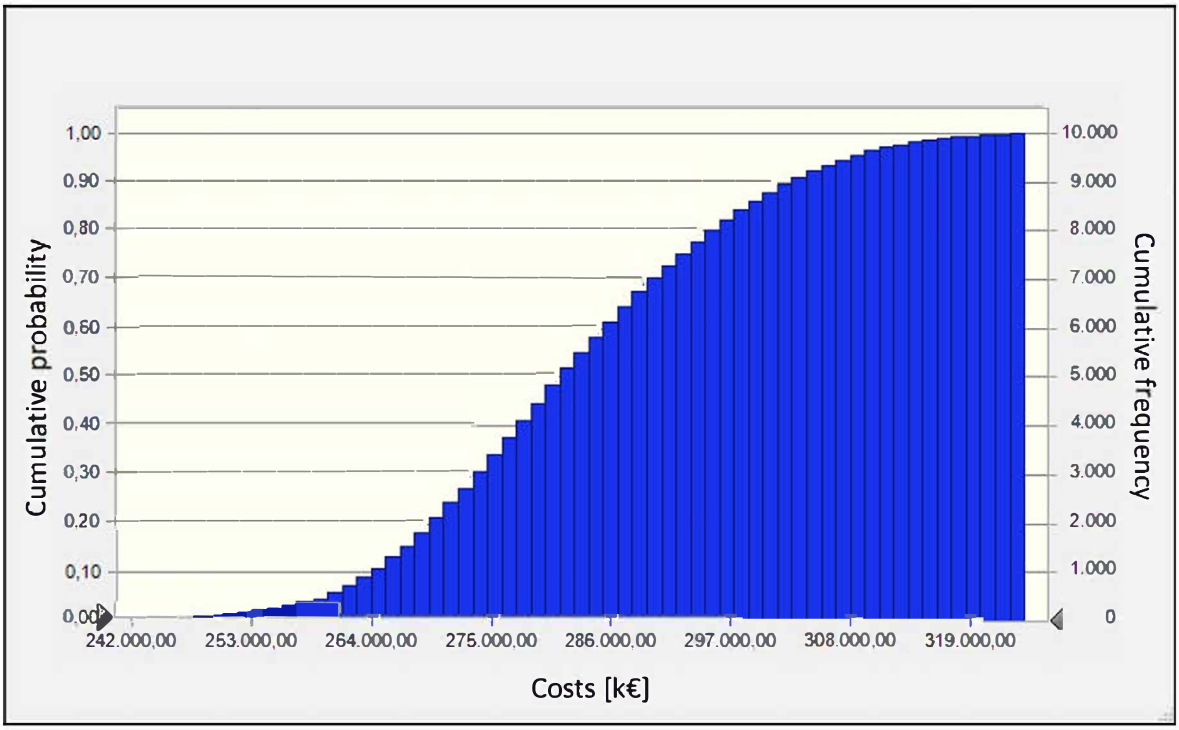



Figure 6-2: Cumulative probability / frequency scale

### Basic statistics for estimating uncertainty

| Item | Value |
|---|---|
| Lowest cost [k€] | 242.423 |
| Highest cost [k€] | 333.793 |
| Standard deviation [k€] | 14.554 |
| Iteration runs [numbers] | 10.000 |
| Median cost [k€] | 281.539 |
| Mean cost [k€] | 282.627 |

Table 6-3: Statistical data

Table 6-4 indicates the required contingency for the estimating uncertainty depending on the selected confidence level.

### Required contingency

| Confidence level | Value [k€] | Add on best estimate / likely costs |
|---|---|---|
| 0% | 242.423 | -10,0% |
| 10% | 264.347 | -1,9% |
| 20% | 269.743 | 0,1% |
| 30% | 273.952 | 1,7% |
| 40% | 277.821 | 3,1% |
| 50% | 281.539 | 4,5% |
| 60% | 285.685 | 6,0% |
| 70% | 289.964 | 7,6% |
| 80% | 295.497 | 9,7% |
| 90% | 302.758 | 12,4% |
| 100% | 333.793 | 23,9% |

Table 6-4: Required contingency

## Referenced documents

[1] GKN Dodewaard - Decommissioning Cost Estimate 2021, Task: Deferred Scenario, Starting date of decommissioning 2045, Clearance levels: KEW, Siempelkamp NIS, 2021.

[2] NEA No. 7344 - Addressing Uncertainties in Cost Estimates for Decommissioning Nuclear Facilities, OECD, 2017.

[3] Besluit basisveiligheidsnormen stralingsbescherming; 2018.

[4] German radiation protection ordinance (Verordnung über den Schutz vor Schäden durch ionisierende Strahlen, Strahlenschutzverordnung - StrlSchV), 29.11.2018.