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## Executive summary

The present report describes the Decommissioning Program (DP) rev.3 for the NPP Krško according to the decommissioning strategy “Immediate Dismantling” after a final shut down in 2043. It contains the operation of the spent fuel dry storage (SFDS) and its decommissioning as well as the successive conventional demolition of the other remaining buildings. Two cases are taken into account. The base case considers an operation of the SFDS till 2103, the sensitivity case till 2075.

Concerning the SFDS DP rev. 3 provides costs related to construction and operation of this facility until the end of NEK operation. This includes the relocation of 1,184 fuel assemblies in 16 containers. All later costs after 2043 related to the SFDS, like spent fuel movement (additional approx. 1,098 fuel assemblies in 30 canisters shall be moved in 2048 – 2051), operation of the SFDS after 2043 and decommissioning are costs related to the RW and SF disposal program. The total number of spent fuel elements to be stored in the SFDS is 2,282 (1,184 until 2028 and 1,098 after 2043).

Based on existing Slovenian-Croatian bilateral agreement [1] and conclusions from 10th Meeting of Intergovernmental Commission held in July 2015 [2], SFDS facility can only be operated at NPP Krško site under domain of NEK until the end of NPP operation (year 2043, for the storage of Slovenian and Croatian part of spent fuel). Further operation of SFDS at NPP Krško site is subject of additional negotiation and potential further agreement between Slovenian and Croatian government.

The results are based on the 6th Revision of the Preliminary Decommissioning Plan NPP Krško [3].

Table 0-1 shows the total masses considered in the present study. The data were revised and updated especially regarding new erected buildings and buildings in planning.

### Physical inventory of the Krško NPP

| Component type | Controlled area [Mg] | Monitored area [Mg] | Area inside fence [Mg] | NPP Krško [Mg] |
|---|---|---|---|---|
| Building structure | 147,527 | 155,593 | 128,289 | **431,409** |
| Concrete in containment | 7,000 | | | **7,000** |
| Biological shield | 1,600 | | | **1,600** |
| Equipment | 8,080 | 9,527 | 4,460 | **22,067** |
| **Total** | **164,207** | **165,120** | **132,749** | **462,075** |

Table 0-1: Physical inventory of the NPP Krško

The review of the radiological evaluation and the waste management approaches leads to the masses per disposal route shown in Table 0-2 considering the updated inventory and secondary masses. It is assumed, that the immobilization will be done by cementation in a new building to be erected on the Krško NPP site. The costs for this building and the cementation are not included in the DP, as they are part of the waste disposal program [4].

### Primary and secondary waste masses related to the disposal route

| Disposal route<br>[Disposal objective + Treatment process] | NPP Krško<br>[Mg] |
|---|---|
| Disposal HLW Repository + No Treatment | 140.0 |
| Disposal LILW Repository + No Treatment | 3,179.4 |
| Disposal LILW Repository + Super compaction | 57.7 |
| Disposal LILW Repository + Evaporation | 2,820.6 |
| External treatment + Melting | 351.1 |
| External treatment + Combustion | 171.4 |
| Conventional Waste (Landfill) + No Treatment | 444,089.2 |
| Release + Mechanical Decontamination | 970.0 |
| Release + Wet Decontamination | 1,022.7 |
| Release + No Treatment | 13,639.3 |
| **Total** | **466,441.5** |

Table 0-2: Primary and secondary waste masses related to the disposal routes

NOTE: The given masses for secondary waste are masses before treatment, i.e. the radioactive waste masses for packaging are lower after treatment (see chapter 2.7). For example: liquids vs. concentrates (4.9 Mg waste); combustible material vs. ashes (8.6 Mg waste). The given primary mass for melting leads to 17.6 Mg radioactive waste (slugs and filters) and this waste is included in the mass of “Disposal LILW Repository + Super compaction”.

The masses of LILW are packaged in N2d containers (50 % of the mass) and RCC (50 % of the mass).

The number of required repository packages and the resulting repository volumes are shown in Table 0-3:

### Waste masses and waste packages for final repository

| Type of package | Packed mass [Mg] | Number of packages [-] | Repository volume [m³] |
|---|---|---|---|
| **Total:** | | | |
| N2d container | 1,625 | 205 | 2,517 |
| Holtec HI-SAFE cask | 140 | 7 | 237 |
| RCC | 1,625 | 537 | 2,636 |
| **Total:** | **3,391** | **748** | **5,390** |

Table 0-3: Waste and packages for final repository (N2d container and RCC (each type contains 50% of radioactive LILW mass)

In addition, Attachment 1 shows the results if only N2d container and the Attachment 2 if only RCC would be considered.

The revision of the planning of the Krško D&D project results to the following main milestones:

**Main milestones D&D project Krško NPP**

| | Base case | Sensitivity case |
|---|---|---|
| Start of project (Pre-decommissioning actions) | 07/2040 | |
| Final shut down / D&D approval | 12/2043 | |
| Old SG dismantled and packed | 12/2045 | |
| Finalisation primary loop | 07/2047 | |
| Finalisation RPV internals | 06/2049 | |
| Finalisation RPV | 03/2051 | |
| Finalisation biological shield | 10/2052 | |
| Building structures cleared (Brown field) | 02/2058 | |
| End of operation SFDS | 01/2103 | 01/2075 |
| Green field | 07/2107 | 07/2079 |

Table 0-4: Main milestones for the decommissioning project

<u>NOTE:</u> Different scenarios for the SFDS operation were chosen based on [5]. This deviation from [6] and the national programmes in the Republic of Croatia and in the Republic of Slovenia was endorsed by KO MDK [7]. Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.

The evaluation and assessment of the Krško NPP D&D project concerning required manpower and costs leads to the results shown in Table 0-5.

The costs are given on price level 2018.

**Overview costs and man-power**

| NPP Krško | Costs without VAT [Million €] | Costs incl. VAT [Million €] | Manpower [Man-year] |
|---|---|---|---|
| Base case (2103) | 417.6 | 474.0 | 5,811 |
| Sensitivity case (2075) | 405.3 | 461.4 | 5,446 |

Table 0-5: Calculated costs and manpower

## Abbreviations

| | |
|---|---|
| ALARA | As low as reasonably achievable |
| CALCOM | Calculation and cost management |
| CORA | Component registration and analysis |
| D&D | Decontamination and decommissioning |
| DP | Decommissioning program |
| FSD | Full system decontamination |
| HEP | Hrvatska elektroprivreda |
| HLW / HLRW | High level radioactive waste |
| IAEA | International atomic energy agency |
| LILW / LILRW | Low and intermediate level radioactive waste |
| MCNP | Monte Carlo N-particle transport code |
| NEK | Nuklearna elektrarna Krško |
| NIS | Siempelkamp NIS Ingenieurgesellschaft mbH |
| NPP | Nuclear power plant |
| NPV | Net present value |
| OWA | Operational waste |
| PDP | Preliminary decommissioning plan |
| POP | Post operational phase |
| PWR | Pressurised water reactor |
| QA | Quality assurance |
| R&D | Research & development |
| RCC | Reinforced concrete container |
| RPV | Reactor pressure vessel |
| SF | Spent fuel |
| SFDS | Spent fuel dry storage |
| SG | Steam generator |
| TTC | Tube type container |
| VAT | Value added tax |
| WBS | Work breakdown structure |

# 1. Introduction

The Krško NPP, a pressurised water reactor (PWR) with a net electric capacity of 696 MWe, is operated by Nuklearna elektrarna Krško (NEK) in Vrbina in the Municipality of Krško, Slovenia. The plant was connected to the power grid in October 1981 and went into commercial operation in January 1983. The final shutdown of the plant is planned in 2043 pending the successful conclusion of periodic safety reviews in 2023 and 2033. The operating company NEK is co-owned by the Slovenian state-owned company GEN-Energija and the Croatian state-owned company Hrvatska elektroprivreda (HEP).

The initial Krško NPP Decommissioning Program (DP) was developed in 1996 [8]. The first joint iteration of the Slovenian-Croatian Program of NPP Krško Decommissioning and Spent Fuel (SF) and Low and Intermediate Level Waste (LILW) disposal [9] was prepared in 2003/2004, as required by the paragraph 10 of the Agreement between the governments of Slovenia and Croatia on the status and other legal issues related to investment, exploitation, and decommissioning of the Nuclear power plant Krško [1]. The DP was adopted by Government of Republic of Slovenia and by Parliament of Republic of Croatia in 2004 according to the Agreement and a new revision has to be elaborated in a 5 years period which will include development of new findings in the area.

During the 2008-2011 period, the Second revision of the Krško NPP Decommissioning Program and the LILW and SF Disposal Program was being prepared, for which purpose a set of technical documents was prepared, including the PDP rev. 5 [10]. Since circumstances changed considerably since the Terms of References (ToR) for the second revision was prepared, the IC (Intergovernmental Commission for monitoring the implementation of bilateral agreement) decided on its 10$^{th}$ session held on July 20, 2015 to suspend all activities related to the second revision and ordered the drafting of ToR for the Third Revision of the Krško NPP Decommissioning Program (see [6]).

The aim of periodic revisions of the DP is to revise, implement new international standards and use to best practices through the period of plant operation. These revisions are needed to provide estimation for expenses of the future decommissioning, radioactive waste and spent fuel management and will represent the bases for decommissioning funds in Slovenia and Croatia. All studies done in past used boundary condition with NEK operation until 2023 (originally planned plant life time). NEK extended lifetime for another 20 year in 2012 which means that all studies will take in to account this extended lifetime until 2043.

The revision of the DP and the Preliminary Decommissioning Plan (PDP) [3] for Krško NPP is obligation under bilateral agreement between the Croatian and the Slovenian government. In 2017 the IC concluded to start this revision coordinated by NEK with the aim of implementing new international standards and gained experiences of the past years concerning nuclear decommissioning issues. In 2018 NEK charges NIS to perform the revisions.

The present DP is a revision of the DP rev.2 and starts with a description of the facility and the presentation of the revised physical inventory in chapter 2. Chapter 4 contains the description of the decommissioning and dismantling techniques as well as the planned decommissioning activities. The following chapter 7 contains the waste management including the treatment of material and the packaging of the radioactive waste. For the purpose of the present study it is considered that 50 % of the LILW is disposed in N2d container and the other 50 % is disposed in RCC. In Attachment 1 and 2 the results are shown if 100 % of the LILW is disposed in N2d container or RCC, respectively.

The planning and the cost estimation use a so called “work breakdown structure” (WBS), which is described in chapter 4.3. The basic assumptions and the results of the estimations are summarised in chapter 15.

Additionally, Attachment 3 provides different options for cementation (packaging). The option with the lowest costs for the disposal of 50% of LILW in N2d containers and the other 50% in RCC is taken into account for the waste management strategy. The decommissioning costs and the DP do not include the costs provided in this attachment as they are part of the waste disposal program [4].

Finally, Attachment 4 shows the results taking into account the expected 6,100 Mg of operational waste at the end of the life time of NPP Krško in 2043.

# 2. Description of facility

## 2.1. General description of the Krško NPP

The Krško Nuclear Power Plant (Krško NPP) is located on the left bank of the Sava River in the industrial zone of Krško town. The access to the plant is provided by means of the industrial road linked to the regional road Krško – Brežice. The plant also has an industrial railway line, which connects it with the Krško railway station.

All principle structures of the NPP are located on a solid reinforced concrete platform, which is situated upon the Pliocene sandy-clay sediments of the Krško basin. The platform of the Krško basin forms solid and seismically safe foundation. The structures are designed and constructed to resist anticipated earthquakes in this area free from major damages.

The reactor building, where the reactor coolant system and safety systems are installed, consists of the inner cylindrical steel shell and the outer reinforced concrete shielding building. The containment airlock is equipped with sealed passage chamber with double doors. Numerous piping and cable penetrations are double sealed. Adjacent to the reactor component cooling building, fuel handling building, diesel generator building and turbine building are located (see Figure 2-1 and Figure 2-3).

Cooling water and essential service water intake structures are located on the Sava River bank above the Sava river dam, which maintains adequate water level. Cooling water discharge structure is below the Sava river dam. In addition, Cooling towers of a draft multi-cell type are provided for cooling circulating water in case of low water flow in the Sava River.

The spent fuel will be stored in a dry storage facility located on the west side of the reactor building. The spent fuel dry storage building (SFDS) will be a concrete-metal construction and will provide weather and flood protection to containers. Cooling will be enabled by natural circulation. The building will have openings on the walls for air natural circulation.

The waste manipulation building is located on the west side of the reactor building. It is a concrete-metal construction and contains several waste treatment facilities.

The bunkered buildings are located on the south-west side of the reactor building close to the Sava River serving as emergency cooling systems.

Solid waste storage is located on the south-western side of the plant; administration building with workshops and the switchyard are located on the north side, at the plant entrance.

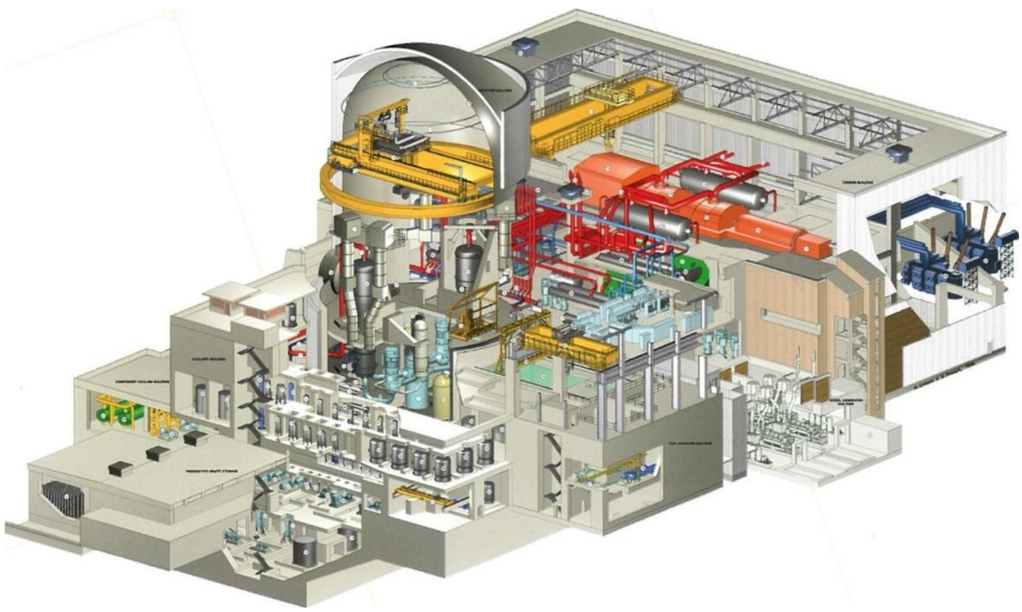


Figure 2-1: Schematic cross-section of the plant

The reactor building contains the Westinghouse pressurized water reactor with two cooling loops consisting of the reactor vessel with its internals and head, two steam generators, two reactor coolant pumps, pressurizer, piping, valves, and of reactor auxiliary systems. During operation

- Demineralised water serves as reactor coolant, neutron moderator and for dilution of boric acid solution;
- In the steam generator the reactor coolant gives up its heat to the feedwater on the secondary side of the steam generator to generate steam;
- Reactor coolant pressure is maintained by the pressuriser, which is supported by electric heaters and water sprays, which are supplied with water from the cold leg of the reactor coolant.

Double-flow high-pressure turbine, generator, condensers, condensate pumps, low pressure heater, feed water pump and high pressure feedwater heater are located in the turbine hall.

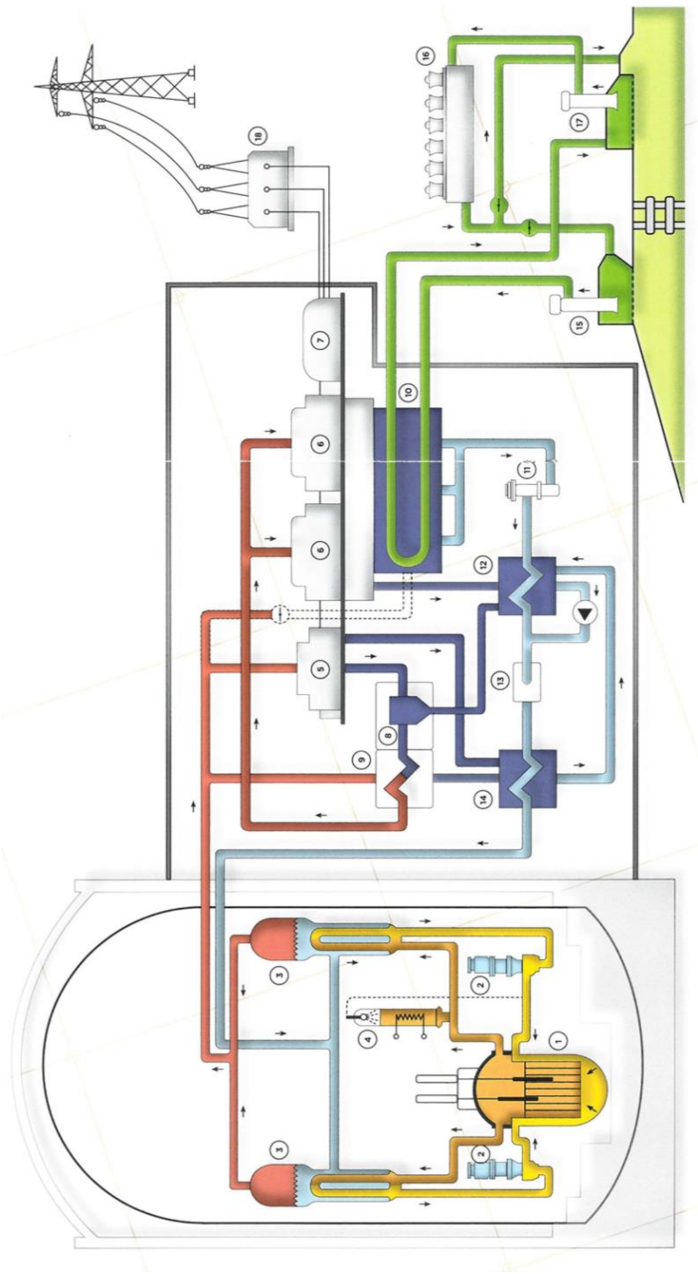
A functional diagram of the plant is shown in Figure 2-2.

During the NPP operation gaseous, liquid and solid wastes are produced. The plant is provided with the gaseous waste processing system which consists of two parallel closed loops with compressors and catalytic hydrogen recombiners and six decay tanks for compressed fission gases. Four of the tanks are used during normal plant operation, while the remaining two are used during reactor shutdown. The capacity of the tanks is adequate for more than one-month gaseous waste hold-up. Within this period the majority of the short-lived fission gases decay, while the remaining gases are released into the atmosphere under favourable meteorological conditions. Automatic radiation monitors in the ventilation duct prevent uncontrolled release when the radioactive gas concentration exceeds the permissible level.

Liquid radioactive wastes are purified in the liquid waste treatment facilities consisting of tanks, pumps, filters, the evaporator, and two demineralizers. The blow-down water from the steam generators is purified separately. The radioactivity of the water discharged into the Sava River is considerably below the maximum permissible concentration.

All solid radioactive wastes, generated during the plant operation, maintenance activities and servicing are collected in the solid waste storage. Used ion exchangers, evaporator concentrates, used filters, and other contaminated solid wastes, as paper, towels, working clothes, laboratory equipment, and various tools are major solid wastes. Solid wastes are compressed and encapsulated into steel casks. The steel casks are temporarily kept in the solid waste storage within the plant area.

The different waste treatment facilities and storage areas will also be used during decommissioning as far as possible.



1. Reactor
2. Reactor coolant pumps
3. Steam generators
4. Pressurizer
5. High pressure turbine
6. Low pressure turbine
7. Generator
8. Moisture separator
9. Reheater
10. Condenser
11. Condensate pumps
12. Low pressure heater
13. Feedwater pump
14. High pressure feedwater heater
15. Circulating water pumps
16. Mechanical draft multi-cell cooling towers
17. Cooling tower circulating pumps
18. Transformer

Figure 2-2: Functional diagram of the plant

## 2.2. Inventory specification

The technical and radiological inventory of the NPP Krško is the most important input for the planning work described in the DP and the decommissioning cost estimation. An overview of the expected radiological conditions of the plant at the beginning of decommissioning is given in chapter 14.

The inventory specification was realized by collection and evaluation of the needed information from different sources, mainly provided by NEK, and completed by NIS experiences. The results are stored in the NIS database CORA for further data use.

In 2009 NEK provided several databases and information in reports; e.g. the NEK operational database. With the help of these data NIS established a database containing the relevant records for decommissioning purposes and to perform the Krško PDP rev.5 [10]. As not all information needed for the decommissioning planning and costing work were given by the NEK information, NIS added about 8,000 records based on their experiences for completion. These data may not be relevant for the operation of a NPP, but for the decommissioning procedure. Also the masses of the most components were acquired by NIS. The missing information was related mainly to:

- Steel girder constructions
- Ventilation stacks
- Pipes and pipe supports
- Concrete and reinforcement of the buildings
- Biological shield
- Lubrication
- Insulation
- “Small Parts” (e.g. electrical, technical and auxiliary equipment, …)

Now, the data are revised and updated especially regarding new erected buildings and buildings in planning.

Finally, the database CORA contains all the collected data and allows reports for the analysis and evaluation of the Krško inventory.

## 2.3. CORA database

The NIS database CORA (Component Registration and Analysis) is developed for the collection, analysis and evaluation of plant specific data for decommissioning purposes, especially for the determination of technical and radiological inventory data, i.e. room data, radiological inventory, waste processing data, and waste packaging data. CORA is developed on the platform of the Microsoft product MS-ACCESS.

Based on the technical and the radiological data of the plant inventory CORA calculates the needed waste management data, containing:

- Material distribution – radioactive waste, reusable non-radioactive material (also after decontamination)
- Packaging data – numbers and types of needed waste containers
- Calculation of the needed repository volume
- Calculation of the expected secondary waste during the decommissioning period
- Balances of the radioactive inventory
- Collection of room data (surfaces, contamination, properties of surfaces)

CORA calculates the expected amount of secondary waste depending on the mass of the existing component in two ways:

- Secondary waste generated during the dismantling work: clothes, gloves, foils, cleaning material, joint material
- Secondary waste generated during the treatment of components: decontamination, melting, incineration

## 2.4. Results of the inventory data collection

### 2.4.1. Technical inventory

The CORA database is filled with about 32,740 data records. These components carry information about their location (building, room) as well as additional information about their specification, material, geometry, type of component, and others.

The collected information result in a total mass for NPP Krško of about **462,075 Mg** that are spread over the site of NPP Krško, excluding the existing operational waste.

For a first grouping of the components, the different areas of the NPP Krško are used:

- Controlled area (marked red)
- Monitored area (marked orange)
- Area inside fence (marked green)

The following figure shows these different areas in a layout drawing related to the NPP Krško site.

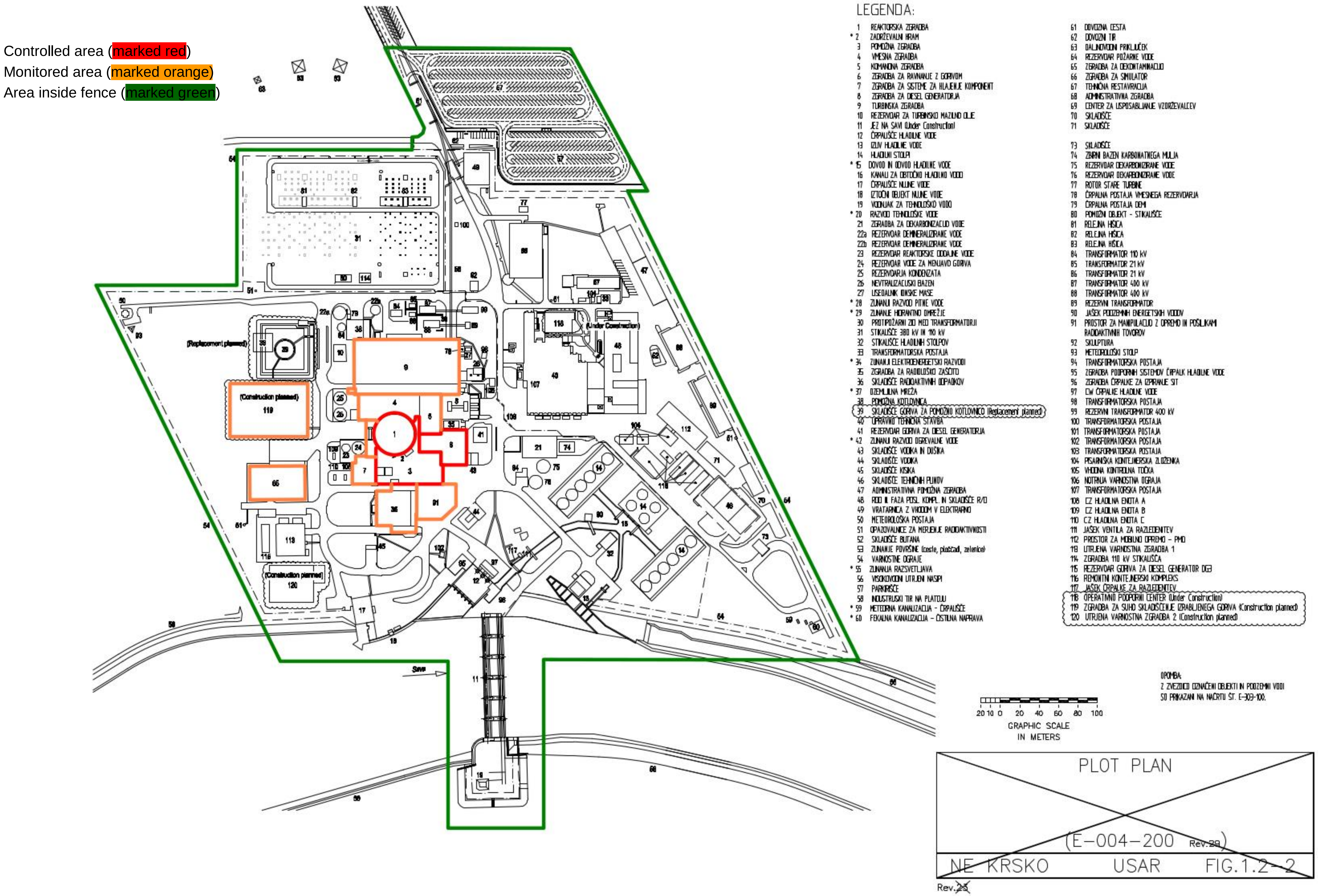



Figure 2-3: Areas of the NPP Krško (site drawing dated 07.12.2016)

The masses of components and buildings related to the different areas of the NPP Krško are given in the following table. They are separated, for better understanding, by component type for each of the areas.

## Physical inventory per type of component and area

| Component type | Controlled area [Mg] | Monitored area [Mg] | Area inside fence [Mg] | NPP Krško [Mg] |
|---|---|---|---|---|
| AIR DUCTS | 289.98 | 172.48 | 17.10 | **479.55** |
| BATTERY EQUIPMENT | 0.38 | 48.70 | 8.01 | **57.09** |
| BIOLOGICAL SHIELD | 1,600.00 | | | **1,600.00** |
| CABLE | 179.37 | 187.35 | 482.72 | **849.43** |
| CABLE TRAY AND SUPPORT | 89.68 | 93.67 | 243.36 | **426.72** |
| CONCRETE OF THE BUILDING | 145,293.87 | 146,695.25 | 121,978.00 | **413,967.13** |
| CONDENSER | 14.93 | 430.23 | 7.50 | **452.65** |
| CORE COMPONENT | 22.00 | | | **22.00** |
| CRANE | 544.41 | 195.15 | 97.23 | **836.79** |
| DOORS | 16.50 | 25.50 | 17.40 | **59.40** |
| ELECTRICAL EQUIPMENT | 67.01 | 535.48 | 1,204.71 | **1,807.20** |
| FILTER | 9.33 | 42.42 | 16.98 | **68.72** |
| HANGER OR SUPPORT | 375.63 | 255.70 | 20.58 | **651.91** |
| HATCH | 80.00 | | | **80.00** |
| HEAT EXCHANGE | 777.73 | 1,133.76 | 24.43 | **1,935.91** |
| INSULATION | 284.25 | 546.50 | 58.74 | **889.49** |
| LINER | 76.00 | | | **76.00** |
| LUBRICATION | | | 285.00 | **285.00** |
| MOTOR AND DRIVE | 177.00 | 830.33 | 291.11 | **1,298.43** |
| OPERATIONAL WASTE | | | | **0.00** |
| PIPE | 1,146.25 | 2,397.50 | 293.70 | **3,837.45** |
| PUMP | 133.42 | 139.37 | 129.92 | **402.71** |
| REACTOR PRESSURE VESSEL + INTERNALS + CONTROL ROD | 367.07 | 33.65 | | **400.72** |
| REINFORCEMENT OF THE BUILDING | 9,233.00 | 8,898.00 | 6,310.50 | **24,441.50** |
| SMALL PARTS | 80.00 | 216.80 | 434.50 | **731.30** |
| STEEL CONSTRUCTIONS | 2,578.36 | 1,077.74 | 147.07 | **3,803.17** |
| STORAGE RACK | 390.74 | | | **390.74** |
| TANK | 240.97 | 206.65 | 528.19 | **975.81** |
| TURBINE | | 406.82 | | **406.82** |
| VALVE | 129.63 | 521.62 | 143.61 | **794.85** |
| VALVE OPERATOR | 9.06 | 29.66 | 8.22 | **46.93** |
| **Total** | **164,206.55** | **165,120.31** | **132,748.56** | **462,075.41** |

Table 2-1: Physical inventory per type of component and area

Table 2-2 shows the component and building masses for each building separated by the different areas:

**Physical inventory per building and area**

| Building name | Building name shortcut | Controlled area [Mg] | Monitored area [Mg] | Area inside fence [Mg] | NPP Krško [Mg] |
|---|---|---|---|---|---|
| PKS I FAZA MONTAZNA HALA IN DELAVNICE | AD1 | | | 5,475.49 | **5,475.49** |
| PKS II FAZA POSLOVNI KOMPLEKS | AD2 | | | 9,356.77 | **9,356.77** |
| RDO III FAZA POSL KOMPL IN SKLADISCE R/D | AD3 | | | 12,203.95 | **12,203.95** |
| BUNKERED BUILDING 1 | BB1 | | | 7,904.00 | **7,904.00** |
| BUNKERED BUILDING 2 | BB2 | | | 4,756.00 | **4,756.00** |
| CRPALNA POSTAJA DEMI | CPD | | | 32.62 | **32.62** |
| COOLING TOWERS AREA | CTA | | | 9,787.10 | **9,787.10** |
| CIRCULATING WATER INTAKE STRUCTURE | CWI | | | 5,940.55 | **5,940.55** |
| DAM AREA | DAM | | | 26,833.10 | **26,833.10** |
| EMERGENCY DIESEL GENERATORS BUILDING | DGB | | | 4,452.50 | **4,452.50** |
| ENTRANCE BUILDING | EB | | | 1,471.15 | **1,471.15** |
| NEK ENVIRONMENT (NEK OKOLJE) | ENV | | | 11.05 | **11.05** |
| ESSENTIAL SERVICE WATER BUILDING | ESW | | | 7,634.97 | **7,634.97** |
| FIRE PROTECTION YARD | FPY | | | 30.04 | **30.04** |
| RADIATION CONTROLLED AREA ACCESS POINT | HP | | | 1,698.61 | **1,698.61** |
| AREA INSIDE FENCE | IF-AREA | | | 1,009.08 | **1,009.08** |
| METEOROLOGICAL TOWER AREA | MT | | | 11.18 | **11.18** |
| NEUTRALIZING SUMP HOUSE | NSH | | | 53.69 | **53.69** |
| OPERATIONAL SUPPORT CENTER | OSC | | | 4,600.00 | **4,600.00** |
| WATER PRETREATMENT BUILDING | PB | | | 2,783.43 | **2,783.43** |
| PLANT GAS STORAGE AREA | PGY | | | 269.86 | **269.86** |
| TRANSFER PUMPS HOUSE | PMH | | | 32.30 | **32.30** |
| SIMULATOR BUILDING | SB | | | 5,215.42 | **5,215.42** |
| SWITCHYARD AREA | SYA | | | 9,371.02 | **9,371.02** |
| 6.3/0.4 KV TRANSFORMER STATION TP-1 | TP1 | | | 11.60 | **11.60** |
| 6.3/0.4 KV TRANSFORMER STATION TP-2 | TP2 | | | 11.70 | **11.70** |
| 6.3/0.4 KV TRANSFORMER STATION TP-3 | TP3 | | | 31.53 | **31.53** |
| 6.3/0.4 KV TRANSFORMER STATION TP-4 | TP4 | | | 17.10 | **17.10** |
| 10/0.4 KV TRANSFORMER STATION TP-E | TP5 | | | 11.60 | **11.60** |
| 6.3/0.4 KV TRANSFORMER STATION TP-B | TP6 | | | 11.60 | **11.60** |
| 10/0.4 KV TRANSFORMER STATION TP-J | TP7 | | | 11.00 | **11.00** |
| 10/0.4 KV TRANSFORMER STATION TP-D | TP8 | | | 10.50 | **10.50** |
| 10/0.4 KV TRANSFORMER STATION TP-A2 | TP9 | | | 10.50 | **10.50** |
| VHODNA KONTROLNA TOCKA | VKT | | | 153.90 | **153.90** |
| NEK YARD (OBMOCJE ELEKTRARNE) | YRD | | | 11,533.68 | **11,533.68** |
| AUXILIARY BUILDING | AB | 92,969.94 | | | **92,969.94** |
| CONTROLLED AREA | CO-AREA | 269.05 | | | **269.05** |
| FUEL HANDLING BUILDING | FHB | 10,056.48 | | | **10,056.48** |
| REACTOR BUILDING | RB | 60,911.08 | | | **60,911.08** |
| AUXILIARY BOILER HOUSE | ABH | | 1,826.41 | | **1,826.41** |
| CONTROL BUILDING | CB | | 7,646.00 | | **7,646.00** |
| COMPONENT COOLING BUILDING | CCB | | 12,711.56 | | **12,711.56** |
| DECONTAMINATION BUILDING | DB | | 8,967.77 | | **8,967.77** |
| INTERMEDIATE BUILDING | IB | | 28,910.54 | | **28,910.54** |
| MONITORED AREA | MO-AREA | | 281.02 | | **281.02** |
| RAD WASTE STORAGE AREA | RWS | | 10,251.39 | | **10,251.39** |
| SPENT FUEL DRY STORAGE | SFDS | | 33,599.50 | | **33,599.50** |
| TURBINE BUILDING | TB | | 42,444.82 | | **42,444.82** |
| WASTE MANIPULATION BUILDING | WMB | | 18,481.30 | | **18,481.30** |
| **Total** | | **164,206.55** | **165,120.31** | **132,748.56** | **462,075.41** |

Table 2-2: Physical inventory per building and area

The materials are selected according to the necessity of the establishment of a DP. The assignment of masses is according to the specification of the system. Only one material type can be chosen for one single component. So the most proportional material is chosen for the component. Most of the components consist of more than one material. In order to take this into account the different material groups of mixed materials have been created. The masses related to the grouping of materials are shown in the table below:

**Physical inventory according to material group**

| Material group | NPP Krško [Mg] |
|---|---|
| Austenitic steel | 3,181.33 |
| Building rubble | 415,389.13 |
| Cable with insulation | 849.43 |
| Conventional mixed waste | 20.05 |
| Filters | 65.08 |
| Galvanized steel (ventilation) | 428.00 |
| Iron steel (ferritic) | 35,163.15 |
| Mineral wool | 772.49 |
| Mixed material (e.g. pumps, motors) | 3,876.21 |
| Mixed material (electric components) | 154.26 |
| Mixed Material (ferritic/austenitic) | 1,652.78 |
| Special waste (batteries, doors (hazadous); oil ) | 523.51 |
| **Total** | **462,075.41** |

Table 2-3: Mass of equipment and buildings according materials

### 2.4.2. Toxic inventory

The information on toxic non-radioactive materials contained in the CORA database are derived from several experiences of NIS and transferred to the situation of NPP Krško.

The toxic materials, mainly asbestos, are in different forms. It is assumed that there is no PCB (polychlorinated biphenyl) in the hydraulic oil onsite the NPP Krško.

Three different types of Asbestos that can be recognized:

- Asbestos insulations
- Asbestos cement
- Compartmentalization for fire protection measures

The assumption that is taken for NPP Krško can be summed up as follows:

**Toxic non-radioactive material**

| | Asbestos insulation [Mg] | Asbestos cement [Mg] | Compartmentalization [Mg] |
|---|---|---|---|
| Controlled area | 5 | 5 | 50 |
| Monitored area | 2 | 3 | 65 |
| **Total** | **7** | **8** | **115** |

Table 2-4: Toxic non-radioactive material

It is assumed that the mentioned masses cover the arising hazardous materials. Generally, the hazardous materials are separated from the normal non-hazardous materials. If the material is contaminated, it is treated like radioactive material anyway, as the requirements are superior and therefore all the necessary standards are fulfilled. If the material is to be seen as non-radioactive, it is assumed that it is treated according to the Slovenian legal requirement and disposed separately on i.e. an available landfill.

### 2.4.3. Basic data for remaining operational waste

NEK's Radioactive Waste Inventory Database shows that at the end of the year 2017 2,284 $m^3$ of operational waste was stored in Solid Radwaste Storage Facility. Based on the waste generation prediction (NEK Radioactive Waste Management Program, TD-0C, rev. 7 and Technical Report NEK ESD-TR-03/97, rev.9, Radioactive Waste Management in NEK) 30 $m^3$ of waste is generated per year. Taking into account normal generation of waste for the end of year 2023 2,464 m3 of operational waste is expected and for year 2043 3,064 $m^3$ is expected.

The average packaging density of NEK's radioactive waste is 1.16 $Mg/m^3$, and therefore the net mass of the waste in 2023 will be 2,858 Mg and 3,554 Mg at the end of 2043.

For accurate gross mass estimation, the additional weight of waste containers shall be taken into the account. Based on above data, the expected gross mass will be 6,100 Mg of operational waste in 2043.

The present estimate is only for the purpose of the cost estimate to get a figure for the date of final shutdown (year 2043).

The operational waste has not been taken into account in the main part of the present study. Nevertheless, in Attachment 4 the corresponding results for the disposal of the above mentioned 6,100 Mg are given.

## 2.5. Integration of data into CORA database

Each component carries certain information like the building and room in which the component is situated, the unique Krško Equipment No, the type of component, and information about the material of the component.

The material specification has been added to components due to information on, i.e. piping materials, given by NEK and information derived from other nuclear power plants.

Site | Description | Assignment | Project | Dismantl. Sequence

| ID | Component | Comp. ID | Unit | | Building | | Room | System | Material | Number | Unit Mass [kg] | Mass [kg] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CENT CHRG PUMP AUX LUBE OIL PMP | 1-ALP1 | 2 | Controlled Ar | 1 | AB | AB-025 | CS | Filters | | | 125,0 |
| 2 | CENT CHRG PUMP AUX LUBE OIL PUMP | 1-ALP2 | 2 | Controlled Ar | 1 | AB | AB-026 | CS | Mixed mate | | | 125,0 |
| 3 | CSAPCH02 1-ALP2 CHRG AUX L/O PMP MOTOR | 1-ALP2-MTR | 2 | Controlled Ar | 1 | AB | AB-026 | CS | Mixed mate | | | 125,0 |
| 4 | GAS DRYER RETURN VALVE | 10 | 3 | Monitored Ar | 31 | TB | TB-035 | GN | Iron Steel (f | | | 5,0 |
| 5 | ESF LOOP A PT2614 ISOLATION VALVE | 10006 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 6 | ESF LOOP B PT2615 ISOLATION VALVE | 10007 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 7 | CC100TNK-001 XOVER ISOL VLV AIR OPERATOR | 10009-AO | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 3,0 |
| 8 | CC100TNK-001 XOVER ISOL VLV IA VALVE | 10009-IA | 2 | Controlled Ar | 1 | AB | AB-094 | IA | Iron Steel (f | | | 7,0 |
| 9 | CC100TNK-001 & 002 VENT VLV AIR OPERATOR | 10010-AO | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 1,0 |
| 10 | CC100TNK-001 & 002 VENT VALVE IA VALVE | 10010-IA | 2 | Controlled Ar | 1 | AB | AB-094 | IA | Iron Steel (f | | | 7,0 |
| 11 | CC100TNK-002 XOVER ISOL VALVE AIR OPER | 10011-AO | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 3,0 |
| 12 | CC100TNK-002 XOVER ISOL VLV IA VALVE | 10011-IA | 2 | Controlled Ar | 1 | AB | AB-094 | IA | Iron Steel (f | | | 7,0 |
| 13 | CC100TNK-002 NITROGEN SUPPLY IN ISOL VALVE | 10019 | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 12,0 |
| 14 | CC100TNK-001 OUT ISOL VALVE | 10020 | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 105,0 |
| 15 | CC100TNK-001 OUT LOC SAMPLE VALVE | 10021 | 2 | Controlled Ar | 1 | AB | AB-094 | CC | Iron Steel (f | | | 5,0 |
| 16 | CF CHEMICAL ADDITION LOOP A ISOLATION VALVE | 10026 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 17 | CC102PMP-01A SUCTION ISOLATION VALVE | 10029 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 1.000,0 |
| 18 | CC102PMP-01A SUCTION PI2737 ISOLATION VALVE | 10030 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 19 | CC102PMP-01A DISCHARGE PI2612 ISOLATION VALVE | 10031 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 20 | CC102PMP-01A DISCHARGE LOCAL SAMPLE VALVE | 10032 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 21 | CC102PMP-01A DISCHARGE CHECK VALVE | 10033 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 1.000,0 |
| 22 | CC101HEX-001 OUTLET PP2624A ISOL VALVE | 10037 | 3 | Monitored Ar | 7 | CCB | CCB-08 | CC | Austenitic S | | | 5,0 |
| 23 | CC101HEX-001 OUTLET FT2618 ISOLATION VALVE | 10039 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 24 | CC101HEX-001 OUTLET FT2618 ISOLATION VALVE | 10040 | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Austenitic S | | | 5,0 |
| 25 | P SIG LOOP A XOVER ISOL VLV MTR ACTUATOR | 10045-MO | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Iron Steel (f | | | 250,0 |
| 26 | P SIG LOOP A XOVER ISOL VLV ACTUATOR MTR | 10045-MTR | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Mixed mate | | | 125,0 |
| 27 | P SIG LOOP A XOVER ISOL VLV MTR ACTUATOR | 10046-MO | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Iron Steel (f | | | 250,0 |
| 28 | S SIG LOOP XOVER ISOL VLV MTR ACTUATOR | 10048-MO | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Iron Steel (f | | | 250,0 |
| 29 | S SIG LOOP XOVER ISOL VLV ACTUATOR MOTOR | 10048-MTR | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Mixed mate | | | 125,0 |
| 30 | S SIG LOOP XOVER ISOL VLV MTR ACTUATOR | 10049-MO | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Iron Steel (f | | | 250,0 |
| 31 | S SIG LOOP XOVER ISOL VLV ACTUATOR MOTOR | 10049-MTR | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Mixed mate | | | 125,0 |
| 32 | P SIG LOOP B XOVER ISOL VLV MTR ACTUATOR | 10050-MO | 3 | Monitored Ar | 7 | CCB | CCB-09 | CC | Iron Steel (f | | | 250,0 |

Total Mass [kg] 433.305.822,0

Detail Data | Datensatz kopieren | DL-Atlas
Radiological Data | Associated Files
Type Specific Data | Make List of Components | Datenblatt
Select Filter | Overwrite? | Apply

Figure 2-4: Extract from CORA database

Some calculations for the waste amount and the treatment and packaging of the radioactive waste is contained and described in the chapter 7.

### 2.5.1. Calculation of component mass

The masses of the components, equipment, and building structures are calculated mainly by NIS based on experiences from several decommissioning planning and calculation actions. Following options have been used for the calculation:

- Detailed information given by NEK (tanks, cable data, etc.), so a calculation of the volume and the associated mass has been performed and integrated
- Information was generally given: a grouping of components has been performed and a mass value has been assigned to each group – this average value has been taken from NIS experiences, so an transfer has been performed
- No information was available – e.g. plans and drawings are used to determine building masses as well as NIS experience
- New component groups have been created to be able to give a full picture of the masses of NPP Krško

The following table gives an overview of the component groups and the mass that is assigned to each of the groups.

**Physical inventory per type of component and area**

| Component type | Controlled area [Mg] | Monitored area [Mg] | Area inside fence [Mg] | NPP Krško [Mg] |
|---|---|---|---|---|
| AIR DUCTS | 289.98 | 172.48 | 17.10 | 479.55 |
| BATTERY EQUIPMENT | 0.38 | 48.70 | 8.01 | 57.09 |
| BIOLOGICAL SHIELD | 1,600.00 | | | 1,600.00 |
| CABLE | 179.37 | 187.35 | 482.72 | 849.43 |
| CABLE TRAY AND SUPPORT | 89.68 | 93.67 | 243.36 | 426.72 |
| CONCRETE OF THE BUILDING | 145,293.87 | 146,695.25 | 121,978.00 | 413,967.13 |
| CONDENSER | 14.93 | 430.23 | 7.50 | 452.65 |
| CORE COMPONENT | 22.00 | | | 22.00 |
| CRANE | 544.41 | 195.15 | 97.23 | 836.79 |
| DOORS | 16.50 | 25.50 | 17.40 | 59.40 |
| ELECTRICAL EQUIPMENT | 67.01 | 535.48 | 1,204.71 | 1,807.20 |
| FILTER | 9.33 | 42.42 | 16.98 | 68.72 |
| HANGER OR SUPPORT | 375.63 | 255.70 | 20.58 | 651.91 |
| HATCH | 80.00 | | | 80.00 |
| HEAT EXCHANGE | 777.73 | 1,133.76 | 24.43 | 1,935.91 |
| INSULATION | 284.25 | 546.50 | 58.74 | 889.49 |
| LINER | 76.00 | | | 76.00 |
| LUBRICATION | | | 285.00 | 285.00 |
| MOTOR AND DRIVE | 177.00 | 830.33 | 291.11 | 1,298.43 |
| PIPE | 1,146.25 | 2,397.50 | 293.70 | 3,837.45 |
| PUMP | 133.42 | 139.37 | 129.92 | 402.71 |
| REACTOR PRESSURE VESSEL + INTERNALS + CONTROL ROD | 367.07 | 33.65 | | 400.72 |
| REINFORCEMENT OF THE BUILDING | 9,233.00 | 8,898.00 | 6,310.50 | 24,441.50 |
| SMALL PARTS | 80.00 | 216.80 | 434.50 | 731.30 |
| STEEL CONSTRUCTIONS | 2,578.36 | 1,077.74 | 147.07 | 3,803.17 |
| STORAGE RACK | 390.74 | | | 390.74 |
| TANK | 240.97 | 206.65 | 528.19 | 975.81 |
| TURBINE | | 406.82 | | 406.82 |
| VALVE | 129.63 | 521.62 | 143.61 | 794.85 |
| VALVE OPERATOR | 9.06 | 29.66 | 8.22 | 46.93 |
| **Total** | **164,206.55** | **165,120.31** | **132,748.56** | **462,075.41** |

Table 2-5: Component groups and assigned masses

### 2.5.2. Verification of mass determination

The masses calculated and collected by NIS have been verified with NEK, for the previous study, in a common work on-site. About 50 % of the component masses in the database have been checked for correctness and plausibility. For the present study the masses of the new buildings

- Spent fuel dry storage building (SFDS)
- Bunkered building 1 (BB1)
- Bunkered building 2 (BB2)
- Waste manipulation building (WMB)
- Operational support centre extension (OSC)

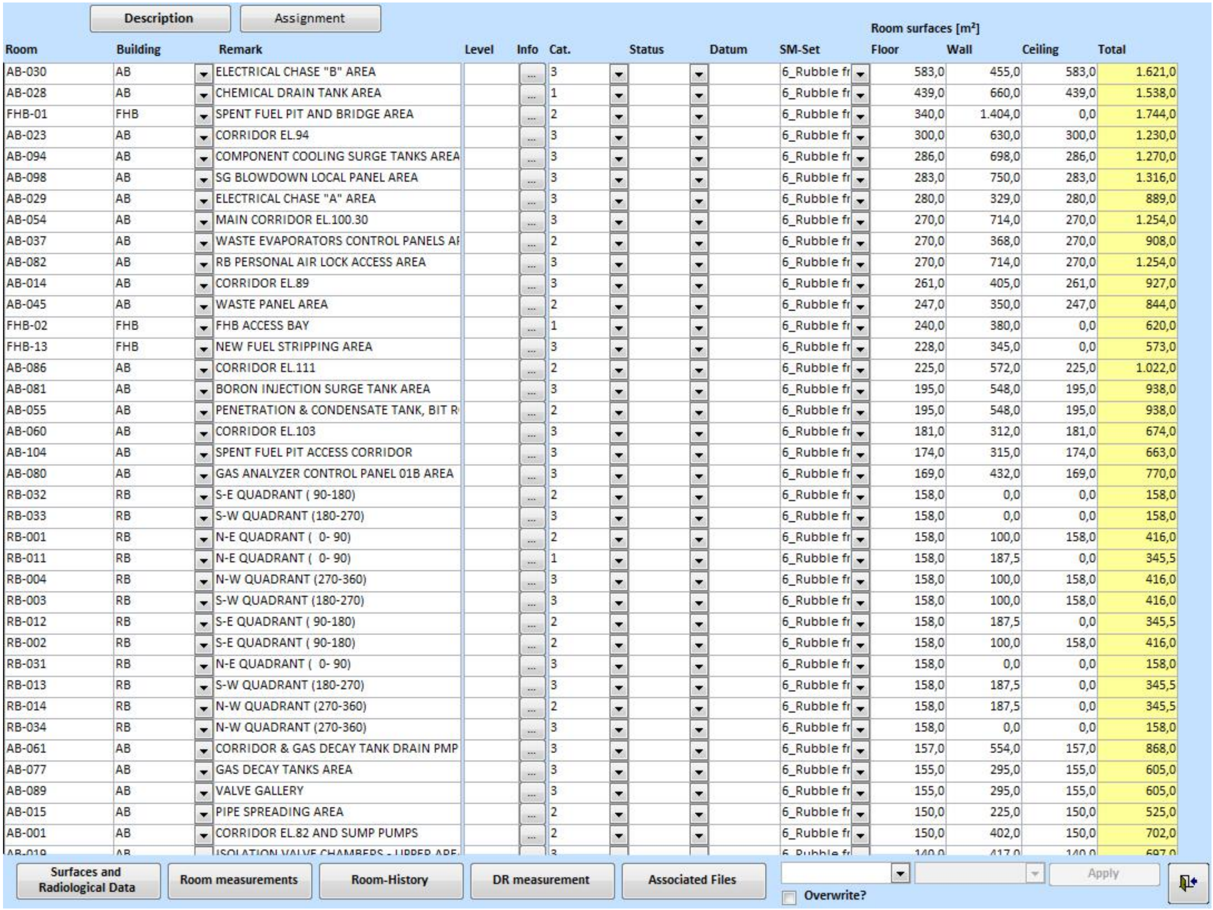
have been estimated by NIS and verified with NEK.

All the components were checked top-down and if necessary the results were adapted to on-site data and information.

The building and reinforcement masses have as well been re-calculated according to new information given by NEK.

## 2.6. Data on buildings, rooms and surfaces

The CORA database contains information to the buildings, rooms and surfaces relevant for the decommissioning project. Figure 2-5 shows examples of room surface data; detailed specified as shown in Figure 2-6.




| Room | Building | Remark | Level | Info | Cat. | Status | Datum | SM-Set | Floor | Wall | Ceiling | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Room surfaces [m²] | | | |
| AB-030 | AB | ELECTRICAL CHASE "B" AREA | | ... | 3 | | | 6_Rubble fr | 583,0 | 455,0 | 583,0 | 1.621,0 |
| AB-028 | AB | CHEMICAL DRAIN TANK AREA | | ... | 1 | | | 6_Rubble fr | 439,0 | 660,0 | 439,0 | 1.538,0 |
| FHB-01 | FHB | SPENT FUEL PIT AND BRIDGE AREA | | ... | 2 | | | 6_Rubble fr | 340,0 | 1.404,0 | 0,0 | 1.744,0 |
| AB-023 | AB | CORRIDOR EL.94 | | ... | 3 | | | 6_Rubble fr | 300,0 | 630,0 | 300,0 | 1.230,0 |
| AB-094 | AB | COMPONENT COOLING SURGE TANKS AREA | | ... | 3 | | | 6_Rubble fr | 286,0 | 698,0 | 286,0 | 1.270,0 |
| AB-098 | AB | SG BLOWDOWN LOCAL PANEL AREA | | ... | 3 | | | 6_Rubble fr | 283,0 | 750,0 | 283,0 | 1.316,0 |
| AB-029 | AB | ELECTRICAL CHASE "A" AREA | | ... | 3 | | | 6_Rubble fr | 280,0 | 329,0 | 280,0 | 889,0 |
| AB-054 | AB | MAIN CORRIDOR EL.100.30 | | ... | 3 | | | 6_Rubble fr | 270,0 | 714,0 | 270,0 | 1.254,0 |
| AB-037 | AB | WASTE EVAPORATORS CONTROL PANELS AI | | ... | 2 | | | 6_Rubble fr | 270,0 | 368,0 | 270,0 | 908,0 |
| AB-082 | AB | RB PERSONAL AIR LOCK ACCESS AREA | | ... | 3 | | | 6_Rubble fr | 270,0 | 714,0 | 270,0 | 1.254,0 |
| AB-014 | AB | CORRIDOR EL.89 | | ... | 3 | | | 6_Rubble fr | 261,0 | 405,0 | 261,0 | 927,0 |
| AB-045 | AB | WASTE PANEL AREA | | ... | 2 | | | 6_Rubble fr | 247,0 | 350,0 | 247,0 | 844,0 |
| FHB-02 | FHB | FHB ACCESS BAY | | ... | 1 | | | 6_Rubble fr | 240,0 | 380,0 | 0,0 | 620,0 |
| FHB-13 | FHB | NEW FUEL STRIPPING AREA | | ... | 3 | | | 6_Rubble fr | 228,0 | 345,0 | 0,0 | 573,0 |
| AB-086 | AB | CORRIDOR EL.111 | | ... | 2 | | | 6_Rubble fr | 225,0 | 572,0 | 225,0 | 1.022,0 |
| AB-081 | AB | BORON INJECTION SURGE TANK AREA | | ... | 3 | | | 6_Rubble fr | 195,0 | 548,0 | 195,0 | 938,0 |
| AB-055 | AB | PENETRATION & CONDENSATE TANK, BIT R | | ... | 2 | | | 6_Rubble fr | 195,0 | 548,0 | 195,0 | 938,0 |
| AB-060 | AB | CORRIDOR EL.103 | | ... | 3 | | | 6_Rubble fr | 181,0 | 312,0 | 181,0 | 674,0 |
| AB-104 | AB | SPENT FUEL PIT ACCESS CORRIDOR | | ... | 3 | | | 6_Rubble fr | 174,0 | 315,0 | 174,0 | 663,0 |
| AB-080 | AB | GAS ANALYZER CONTROL PANEL 01B AREA | | ... | 3 | | | 6_Rubble fr | 169,0 | 432,0 | 169,0 | 770,0 |
| RB-032 | RB | S-E QUADRANT ( 90-180) | | ... | 2 | | | 6_Rubble fr | 158,0 | 0,0 | 0,0 | 158,0 |
| RB-033 | RB | S-W QUADRANT (180-270) | | ... | 3 | | | 6_Rubble fr | 158,0 | 0,0 | 0,0 | 158,0 |
| RB-001 | RB | N-E QUADRANT ( 0- 90) | | ... | 2 | | | 6_Rubble fr | 158,0 | 100,0 | 158,0 | 416,0 |
| RB-011 | RB | N-E QUADRANT ( 0- 90) | | ... | 1 | | | 6_Rubble fr | 158,0 | 187,5 | 0,0 | 345,5 |
| RB-004 | RB | N-W QUADRANT (270-360) | | ... | 3 | | | 6_Rubble fr | 158,0 | 100,0 | 158,0 | 416,0 |
| RB-003 | RB | S-W QUADRANT (180-270) | | ... | 3 | | | 6_Rubble fr | 158,0 | 100,0 | 158,0 | 416,0 |
| RB-012 | RB | S-E QUADRANT ( 90-180) | | ... | 2 | | | 6_Rubble fr | 158,0 | 187,5 | 0,0 | 345,5 |
| RB-002 | RB | S-E QUADRANT ( 90-180) | | ... | 2 | | | 6_Rubble fr | 158,0 | 100,0 | 158,0 | 416,0 |
| RB-031 | RB | N-E QUADRANT ( 0- 90) | | ... | 3 | | | 6_Rubble fr | 158,0 | 0,0 | 0,0 | 158,0 |
| RB-013 | RB | S-W QUADRANT (180-270) | | ... | 3 | | | 6_Rubble fr | 158,0 | 187,5 | 0,0 | 345,5 |
| RB-014 | RB | N-W QUADRANT (270-360) | | ... | 2 | | | 6_Rubble fr | 158,0 | 187,5 | 0,0 | 345,5 |
| RB-034 | RB | N-W QUADRANT (270-360) | | ... | 3 | | | 6_Rubble fr | 158,0 | 0,0 | 0,0 | 158,0 |
| AB-061 | AB | CORRIDOR & GAS DECAY TANK DRAIN PMP | | ... | 3 | | | 6_Rubble fr | 157,0 | 554,0 | 157,0 | 868,0 |
| AB-077 | AB | GAS DECAY TANKS AREA | | ... | 3 | | | 6_Rubble fr | 155,0 | 295,0 | 155,0 | 605,0 |
| AB-089 | AB | VALVE GALLERY | | ... | 3 | | | 6_Rubble fr | 155,0 | 295,0 | 155,0 | 605,0 |
| AB-015 | AB | PIPE SPREADING AREA | | ... | 2 | | | 6_Rubble fr | 150,0 | 225,0 | 150,0 | 525,0 |
| AB-001 | AB | CORRIDOR EL.82 AND SUMP PUMPS | | ... | 2 | | | 6_Rubble fr | 150,0 | 402,0 | 150,0 | 702,0 |
| AB-019 | AB | ISOLATION VALVE CHAMBERS - UPPER ARE | | | 3 | | | 6_Rubble fr | 140,0 | 417,0 | 140,0 | 697,0 |

Figure 2-5: Room data in the CORA database

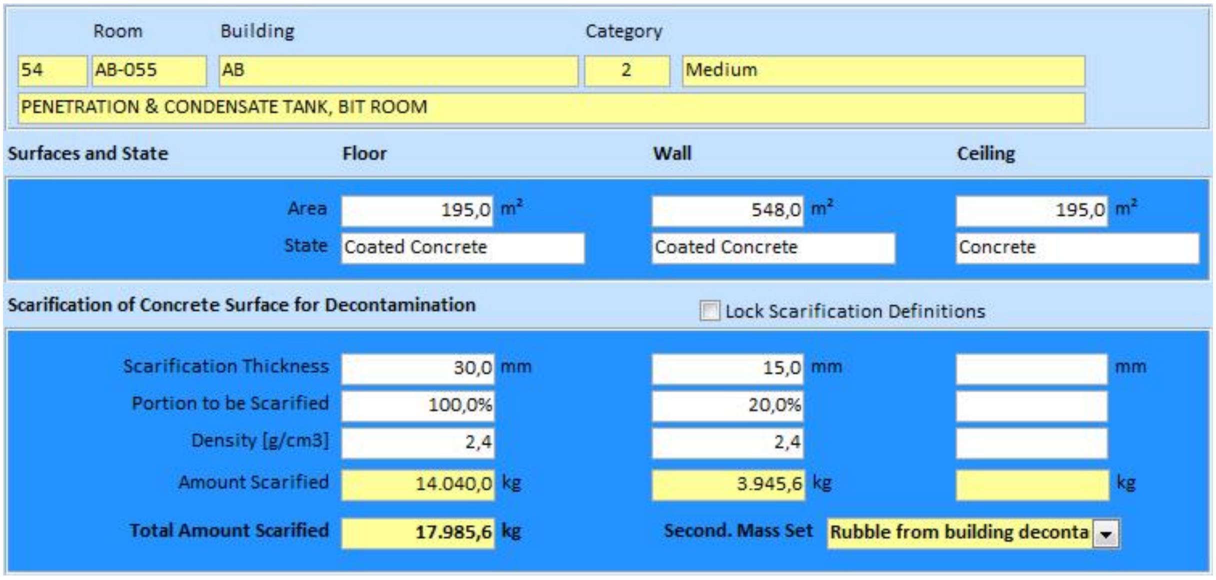



Figure 2-6: Room data in CORA (example)

The room data are collected and evaluated for the controlled area and also some monitored area rooms with regard to the later decommissioning (e.g. for the decontamination building and waste manipulation building).

This information allows the calculation of the surfaces which have to be scarified for the release of the building after dismantling of all components.

The result of this calculation is shown in the table below:

### Surfaces and concrete-removal rates

| Building shortname | Building name | Surface [m²] | | | | Concrete removal [Mg] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Floor | Wall | Ceiling | **Total** | Floor | Wall | Ceiling | **Total** |
| **Controlled Area** | | | | | | | | | |
| AB | AUXILIARY BUILDING | 9,153 | 27,768 | 9,153 | **46,074** | 509.26 | 183.42 | 2.48 | **695.16** |
| FHB | FUEL HANDLING BUILDING | 1,318 | 4,910 | 1,094 | **7,322** | 86.72 | 31.53 | 0.00 | **118.26** |
| RB | REACTOR BUILDING | 2,170 | 5,580 | 893 | **8,643** | 145.85 | 87.97 | 0.59 | **234.41** |
| **Monitored Area** | | | | | | | | | |
| DB | DECONTAMINATION BUILDING | 1,410 | 1,550 | 1,410 | **4,370** | 101.52 | 11.16 | 0.00 | **112.68** |
| SFDS | SPENT FUEL DRY STORAGE | 2,970 | 5,480 | 2,970 | **11,420** | 0.00 | 0.00 | 0.00 | **0.00** |
| WMB | WASTE MANIPULATION BUILDING | 1,140 | 2,055 | 1,140 | **4,335** | 82.08 | 14.80 | 0.00 | **96.88** |
| **Total** | | | | | **82,164** | | | | **1,257.38** |

Table 2-6: Surfaces and mass of scarified material

## 2.7. Calculation of secondary masses

Clothes, tools and other consumables used during the decommissioning work are the so called “Secondary masses”. The amount of this kind of waste will be calculated in the CORA database and taken into account for the treatment of radioactive waste and also in the cost estimation.

The amount of secondary waste will be calculated based on specific factors [kg/kg respectively in %] related to the primary waste. Some modifications have been considered compared to PDP rev. 5 [10] based on return of experience over the past years. As an example the secondary waste which is expected during the dismantling of metallic components in the controlled area is shown below:

- 1.00 % combustible material (e.g. clothes, shoes, gloves, …)
- 0.13 % compressible material (e.g. tools, rubber, other consumables, …)
- 15.50 % waste water

A survey of the used factors is given in Table 2-7:

**Secondary mass sets content**

| Content / Secondary mass set name | Dismantling - metal | Dismantling - metal, complicated | Dismantling - metal, remote | Dismantling - concrete, simple | Dismantling - concrete, complicated | Rubble from building decontamination | Conditioning without supercompaction | Conditioning with supercompaction | Decontamination - mechanical | Decontamination - wet | Melting | Distribution factor set |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Combustible material | 1.00% | 1.40% | 5.80% | 0.12% | 0.96% | 0.96% | 1.20% | 1.20% | 0.96% | 0.96% | | 6 |
| Compressible material | 0.13% | 0.20% | 0.81% | 0.02% | 0.16% | 0.16% | 0.16% | 0.16% | 0.13% | 0.13% | | 2 |
| Solids mech. decont. | | | | | | | | | 7.80% | | | 3 |
| Waste water | 15.00% | 23.00% | 92.00% | 1.80% | 18.00% | 18.00% | 18.00% | 18.00% | 18.00% | 18.00% | | 1 |
| Rubble from building scarification | | | | | | 100.00% | | | | | | 7 |
| Slags and filters from melting | | | | | | | | | | | 5.00% | 5 |
| Rinsing water from decontamination | | | | | | | | | | 7.80% | | 4 |

Table 2-7: Specific factors for the calculation of secondary masses

The table shows additionally the planned treatment for the calculated secondary masses (see chapter 7). The amount of waste, the needed number of containers, and the necessary repository volume are calculated due to the assigned distribution factor sets.

The results of the calculation based on return of experience over the past years are given in Table 2-8.The number of container and the repository volume is described in chapter 7.

**Total secondary masses**

| Secondary mass name | Mass [Mg] | Radioactive waste [Mg] |
|---|---|---|
| Combustible material | 171.4 | 8.6 |
| Compressible material | 23.4 | 23.4 |
| Rinsing water from decontamination | 79.8 | 0.8 |
| Rubble from building scarification | 1,257.4 | 377.2 |
| Slags and filters from melting | 17.6 | 17.6 |
| Solids mech. decont. | 75.7 | 75.7 |
| Waste water | 2,740.8 | 4.1 |
| **Total secondary masses** | **4,366.1** | **507.3** |

Table 2-8: Calculated secondary masses and resulting radioactive waste masses

# 3. Decommissioning strategy

The Krško NPP, a pressurised water reactor (PWR) with a net electric capacity of 696 MWe, is operated by Nuklearna elektrarna Krško (NEK) in Vrbina in the Municipality of Krško, Slovenia.

The operating company NEK is co-owned by the Slovenian state-owned company GEN-Energija and the Croatian state-owned company Hrvatska elektroprivreda (HEP).

The plant was connected to the power grid in October 1981 and went into commercial operation in January 1983. The final shutdown of the plant is planned in 2043 pending the successful conclusion of periodic safety reviews in 2023 and 2033.

In this revision of the DP only the strategy of "Immediate Dismantling" is considered respecting the need for wet storage with 5 years of operation beyond NPP Krško operation for last discharges of reactor fuel (see [6], [5]). Therefore the real dismantling work will start not before end of 2048.

The decommissioning strategy take into account that a Spent Fuel Dry Storage (SFDS) is constructed on site and that it may be in operation for at least additional 60 years after the end of NPP Krško operation. Additionally according to [11] the assumption that the fuel will remain on site in the SFDS until 2075 with the possibility of prolongation has to be taken into account.

As a consequence of the above two statements two cases have been defined:

- **Base case**: Transfer of spent fuel from the fuel handling building (FHB) to SFDS and dismantling of all installations of buildings that contains radioactive materials (e.g. reactor building, auxiliary building, fuel handling building, decontamination building, etc.). After decontamination and release of the remaining building structures the so called "Brown field" status is reached. All other buildings and systems that are needed for SFDS operation remain operable until 2103 (end of SFDS operation). "Brown field" applies for the period between releases of the mentioned building structures until the end of SFDS operation in 2103. The decommissioning of the whole site (including the SFDS) is done after 2103 up to the so called "Green field" status (removing all installations and building structures).
- **Sensitivity case**: The "Green field" scenario with complete removal of the whole site (including SFDS) is done after 2075. That implies "Brown field" status for the period between releases of the above mentioned building structures (see base case description) until the end of SFDS operation in 2075.

Additionally both cases are illustrated in the following Figure 3-1 again.

A timeline and a schedule of planned immediate strategy activities are presented in Figure 4-39 and Figure 4-40.

NOTE: Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.

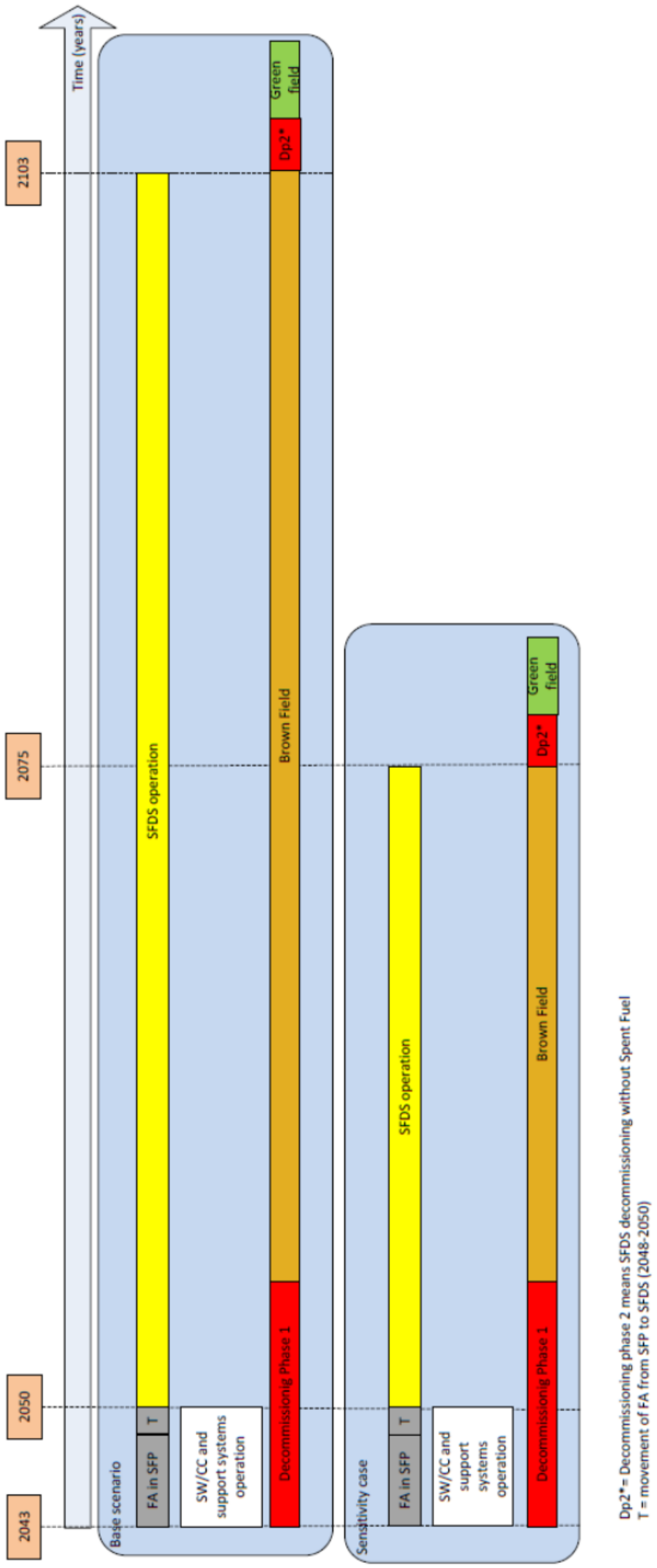



Figure 3-1: Decommissioning cases considered in DP rev.3

# 4. Decommissioning activities

## 4.1. Techniques

### 4.1.1. Introduction

#### 4.1.1.1. Review

For the present study NIS reviewed nuclear decommissioning and dismantling projects concerning the used equipment and techniques. It turns out that a wide variety of equipment and techniques from a wide range of fields have been tested in nuclear power plants. A closer look reveals that only a few of the conceived solutions are used in nuclear decommissioning and dismantling projects today. An example of such a technique is surface decontamination using laser technology, which was not used except for trial applications in nuclear facilities. For this reason, this chapter only deals with proven technologies that are currently used in nuclear decommissioning and dismantling projects and have been proven in some cases over decades. The listed and established techniques are generally subject to certain improvements. However, these do not change the principle of the technology used. Examples of such improvements are in material and design as well as in instrumentation technology.

#### 4.1.1.2. Radiological classification of the plant inventory

When the first nuclear installations were decommissioned and dismantled, available techniques and tools have to be adapted to the special needs of the nuclear boundary conditions after the operational phase. In some cases completely new techniques and tools have to be developed. Today experience is available with a wide variety of dismantling and decontamination techniques. The needed techniques are available and known. Not all techniques that were developed in the past could achieve acceptance in practice. In the course of the last ten years there has been a process of consolidation.

The techniques mentioned hereafter were selected, because they are commonly used today. They are the basis of the calculations for the present report.

#### 4.1.1.3. Non-contaminated and non-activated objects

Non-activated and non-contaminated objects from the controlled area will be regarded as potentially activated/contaminated. After showing to the authorities that the radioactivity of these materials is below the clearance levels they will be removed from the units.

Further treatment might be needed if this is required for the release measurements, for example if the geometry of the components makes release measurements too difficult or impossible.

#### 4.1.1.4. Contaminated objects

Contaminated objects will be removed from the units and treated for release or repository. The components can be dismantled in-situ

- Cut of contaminated parts for suitable dimensions for internal transfer

and further cut to separate portions

- That can be released after decontamination
- That must be conditioned and packed as radioactive waste

#### 4.1.1.5. Activated objects

Activated objects will be dismantled in-situ, either under water, at a distance or from behind a local shielding. As a consequence, remote controlled techniques will be used. The aim of the dismantling is to do the following as effectively as possible:

- To cut the activated parts to suitable dimensions for packaging
- To put them in the repository package

### 4.1.2. Dismantling techniques

#### 4.1.2.1. General

Today a great experience on dismantling of components in nuclear installations is available. New developments are needed only in some specific cases where the local situation is very special. Most of the useable techniques and tools are marketable and commonly used.

Different dismantling techniques can be used according to the requirements of the different material and radiological categories during the decommissioning project, as described in the following.

The dismantling makes that the components are in suitable dimensions for:

- Internal transfer
- Decontamination
- Measuring for free release
- Conditioning and packaging as radioactive waste as effectively as possible

Some components can be removed in one piece, e.g. tanks with a huge diameter and no or low level contamination.

Additional cutting actions in separate cutting stations are needed either to facilitate decontamination, to achieve a better use of the packages, or to facilitate free release measurements.

So dismantling techniques are needed for the following:

- Dismantling in situ: This is the case for most of the components and equipment which have to be removed from the facility. After the cut-off from the systems the components will be cut additionally into more suitable pieces. These are optimized for internal transportation, easier handling, decontamination and free release measuring afterwards;
- Remote dismantling: This is the case for the reactor internals and sometimes for parts of the biological shield will be dismantled in situ, but under remote control. The reactor internals will be dismantled under water. The cut pieces are directly put in repository packages.

The main dismantling techniques foreseen in the present project are described below.

#### 4.1.2.2. Mechanical cutting

Mechanical cutting is the name for techniques such as sawing, cutting, milling, planning, abrasive cutting etc. These separation processes are possible under dry conditions as well as under water.

Many mechanical cutting tools exist that meet the needs of nuclear decommissioning. A typical application is cutting of small diameter pipes or thin sheet metal. This technique generates negligible aerosols and no slag. Most of the cutting techniques can be remotely operated if the remote equipment can withstand the forces incurred in the cutting process.

The criteria used to compare different tools are speed, handling, kerf, and the production of secondary waste. The joint material resulting from the separation processes (chips, etc.) will be treated as secondary waste.

In principle, it is possible to dismantle all components through mechanical separation processes. The thicker the wall, the bigger the stress which requires a massive construction of the tool supports.

Band saw cutting (see Figure 4-1) is especially suitable for cutting large components with thick walls. The equipment needs space: for bringing in the large components, for the removal of the cut parts, also for the traverse path of the saw and for interventions and maintenance (for example: replacement of the saw band).

The component to be cut is put on a deposit table, fixed by clamps, and then taken to the saw blade, or the saw has a movable sawing frame. Some components may require a substructure to fix the cut piece and the remaining component so as to guarantee a trouble free cutting (without pieces falling down, or vibrations, etc.).

The large components are usually handled by means of a crane. The cut pieces can also be removed by the crane, or by other means.

When selecting replacement cutting bands, of course the cutting performance is an important parameter, but when selecting cutting bands the emphasis will be put on the lifetime of the band.

Figure 4-1: Band saw [reference Kahl NPP]

Swarf from cutting contaminated or activated components will be removed at the place of origin (by suction) or it will be guided (guiding plates) and collected to be removed without problems.

The factors that influence the total cutting time are the actual time for cutting, but also the non-productive time (handling time, maintenance and repair downtime). The ratio of actual cutting time to non-productive time depends on the geometry and the thickness of the component.

*Angle grinder*

Angle grinders are used to remove obstacles or bulky parts such as brackets, sieve inserts, sticky screws, and nuts etc. from the components with relatively moderate machine and manpower effort. But they are not always the optimum tool.

*Circular diamond saws*

The maximum thickness which can be cut by a circular saw depends on the diameter of the saw and is, in general, about one third of its diameter.

The largest saw made was developed for cutting concrete biological shields in power reactors and has a diameter of 2.5 m and can cut 1 m thick reinforced concrete. The blade advance of this saw is 180 mm per minute, giving a cutting yield of 10 square meters per hour. The blade has to be changed about once every 200 square meters, which is about once every 20 hours of operation. This tool weighs 2.5 Mg which involves the use of manipulation and guidance equipment which are adapted to the prevailing conditions in the work zone. Saws of all diameters can be purchased readily and may be portable or operated by remote control. Circular saw drive motors are usually hydraulic or pneumatic.

Diamond saws produce little pollution and are well suited to cutting concrete. They are good for breaching concrete walls, floors and ceilings at competitive costs and with a minimum of harmful effects. Setting them up becomes more difficult when cutting thicknesses of more than 30 cm, the weight and bulk of the machines then require special adaptations to the manipulation and guidance equipment.

*Diamond cables*

Diamond cables offer all the advantages of circular saws and enable greater thicknesses to be cut through. In theory, the thickness is limited by the fact that the cable must pass right around the piece being cut. The drive motor must be powerful enough to overcome the resulting friction, which is proportional to the length of the kerf (the width being a constant).

Wire saw cutting is suitable for reinforced concrete but also for simple thick steel structures, as far as they do not tend to jamming.

The wires are provided with small blades.

Figure 4-2: Cutting wire with diamond “pearls” and distance springs [reference Wikipedia]

Wire cutting can be done either dry or wet. Dry cutting is slower than wet cutting (50% performance), but it avoids wet waste with high costs for removal. On the other hand it requires a well-directed suction of the cutting gap and the wire guide with a separate ventilation unit.

The technique of wire cutting is well known in conventional industry and it is capable of cutting cleanly and precisely with minimal effects on the surroundings e.g. shocks, vibrations, noise, sparks and dust and with reduced production of secondary waste. The loop is made up of lengths of wire assembled for particular operation. The lengths must be about equally worn otherwise the least worn lengths will do all the work and will have a much shorter life. It is thus important to keep up to date records on wire use.

*Hydraulic shear*

A hydraulic shear is suitable for cutting pipe shaped parts or smaller steel equipment (angle, flat bars, small T-profiles). Commercial shears are available operating with 400 bar pressure and providing a cutting force up to 400 kN.

Figure 4-3: Hydraulic shear [reference EWN]

In case of remote controlled operation the cutting forces and the resulting moments must be observed to prevent damages to the remote control handling tools.

### 4.1.2.3. Thermal cutting

Thermal cutting processes include, for example, acetylene cutting, plasma torching, arc oxygen wire cutting. High thermal energies are applied for separating the components. In general, thermal cutting is very efficient. It can cut thick steel, it is easy to use, and it can be used under water. Thermal cutting is also possible in case of complicated geometry. The thicker the wall, the more difficult is the application of thermal processes.

On the other hand, thermal cutting generates gas, smoke and aerosols that require the installation of filtration and ventilation systems which in turn increase the cost of cutting. Thermal separation “in the air” produces dust and aerosols, which may contaminate the surrounding surfaces. Additional ventilation systems and/or caissons can avoid or restrain this. “Under water" particles and aerosols are held back at a high rate by the water, but this water has to be treated as radioactive waste.

Figure 4-4: Thermal cutting [reference EWN]

*Autogenous fuel cutting*

Autogenous fuel cutting is a thermal cutting technique which is performed by a fuel gas (e.g. acetylene or propane) in combination with oxygen. The flame heats up the metallic work-piece to an ignition temperature. After that the metal burns up in the beam of cutting oxygen. The material to be cut has to fulfil the following requirements:

- The material must react with oxygen in an exothermal process
- The ignition temperature of the material must be lower than its melting temperature. For temperatures above the ignition temperature, the combustion heat exceeds the dissipated heat. For mild steel, which is well-suited to flame cutting, the ignition temperature is about 1,150°C
- The melting temperature of the generated oxides must be lower than the melting temperature of the material
- The viscosity of the slag should be as low as possible
- The thermal conductivity of the material should be as low as possible
- The combustion energy should be as high as possible

Due to these restrictions, the use of autogenous fuel cutting is limited to mild steel, titanium and molybdenum. Stainless steel and the remaining non-ferrous metals are not suitable for flame cutting without additional powder injection. Maximum cut thicknesses of more than 2,000 mm can be achieved for mild steel.

There are many examples for cutting components with this thermal cutting technique e.g. the reactor pressure vessel head in the NPP Gundremmingen A, the reactor pressure vessel (RPV) in the NPP Stade or in the NPP Zion.

*Plasma arc cutting*

Thermal plasma is a highly heated gas or gaseous mixture which is conductive and consists of ions, electrons and neutral atoms or molecules. Monatomic gases such as argon and helium, polyatomic gases such as nitrogen and hydrogen, and also mixtures of these or air can be used as plasma gases.

The plasma arc is constricted by means of a copper nozzle. The thermal and electrical pinch effects are used to attain temperatures which are considerably higher than the temperatures obtained with the open arcs described in the section above. Maximum temperature in the inner plasma arc is approximately 20,000 K or more.

For practical applications, the transferred arc is used almost exclusively for cutting and eroding any conductive material. The non-transferred arc can cut any material, i.e. also non-conductive materials, but significantly less energy is transmitted to the work piece.

For decommissioning purposes, modular cutting torches were developed for the remote-controlled replacement of worn parts by means of manipulators. Thus, those parts with the highest wear rate, i.e. the nozzle and electrode, can be easily replaced and the torch can be adapted for individual cutting tasks. This also gives the possibility of switching between straight and cranked cutting units. Such a unit must be as small as possible, since it is used for cutting confined, complex structures.

The maximum cut thickness obtainable in atmosphere is 172 mm for stainless steel, 150 mm for mild steel and 80 mm for aluminium.

For decommissioning purposes, plasma arc cutting is the most commonly used thermal cutting technique for activated components. Since 1963 the technique is used in several projects.

#### 4.1.2.4. Hydraulic cutting

Hydraulic cutting techniques can be used for metallic structures and for concrete. There are many different techniques. The most interesting for the present project is the high pressure water technique in which abrasive additives are added to a high pressure water jet.

The used abrasives are not regenerated because the grain size has changed and the additives are not useable anymore. The used additives are removed together with the material from the gap and treated as radioactive waste.

The technique can be used in the air or under water, for wall thicknesses up to 300 mm. Among its advantages are the low dust and aerosol emissions.

*WAS technique*

Using the water abrasive suspension (WAS) cutting process with the aid of a water jet and sharp-edged abrasive material – preferably very fine garnet sand – even high-strength steels up to 30 cm thick and reinforced concrete up to a meter in thickness, as well as a wide variety of other materials, can be effectively and precisely parted.

The special features of this process are: the cuts are executed in a contact-free manner, with no significant heat generation or deformation, regardless of the material in question, and can also be performed using remote manipulation at distances of more than 1,000 meters. Only very thin parting seams are produced, with low secondary waste.

The important parts of the equipment include a high pressure pump, a mixing unit for the abrasive material, high pressure hoses, and a cutting nozzle of 0.5 to 1.3 mm diameter. The water jet and the abrasive material are pushed through the cutting nozzle. Depending on the intended application and requirements cutting equipment with a range of pressure levels from 450 to 2,500 bar is available. The composition of the jet stream will be (2-phase system) water 92.5% and abrasive 7.5% or (3-phase system) air 90%, water 6%, abrasive 4%.

The advantages of the WAS cutting are:

- Cold cutting without thermal influence
- Rapid precision machining of materials including non-conductive materials
- Narrow cutting kerfs
- Easy operation of the cutting tools
- Easy replacement of tools
- Easy access for interventions

#### 4.1.2.5. Remote control techniques

Work on activated or highly contaminated components may require remote control. Several techniques exist such as a telescopic beam, self-locking ring supports, electrical master-slave-manipulators, and special tools for picking up, lifting and holding. These remote control tools are carriers for mechanical, hydraulic or thermal cutting tools.

Marketable tools will be used, but they may have to be adapted to the local conditions.

The following properties are relevant:

- Easy operation of the cutting tools
- Easy replacement of tools
- Easy accessibility for interventions
- Easy handling of cut parts for sluicing out and packaging
- Simple further processing (cutting on site or at separate cutting place)

#### 4.1.2.6. Shielding measures

Shielding measures are to be understood as an aid for the dismantling work, to minimize the radiation exposure for the dismantling personnel. Shielding can be temporary or permanent.

Temporary shields are installed for individual, maybe even short activities. Usually they consist of shielding walls, made of individual elements that can be installed and removed quickly.

Permanent shields and equipment such as caissons serve as a shielding for the direct radiation, but they also create a defined environment with a separate ventilation system to avoid spreading of dust/aerosols.

Adequate shielding can also be provided by water. Underwater dismantling using remote controlled tools is used for example for the dismantling of the RPV internals.

### 4.1.3. Decontamination techniques

Decontamination is an important issue in the D&D project. Decontamination before and during the dismantling work can reduce the radiation level for the dismantling crew. Decontamination after dismantling is used to reduce the amounts of radioactive waste. So the fields of application are:

- Full system decontamination (FSD)
- Accompanying decontamination during dismantling[1]
- Decontamination of dismantled components and structures
- Decontamination of building structures
- Decontamination of tools and equipment
- Decontamination of transport equipment and packages

The selection of the decontamination techniques depends on the expected result, the duration of the decontamination process, the secondary waste and also on the expected radiation exposure for the personnel. The geometry, the surface properties of the material and the physical properties of the material must also be considered.

The decontamination techniques hereafter focus on the cleaning of the surfaces of the dismantled components and equipment. The purpose is to get the contamination below the free release level.

#### 4.1.3.1. Full system decontamination (FSD)

As in explained in chapter 14.1.2, the purpose of the FSD is to reduce the radiation level during decommissioning and dismantling of the primary circuit components:

- RPV
- Steam generators (SG)
- Primary coolant circuit piping and pumps
- Pressurizer
- Pressurizer relief tank

Each of the available technique uses chemical fluids, such as permanganic acid, which is introduced in the primary circuit to decontaminate it. In the following the most well-known processes should be introduced:

- The chemical Decontamination Process ASDOC (Siempelkamp NIS)
- The CORD® concept (AREVA)

*The Chemical decontamination process ASDOC:*

ASDOC (Advanced System Decontamination by Oxidizing Chemistry) uses known and freely accessible process chemicals in significantly reduced concentration and with modified operating logic. The chemical concentrates are injected into the reactor primary system via the site's dosing installations. The process solutions are circulated through the primary system by normal reactor system operation. Like in a normal power plant, the control of power plant systems needed for the decontamination is being performed by the operating personnel from the power plant maintenance. Required parameters for e.g. dosing processes, throughputs or temperatures are given by the NIS. Dissolved ions and nuclides from the primary system's oxide layers are removed by means of the site's ion exchange water clean-up system. The ASDOC process may be interrupted and restarted at any arbitrary moment without there be-

[1] This is the decontamination work in the unit before / during / after the dismantling work. It can be needed to reduce the radiation level in the working area, or to keep the working area clean and to prevent spreading of contamination.

ing precipitation for instance of chemical compounds. The decontamination process which is subdivided in several processing steps can precisely be terminated at the interface between oxide layer and bulk material. An unintentional damage of the base metal and related increase of wastes can thereby certainly be prevented.

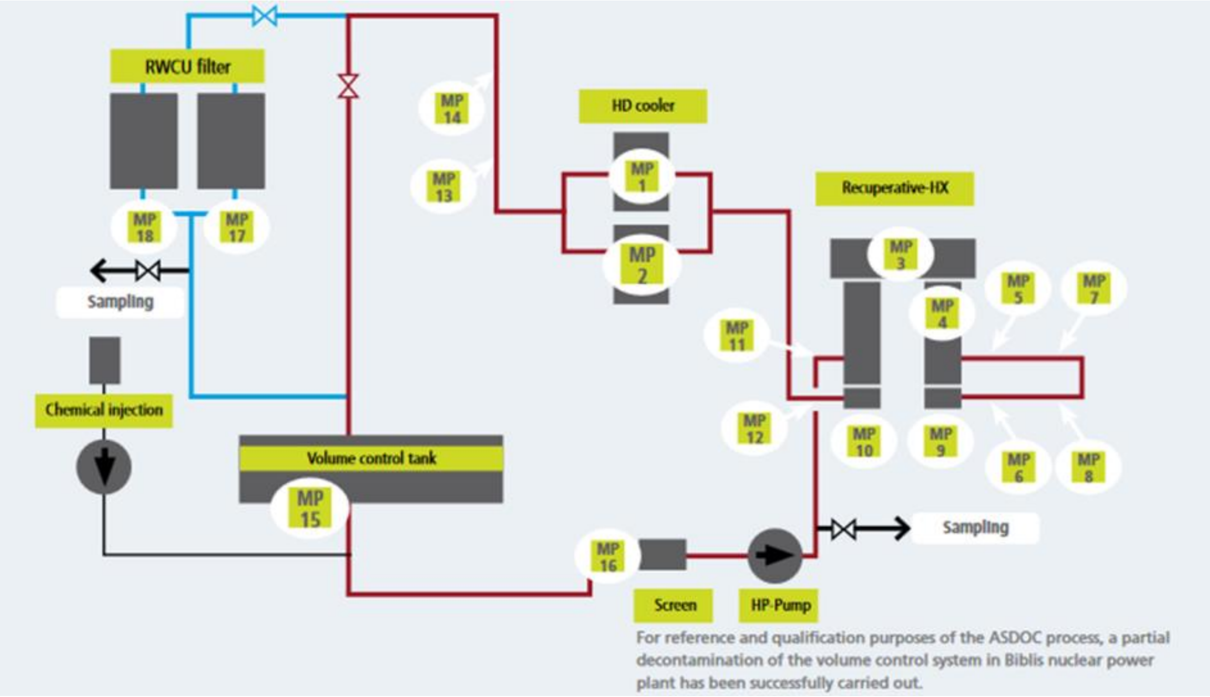



Figure 4-5: ASDOC process flowchart

The process shows that a removal of the oxide layers can be performed and tracked controllably. These results from the precise and limited amount of chemicals dispensed. After the individual process steps, the chemicals used are stoichiometrically converted. Therefore no surplus chemicals remain in the decontamination cycle. The oxide layers dissolve during the individual process steps: this is achieved by nearly constant ablation rates. There is no particulate release. The process steps can be repeated several times until the desired decontamination result is achieved. The activity distribution on metal surfaces can thereby be lowered to the release limit. Due to the omission of external components which do not need to be assembled or disassembled, the accumulated operator dose rate during a decontamination campaign stands at around several mSv. Thanks to the precise process control, the ASDOC process can reach decontamination factors of >75.

*<u>The CORD® concept:</u>*

In general standard system decontaminations are performed by applying the HP/CORD UV process in connection with the AREVA NP mobile decontamination equipment AMDA as external decontamination system. Typical applications are:

- Decontamination of components
- Decontamination of systems or subsystems
- FSD

The HP/CORD UV process can be also applied for decontamination of systems with a mix of the base materials such as stainless /carbon steel.

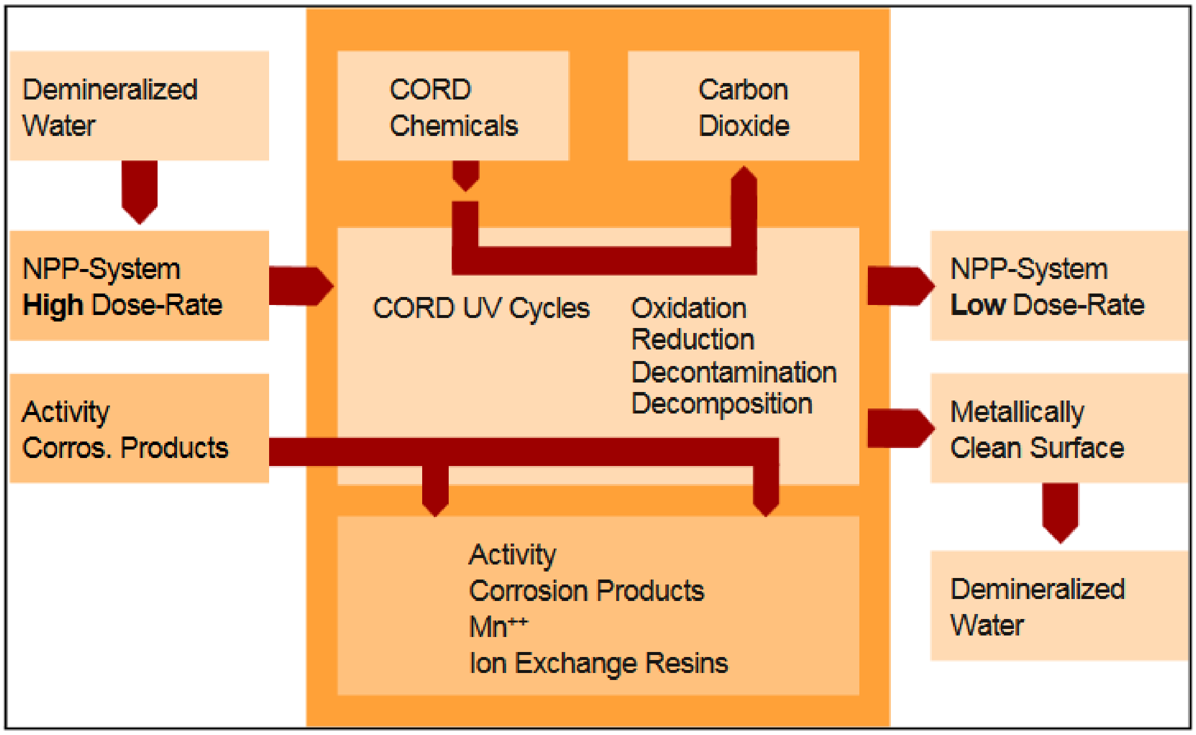



Figure 4-6: Logistics of the HP/Cord UV process

The HP/CORD UV process, like all state-of-the-art decontamination processes of the CORD-family, is applied as a multi-cycle process according to the decontamination targets. The whole process is done with only one fill of water. Each cycle is divided into the following steps:

- Step 1: Oxidation with HP
- Step 2: Reduction of HP with chemical decontamination
- Step 3: Decontamination
- Step 4: UV-decomposition of decontamination chemicals and clean up

Bypass purification is performed during the decontamination step to fix the dissolved activity and corrosion products on ion exchange resins. At the end of the decontamination step the in-situ UV-decomposition of the remaining decontamination chemicals take place. The decontamination chemicals are decomposed to water and carbon dioxide while the purification of remaining activity and corrosion products is ongoing. By this procedure the system water reaches a purity that is close to demineralized water quality at the end of the cycle. The HP/CORD UV process does not require a predetermined number of cycles to be performed. The number of cycles is part of the tailored concept according the given decontamination tasks and targets. Especially for decommissioning projects in the last cycle HP/CORD D UV (process developed for specific decommissioning requirements) can be applied for removal of activity penetrated into base metal. This activity removal can be realized by a controlled initiated base metal attack with an accuracy of 0.1 µm. The controlled base metal attack is only realized by a targeted reduction of the Redox Potential of the decont solution. Hereby, the logistics of the HP /CORD UV Processes (such as the chemicals used or process steps) remain unchanged (see Figure 4-7).

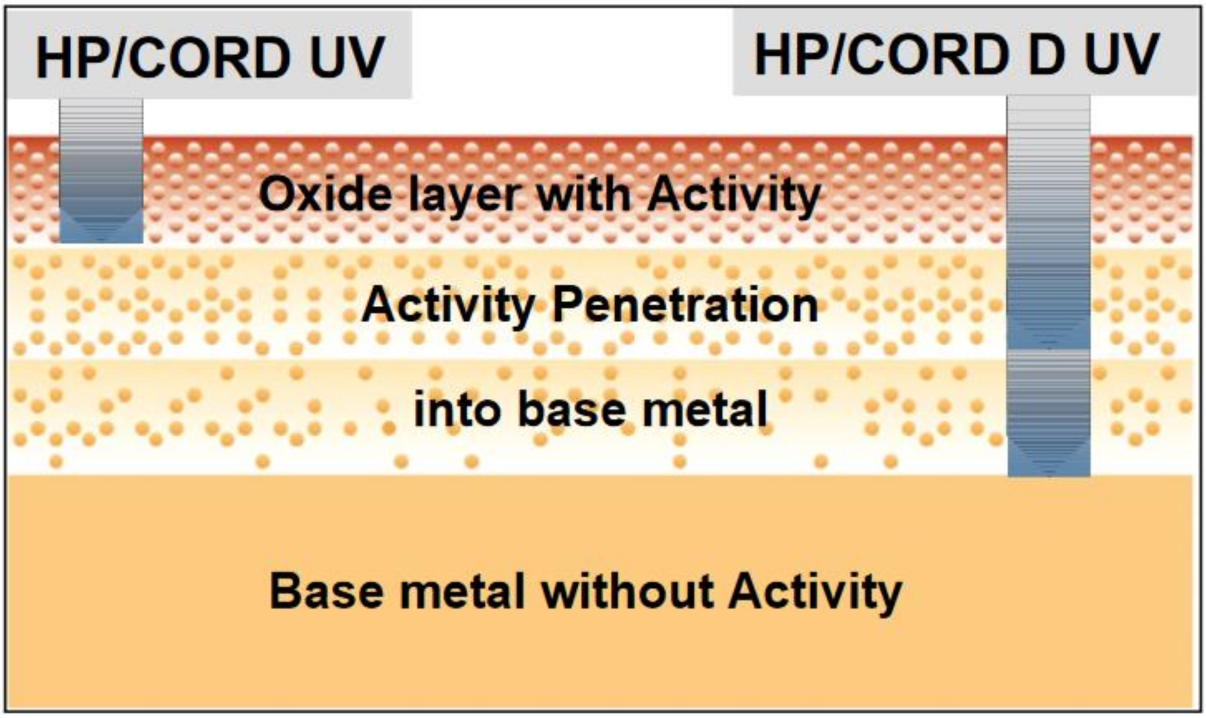



Figure 4-7: HP/CORD UV – HP/CORD D UV principles

### 4.1.3.2. Wet decontamination

This technique is well known from non-nuclear applications. It is used for superficial contaminations. Water at high pressure is used to spray on the surface. Complicated surfaces can also be cleaned. The consumption of additives is low.

Figure 4-8: Wet decontamination by high pressure water [reference EWN]

The applicability of the wet decontamination technique becomes limited when the contamination is chemically bound to the surface or has penetrated into the surface. In such a case a surface removal technique is advised.

For the sake of completeness, the simple washing with detergents, which is also a type of wet decontamination, is mentioned here.

### 4.1.3.3. Mechanical decontamination

Mechanical decontamination methods can be classified as either surface cleaning (e.g., sweeping, wiping, scrubbing) or surface removal (e.g., grit blasting, scarifying, drill and spall).

The procedures range from simple brushing with steel brushes to abrasion and mechanical removal of the surfaces for example by sandblasting. The procedures are applied on outer, well accessible surfaces of all materials with loose, dust like to firmly clinging contamination. The volume of secondary waste is relatively small, as the abrasive media, for instance, may be applied several times. A partial decontamination of surfaces is possible in order to remove so-called hot spots. Mechanical decontamination can be used as an alternative to chemical decontamination, simultaneously with chemical decontamination, or in sequence with chemical decontamination.

Mechanical decontamination can only be applied to accessible surfaces. The personnel needs are high; also the required protection measures against spreading of the dust are significant. The grit blasting technique is commonly called sand blasting or abrasive jetting. This technique uses abrasive materials suspended in a medium that is projected onto the surface being treated. It results in a uniform removal of surface contamination. Compressed air or water or some combination of both can be used to carry the abrasive. Removed surface material and abrasive are collected and placed in appropriate containers for treatment and/or disposal.

Grit blasting is applicable to most surface materials except those that might be shattered by the abrasive such as glass or Plexiglas. It is most effective on flat surfaces and because the abrasive is sprayed it is also applicable on hard-to-reach areas such as ceilings or areas behind equipment. Nonetheless, obstructions close to or bolted to the wall must be removed before application, and precautions should be taken to stabilize, neutralize, or remove combustible contaminants because some abrasives can cause some materials to detonate. Static electricity may be generated during the blasting process. Therefore the component being cleaned should be grounded. Remotely operated units are available.

Under dry conditions, dust-control measures may be needed to control dusts and/or airborne contamination. This problem can be reduced by using filtered vacuum systems in the work area. Depending on the application, the following variety of materials can be used as the abrasive media:

- Minerals (e.g. magnetite or sand)
- Steel pellets
- Glass beads/glass frit
- Plastic pellets
- Natural products (e.g., rice hulls or ground nut shells)

Figure 4-9: Dry blasting decontamination [reference EWN]

Figure 4-10: Blasting caisson at Kahl NPP

### 4.1.3.4. Scarification techniques

Scarification physically abrades both coated and uncoated concrete and steel surfaces. The scarification process removes the top layers of contaminated surfaces down to the depth of sound, uncontaminated surfaces. Today's refined scarifiers are not only very reliable tools, but they also provide the desired profile for new coating systems in the event the facility is to be free released for unrestricted use. For steel surfaces, scarifiers can completely remove contaminated coating systems, including mill scale, leaving a surface profile to bare metal. To achieve the desired profile and results for contaminated concrete removal, a scraping scarification process is implemented; for steel decontamination, a needle scaling scarification process is used.

### 4.1.3.5. Chemical decontamination

Chemical decontamination uses concentrated or dilute solvents in contact with the contaminated item to dissolve either the base metal or the contamination film covering the base metal. Dissolution of the film is intended to be non-destructive for the base metal and is generally used for operating facilities. Dissolution of the base metal should only be considered when reusing the item will never occur. Chemical flushing is recommended for remote decontamination of intact piping systems (primary system). Chemical decontamination has also proven to be effective in reducing the radioactivity of large surface areas such as floors and walls as an alternative to partial or complete removal.

The success of chemical decontamination methods depends on how aggressive the solvent is, on the duration, and on the temperature.

Figure 4-11: Chemical decontamination [reference EWN]

The advantages of chemical decontamination are that it can be used for inaccessible surfaces, it requires fewer work-hours, it can decontaminate process equipment and piping in place, and it can usually be performed remotely. Chemical decontamination also produces few airborne hazards, uses chemical agents that are readily available, produces waste that can be treated remotely, and generally enables the recycling of the wash liquors after further processing. For these procedures solvents, acids and alkali are used as decontamination agents. The decontamination result strongly depends on the aggressiveness, the reaction duration, the reaction temperature, and the material. While combined, mostly two-step procedures are the most successful.

The disadvantages of chemical decontamination are that it is not effective on porous surfaces, it produces large volumes of waste, it generates mixed waste and it can result in corrosion and safety problems when misapplied. In addition, it requires different reagents for different surfaces and drainage control; the construction of chemical storage and collecting equipment; and it requires addressing criticality concerns, where applicable. More disadvantages are the long reaction durations, the decreasing effect of the decontamination agent with increasing chemical saturation as well as the large quantity of secondary waste. The treatment and conditioning of the secondary liquid waste can also be challenging in order to meet the waste acceptance criteria.

### 4.1.3.6. Decontamination by melting

In the D&D process melting can be regarded as a method of decontamination. Whereas the melt (representing the main mass flow) is partially decontaminated, the activity will be accumulated in the slag, in the dust and in the cladding of the furnace. This distribution of activity can be controlled to a certain extent by adding slag forming materials. Imbedding activity into a liquid slag may be considered as a type of vitrification.

A particularly advantageous consequence of melting is its “decontamination” effect on Caesium-137, a volatile element that has a half-life of 30 years. During melting Cs-137 accumulates in the dust collected by ventilation filters and is removed. The dominant remaining nuclide in the ingots (for most reactor scrap) is Cobalt-60. This element has a half-life of only 5.3 years. Other remaining nuclides have even a shorter half-life. Consequently, ingots with reasonably low-activity concentrations may be stored for free release in a foreseeable future.

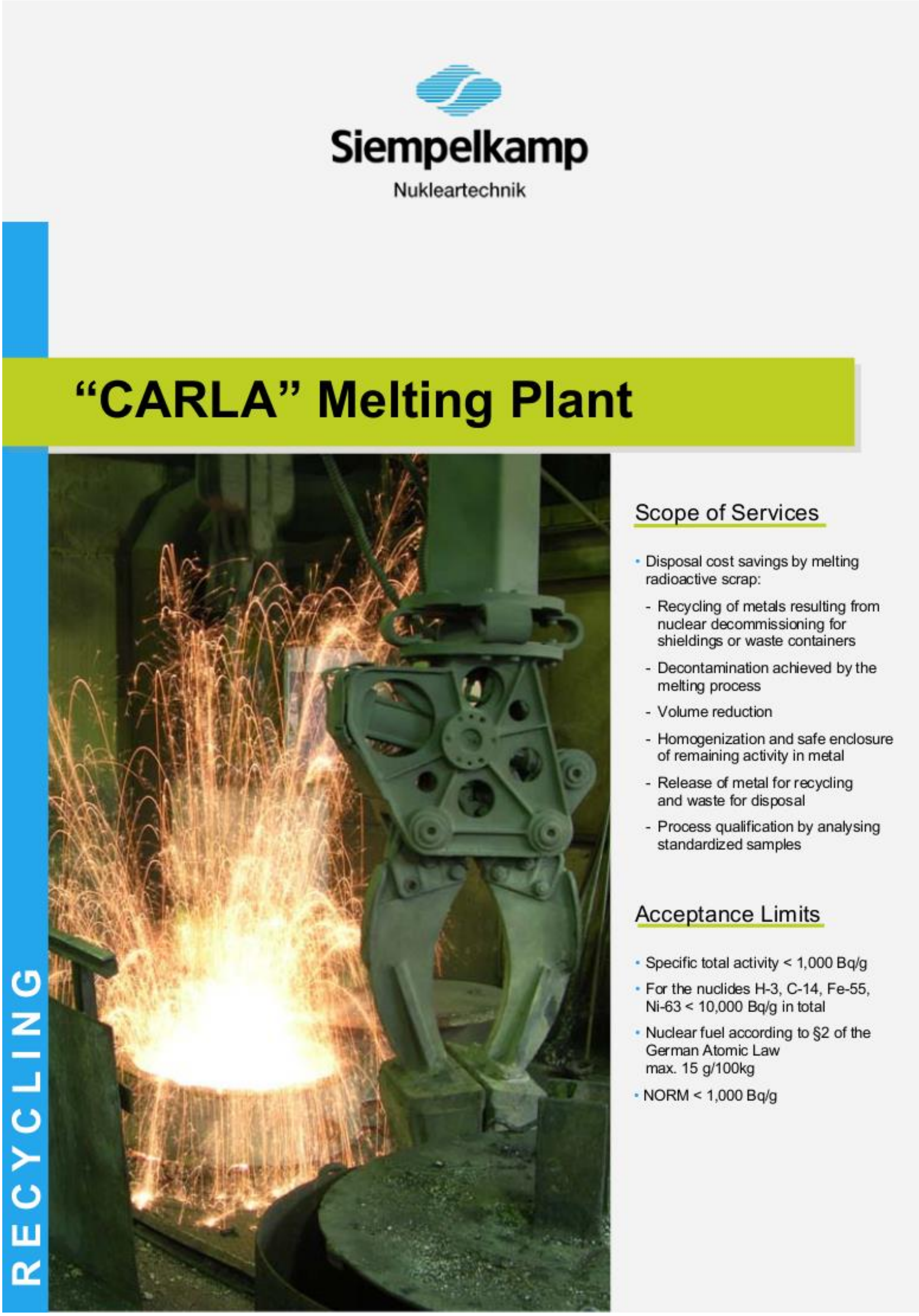
The dust is radioactive waste. Dust separated by electrostatic filters will be collected and filled in the same packages as the slag from melting. Filter cartridges from the ventilation system will be disposed of by the operator of the melting facility.

The melting of contaminated steel in special-purpose plants for recycling has developed as a new industry. Established techniques are used to minimize the quantity of active metallic waste. A number of plants have used and still use the melting process for contaminated metals on an industrial scale, including:

- CARLA Plant, Siempelkamp, Germany (see Figure 4-12, Figure 4-13)
- STUDSVIK Melting Facility, Sweden
- Energy Solutions Melting Facility, USA
- INFANTE Plant, Marcoule, France
- Science Ecology Group (SEG) Plant, Oak Ridge, USA
- Capenhurst Melting Facility, United Kingdom
- Manufacturing Science Corporation (MSC), Oak Ridge, USA

Not all of the a.m. facilities or plants offer melting services to external companies.

All melting equipment is operated in controlled areas using safety precautions, including filtered ventilation and health physics supervision. The slag and dust collected in the filters are treated as radioactive waste.



Siempelkamp
Nukleartechnik

# "CARLA" Melting Plant

RECYCLING

## Scope of Services

- Disposal cost savings by melting radioactive scrap:
  - Recycling of metals resulting from nuclear decommissioning for shieldings or waste containers
  - Decontamination achieved by the melting process
  - Volume reduction
  - Homogenization and safe enclosure of remaining activity in metal
  - Release of metal for recycling and waste for disposal
  - Process qualification by analysing standardized samples

## Acceptance Limits

- Specific total activity < 1,000 Bq/g
- For the nuclides H-3, C-14, Fe-55, Ni-63 < 10,000 Bq/g in total
- Nuclear fuel according to §2 of the German Atomic Law max. 15 g/100kg
- NORM < 1,000 Bq/g

Figure 4-12: "CARLA" melting plant (Siempelkamp; Page 1)

# CARLA
Central Plant for the Recycling of Low-Level Radioactive Wastes

## Technical Data

- Melting plant approved according to § 7 of the German Radiation Protection Ordinance for the treatment of radioactive materials
  - Melting unit: 3.2 to MF induction-furnace
  - Equipped with a 3 -step filter unit in 2 lines
- Mechanical and thermal cutting facilities available
- Pre-decontamination by blasting
- Melting and pouring to 1 ton metal blocks or to granules
- Recycling of the metal blocks to shieldings or waste containers made of ductile cast iron or heavy concrete
- Storage of metal blocks for decay
- Release of metal for recycling or waste for disposal

## Metals

- Carbon steel (coated, uncoated)
- Carbon steel (galvanized)
- Stainless steel
- Alloys
- Compound materials (e.g. lead/steel)
- Aluminium
- Cooper, brass
- Lead

## References

- Melted scrap 24,000 tons (as of 12/2008) from
  - Operation and decommissioning of nuclear facilities from national- and international sites
  - The decommissioning of the fuel fabrication plant
  - Operation and decommissioning of uranium enrichment facilities
  - Decommissioning of national and international research reactors
  - Production of more than 5.000 MOSAIK® casks using recycling material

Charging the furnace

Pouring liquide iron to granules

Ingots stored for recycling

**www.siempelkamp.com**

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Figure 4-13: “CARLA” melting plant (Siempelkamp; Page 2)

### 4.1.4. Radiological measurement equipment

*Measuring of superficial contamination by direct measurement*

For a direct measurement the measuring device needs access to the surface of the material. A technical instruction manual will describe items such as the distance between measuring device and the measured material, the damping factor to be used, and the duration of the measurement. The calibration instructions will consider the type of material, the surface condition and the assumed penetration depth of the contamination.

If the distribution of the contamination is known to be rather homogeneously distributed, then samples can be taken from representative surfaces.

*Measuring of superficial contamination by indirect measurement*

Such measurements are normally used for preliminary inspections. Material samples (pieces of material, drill samples) and / or superficial samples (from scratching or wiping) will be investigated. The analysis can be nuclide specific. Usual techniques are the gamma nuclide analysis and the liquid scintillation measurement technique. In some cases special analyses must be made for non-gamma emitters (alpha, or pure beta emitters).

*Total gamma measurement*

Total gamma measuring devices will measure complete materials. The measuring result data will be processed by specialized software to make sure that the free release levels are complied with and all measurements and decisions will be documented in a traceable way.

*Measurement of representative samples*

Sometimes – especially in case of decision measurements for bulk material or for liquids – it is more favourable to measure the specific activity using samples of the material. In that case representative samples will be taken and measured. For material with large volume a combination of sampling and direct measurement can be the optimum solution.

*In situ gamma measurements*

Infrastructure (such as parts of building structures, or external areas: earth, roads) can be measured using in situ gamma spectrometry. In this case for example complete rooms or room areas are measured at once. This assumes that a pre-examination has shown that the distribution of the contamination is sufficiently homogenous, and that the penetration depth of the contamination is known.

*Nuclide specific gamma measurements (gamma spectrometry)*

Nuclide specific gamma spectrometers can measure complete batches at once for gamma nuclides. The result is a spectrum of the total batch with additional information about the partition of the activity in the batch. This procedure is more complex than the total gamma measurement, but it delivers more information.

*Hand-held monitors*

The hand-held beta-gamma contamination monitor for the measurement of radioactive surface contamination is based on high performance Xenon filled proportional counter technology or another proven technique.

The detection technique provides extremely high sensitivity for both beta and gamma radiation. The instrument is therefore ideally suited for the measurement of photon emitting radionuclides, widely found in nuclear facilities.

The software of these monitors offers many useful modes of operation, complex functions, utilities, and access to all parameters for experienced users. For unskilled users the instrument's configuration can be defined in supervisor mode as a simple or even extremely simple system. The supervisor can grant access authorization for user profiles only for selected menus, functions or parameters according to the special needs of the site. The instrument has a memory to store measured values and bi-directional serial RS232 communication. This provides program download, parameter download, remote control and data transfer to a host computer or printer.

*Germanium detectors*

Germanium detectors are semiconductor diodes having a P-I-N structure in which the Intrinsic (I) region is sensitive to ionizing radiation, particularly X-rays and gamma rays. Under reverse bias, an electrical field extends across the intrinsic or depleted region.

When photons interact with the material within the depleted volume of a detector, charge carriers (holes and electrons) are produced and are swept by the electrical field to the P and N electrodes. This charge, which is in proportion to the energy deposited in the detector by the incoming photon, is converted into a voltage pulse by an integral charge sensitive preamplifier. Because germanium has a relatively low band gap, these detectors must be cooled in order to reduce the thermal generation of charge carriers (thus reverse leakage current) to an acceptable level. Otherwise, leakage current induced noise destroys the energy resolution of the detector. Liquid nitrogen, which has a temperature of 77 K is the common cooling medium for such detectors.

The detector is mounted in a vacuum chamber which is attached to or inserted into a liquid nitrogen Dewar or an electrically powered cooler. The sensitive detector surfaces are thus protected from moisture and condensable contaminants.

*Preamplifiers for germanium detectors*

There are only two basic types of preamplifiers in use on Ge detectors. These are charge sensitive preamplifiers that employ either dynamic charge restoration (RC feedback) or pulsed charge restoration (Pulsed optical or Transistor reset) methods to discharge the integrator.

Pulsed Optical Reset preamplifiers are widely used on low energy detectors where resolution is of utmost importance. Eliminating the feedback resistor decreases noise without a serious impact on dead-time, as long as the average energy per event is low to moderate.

At 5.9 keV per event, a preamplifier may process almost 1,000 pulses between resets. Since the reset recovery time is 2-3 amplifier pulse widths, little data is lost in this situation. Optical feedback systems can, however, exhibit long recovery times due to light activated surface states in the FET (field effect transistors).

Proper selection and treatment of components can minimize the problem, but it is generally present to some degree in pulsed optical systems. With high energies, where resets necessarily occur very often, perhaps after as few as 10 events, this spurious response can be a serious problem. As a consequence, pulsed optical feedback systems are not in general used with coaxial detectors.

The Transistor Reset Preamplifier was developed in an attempt to overcome the problems associated with pulsed optical reset preamplifiers in high energy, high rate systems. The feedback capacitor is discharged by means of a transistor switch connected to the FET gate. This transistor adds some capacitance and noise to the input circuit but this is tolerable in most applications involving high count or energy rates. Compared to an RC preamplifier with selected feedback resistor for high rate performance, the transistor reset preamplifier will exhibit less noise but will sacrifice dead-time because the amplifier will require 2-3 pulse widths to recover from the periodic reset of the preamplifier.

*Measurements in free release stations*

The free release decisions will be made on the basis of total gamma activity measurements. The measurement equipment and the software used will be flexible so they can be adapted to special cases, and they will be capable to detect any local concentrations of activity.

As the nuclide vectors will be complex, the key nuclides will be determined first, and the free release levels for these key nuclides will be fixed. The selected measuring technique will allow demonstrating that the relevant nuclides are below the free release level.

Depending on the type and properties of the material, the throughput is approx. 10 Mg per day. Experience shows that, as a typical value, more than 90% of the material presented for free release can be free released without restrictions, or as conventional waste.

### 4.1.5. Free release of components, equipment, buildings and site

#### 4.1.5.1. Types of free release

*Free release from nuclear regulations*

In most cases the expression "free release" means the free release from nuclear regulations as regulated in the radiation protection regulations [12]. Measurements will be made to demonstrate that the components, batches, building structures, areas, etc. are below the permissible maximum limits. The instructions to be followed and the limits to be complied with will be described in a working procedure. The materials to be free released may be checked and measured by the competent authorities. The material can leave the site only after official free release by the authorities.

*Free release for transportation*

A special type of free release is the free release for the transportation of radioactive material. Measurements will be made to demonstrate that the individual packages are below the limits for transportation, and also the complete batch (for example a truck with several waste packages) will be measured. The instructions to be followed and the limits to be complied with will be described in a working procedure. The waste packages can leave the site only after official free release by the authorities.

#### 4.1.5.2. Concept for free release from nuclear regulations

A site specific free release concept will be prepared as a basis for the free release of material from the controlled area. The free release concept will cover the legal aspects, the relevant extracts from the D&D license, the agreements with the authorities, the description of the measurement and free release procedures, and the documentation of the results and decisions.

#### 4.1.5.3. Requirements to be satisfied for free release

The requirements and the procedures for free release are different for components and equipment on one hand, and for building structures and site on the other hand.

Stationary free release equipment is used for components and equipment. If needed the parts are cut and decontaminated, and then sent to the decision measurement station.

The operator of the site will prepare work instructions for the free release of components and equipment. These are detailed documents that are based on the free release concept. They include all technical and practical details that must be observed and complied with, for example:

- With respect to the product:
  - The types of material susceptible to free release
  - The physical, chemical, and radiological acceptance criteria for the measurement station
  - The packages to be used
- With respect to the measurements:
  - The measurement devices to be used
  - The settings (range of measurements, sensitivity, duration of measurements, etc.)
  - The limits to be complied with
- With respect to the documentation:
  - The forms to be used
  - The data to be recorded

- Signatures, distribution, filing
- Interactions with the authorities (information of authorities, waiting points, independent measurements, checks)
- References to other documents to be complied with (for example: references to the calibration instructions for the measuring equipment)

The same is valid for building rubble, concrete blocks etc. from dismantling work in the controlled area as described in the following sections:

- 4.1.5.5 “Dismantling of the building structures inside the primary containment”
- 4.1.5.6 “Mass specific free release of building concrete”

Buildings, external areas, and the site will be free released in another way. Work instructions will also be prepared for this type of free release. The measurements will be performed in situ using mobile measurement equipment. This is described in the following sections:

- 4.1.5.7 “Building decontamination and free release of nuclear buildings“
- 4.1.5.8 “Free release of non-nuclear buildings”
- 4.1.5.9 “Free release of external areas”
- 4.1.5.10 “Clearance of unit from nuclear regulations”

As described above for the components and equipment, the work instructions will contain detailed descriptions of what has to be done precisely. But there is a difference: in case of a component, if the free release fails, then the component can be rejected and declared as radioactive waste. In case of a building this is not a satisfactory solution. Therefore in case of buildings, external areas, and the site, the work instructions will describe what has to be done under which circumstances such as:

- What to do with building joints?
- What to do with cracks in the concrete?
- What to do with embedded pipes?
- What to do in case of any other finding?

The work instructions will contain detailed prescriptions on how to proceed under different circumstances. For example, for the free release of a building for conventional demolition (this means for clearance of a building from nuclear regulations) it makes a big difference if the building is a reactor building or a nuclear auxiliary building (where it is quite sure that there are contaminated concrete structures), or a turbine building (where light local contamination is likely), or a visitor building (where no contamination at all is expected). Therefore the work instructions to be followed will differ from building to building (or even from building area to building area) to reflect the use and the history of the buildings.

#### 4.1.5.4. Free release of components and equipment

Components and equipment to be free released are cut and decontaminated, if needed, and then sent to the decision measurement station. The decision measurements will be performed per batch. The free release procedures will be complied with, and all measurements will be documented. Portions that cannot be free released will be removed from the batch and sent back to the waste conditioning station.

The documentation for the batch will be presented to the authority or its representation. They will check the documentation and perform independent measurements. After free release by the authority the batch is cleared from nuclear regulations and can be removed from the site.

Figure 4-14: Free release measurement facility for components [reference Kahl NPP]

Figure 4-15: Free released metallic material for recycling [reference Kahl NPP]

### 4.1.5.5. Dismantling of the building structures inside the primary containment

The building concrete structures, inside the primary (inner) containment, are a special case. After building decontamination they are dismantled under controlled area conditions and the pieces and rubble undergoes a measurement and free release (as if they were dismantled components). During this civil dismantling work the static stability of the remaining structures will be secured.

Figure 4-16: Dismantling of concrete inside containment

After removal of the steel liner on the internal surface of the primary containment, the inner and outer surfaces of the primary containment will be accessible for radiological measurements. It is likely that these structures can be free released as a whole and that after the free release of the building these structures can be dismantled under conventional (non-nuclear) conditions. If needed, holes will be drilled to take samples from the concrete to demonstrate that the structure can be free released as a whole.

### 4.1.5.6. Mass specific free release of building concrete

Dismantled concrete, candidate for free release will be crushed, and the rubble will be put in drums for easier handling, to minimize dust, and to enable mass specific measurements.

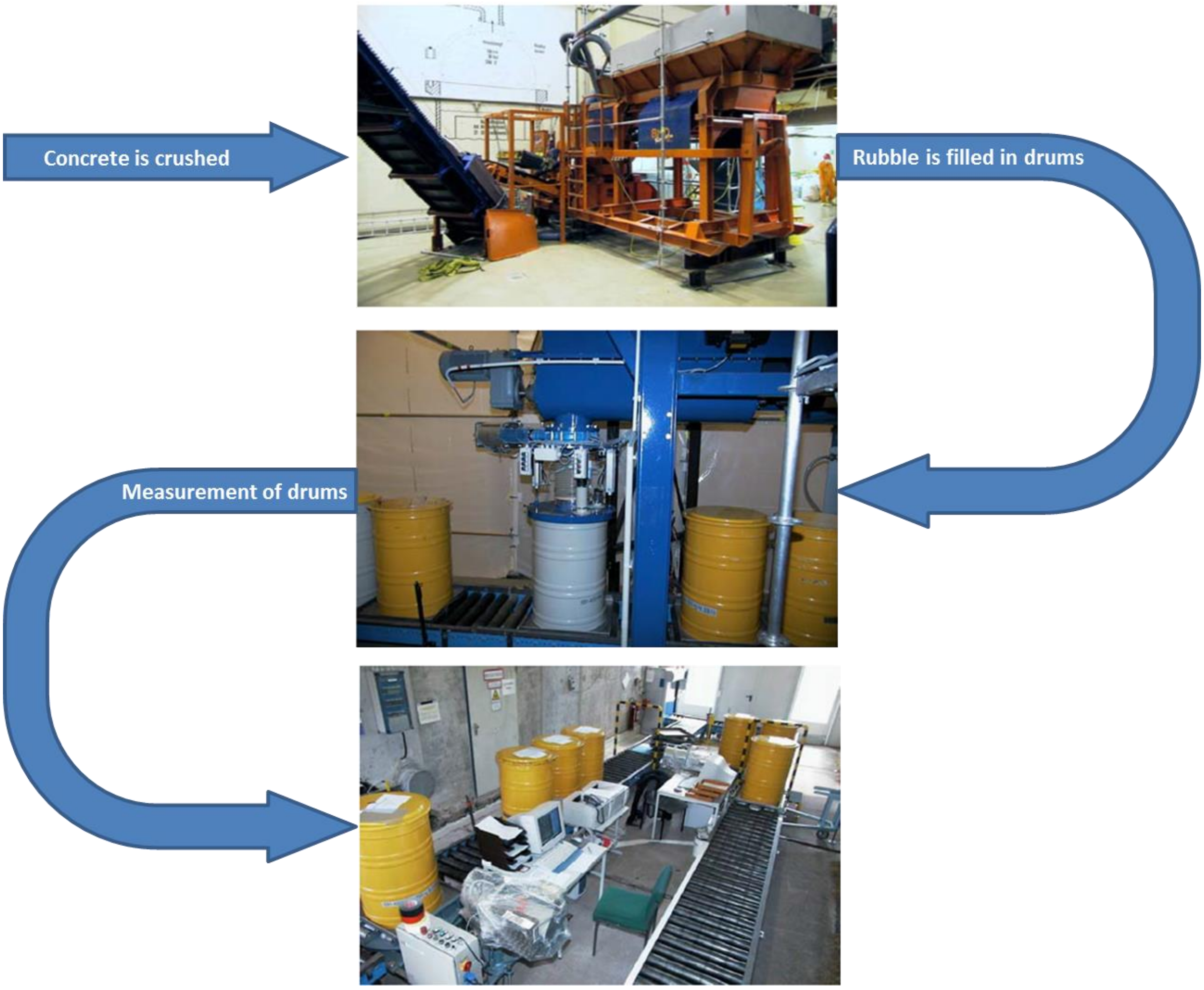


Figure 4-17: Mass specific free release measurements for dismantled concrete

Figure 4-18: Free released concrete to be used for filling of pits

### 4.1.5.7. Building decontamination and free release of nuclear buildings

Building structures outside the metallic liner of the primary containment will be decontaminated, if needed, and free released in situ. The dismantling can then be performed under conventional conditions.

When all components and equipment are removed from a specific area, and the modified ventilation and media supply systems are in operation (pressurized air, electrical energy and lighting), this area is separated from the rest of the controlled area.

*Characterization in advance*

The operator will perform a detailed radiological characterization to identify the nuclide vectors and to localize the contamination. The relevant surfaces to be measured and the measurement grid for specific measurements will be marked on the surfaces. The characterization will be done in the first place by fully scanning the surfaces using common tools such as Contamat[2] or Scintomat[3].

Figure 4-19: FHT 111 CONTAMAT®

Figure 4-20: SCINTOMAT ® Hx model: 6134A

At some places the removal of concrete layers or core hole drilling will be used to take samples which will be measured in the laboratory. Other places such as embedded steel or anchor plates can be suitable for wipe tests. The results will be documented in an “initial state report”. Some illustrations are shown in Figure 4-21 and Figure 4-22.

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[2] CONTAMAT® is a trademark of company Thermo Fisher Scientific (www.thermo.com/rmp). A Contamat is an alpha, beta, gamma meter with simultaneous measurement of alpha and beta.
[3] SZINTOMAT® (English spelling: SCINTOMAT) is a trademark of company Automess GmbH (www.automess.de). A Scintomat is a photon (gamma and X-rays) meter.


Figure 4-21: Concrete in controlled area during radiological characterization


Figure 4-22: Hotspots are identified and marked

*Detailed planning of building decontamination*

The initial state report is the basis for the detailed planning of the building decontamination measurements. The detailed planning will cover the following:

- The list of hotspots to be removed at the beginning
- The areas to be decontaminated and to which extent
- The thickness of the concrete layer to be removed
- What to do exactly in areas where contamination has entered into cracks
- The areas where concrete will be removed and for what purpose (to be free released using mass specific free release or to be packed as radioactive waste)

The detailed planning of the concrete decontamination measurements will be checked and approved by the authority.

*Surface decontamination*

The surface decontamination is performed in three steps:

- First superficial hot spots are removed
- Then superficial discontinuities are treated (concrete cast-in anchoring rails, dowels, fixation elements)
- Finally the surface is scarified

The scarification techniques are described in section 4.1.3.4.

Figure 4-23: Preparation of scarification: removal of dowels

*Removal of deeper contamination*

Deeper contamination can be found for example:

- In deeper discontinuities;
- In cracks, in pipe penetrations;
- In civil work joints;
- In narrow spaces or shafts.

The decontamination is done by removing material using hand-held pneumatic hammers, core hole drillers, small excavators with a chisel, and sometimes wire ropes.

Figure 4-24: Removal of deeper contamination

*Removal of activated or large amounts of contaminated material*

Larger amounts of material can be removed either using an excavator with a chisel, and sometimes wire ropes. In some cases complete walls or bottoms are removed.

Figure 4-25: Removal of large quantities: left excavator, right: wire rope

Mass specific free release can be used for such material.

*Characterization for free release*

After finalization of the decontamination work, the operator will perform a final characterization using in situ gamma spectrometry, and Contamat measurements at locations which are difficult to access.

At specific points, depth profiles are prepared and measured.


Figure 4-26: Free release measurements

The results will be documented in a “final state report”. This will be presented to the authorities, with the application for free release.

The in situ gamma spectrometry can measure non-superficial radioactivity which is of great importance in case of cracks or at building joints. The calibration can be adapted to the actual situation. Gamma nuclides are identified selectively, and the threshold for the recognition of low level gamma rays (Am-241) is very low.

*Checks by authority*

The authorities will check the paperwork and the documentation, but they will also perform their own independent measurements. At the end, they will free release the area(s) or the building(s) which means that they are no longer part of the controlled area. The free release is an official act.

#### 4.1.5.8. Free release of non-nuclear buildings

The non-nuclear buildings can be classified as follows:

- Buildings for which it is evident that they have never been contaminated (e.g. administrative buildings)
- Buildings for which one can be quite sure that there has never been a contamination (buildings containing systems with no potential contamination)
- Buildings with a non-negligible risk of contamination (turbine building)

In preparation of the free release of the non-nuclear buildings the operator has to prepare an explanatory report which describes the operational history of a building and the risk of contamination. If the operator can demonstrate that there is no risk of contamination, an immediate demolition is possible. If not, the free release procedure and the radiological limits are in principle the same as for (potentially) contaminated buildings in the controlled area, see section 4.1.5.7.

#### 4.1.5.9. Free release of external areas

Spot tests will be performed to prove that the surroundings (streets, free areas) are free from nuclear contamination. The techniques to be used and the samples to be taken (location, specification, and number) will be described in a technical report that will be agreed upon with the authority.

Figure 4-27: Gamma spectrometry of paved (left) and unsurfaced (right) external areas

The present study is based on the assumption that outside the controlled area no contamination will be found that could have a significant impact on the D&D plan, on the time schedule, or on the costs.

#### 4.1.5.10. Clearance of unit from nuclear regulations

When all the aforementioned steps are performed for a unit, the unit can be cleared from nuclear regulations. A report will be prepared describing the actual status of the unit. The authorities will check the report and confirm the clearance from nuclear regulations. The area and the activities on it are then ruled by the conventional regulations for industrial sites under dismantling.

### 4.1.6. Dismantling of non-nuclear equipment and buildings

The present section describes the procedures to be followed in the non-nuclear buildings and in the nuclear buildings after free release. In the present section, the expression “contamination” refers to conventional (non-nuclear) contamination.

The conventional dismantling includes:

- The preparation of a report on toxic substances
- The preparation of the dismantling
- The removal of toxic substances such as asbestos and other mineral fibres
- The removal of building related toxic substances such as tar or polychlorinated biphenyls (PCB)
- The removal of toxic substances from operation such as spilled oil
- The removal of wooden doors with lacquer or varnish coating
- The dismantling of the buildings
- The separation of the material fractions

#### 4.1.6.1. Preparation of report on toxic substances

The aim of this exercise is to explore the equipment and the building structures to find and identify present or potentially present toxic substances in the building or in the surroundings. The findings will be classified from the waste handling, treatment, conditioning and disposal points of view, and the risk potential for the planned dismantling works and for the waste management will be evaluated.

The data collection for the compilation of toxic substances from operation (for example from oil in workshops) or from building related substances (such as asbestos, tar, or PCB) will rely on a detailed visiting and sampling program. Samples will be taken in the suspected and in the apparent areas with toxic substances (worst case), but also in the peripheral areas to define the limits of these areas.

For the exploration of eventual accompanying contaminants and for the analysis of the inconspicuous basic structure of the building a two-stage procedure will be applied. In the first stage the parameters relevant for the repository (pH value, electrical conductivity, chloride and sulphate content) will be measured on individual test probes. When the results are known, mixed probes will be prepared for the additional analyses to be performed for the waste categorization (declaration analyses) and checked with respect to the relevant parameters of the legal prescriptions.

Samples will be taken from the whole thickness of the mineral basic structures of the buildings (concrete, brickwork) by using diamond core drills. Brickwork is removed by core drills or by chiselling, and individual samples are taken as needed from grouting material, from substances suspected to contain asbestos, from insulation material etc. (by cutting, levering, scratching or similar). The samples are collected in suitable boxes and identified (identification and date).

The samples will be examined immediately after they have been taken. If needed, on-site tests will be performed to get a first orientation (for example flame tests as a first indicator – not as a replacement for laboratory tests – if the building material is suspected to contain asbestos).

### 4.1.6.2. Notices with respect to dismantling

The report on toxic substances will reveal where toxic or contaminated substances will be encountered during dismantling. Before the dismantling work can start, a work and safety plan will be prepared. The owner will designate a responsible person for health and safety, and the works will be supervised by a surveyor department. The planning of the work will strive for a high rate and quality of recycling for the dismantled material. The different fractions will be strictly separated and lead to the correct waste management paths.

### 4.1.6.3. Preparation of the dismantling

*Dismantling and removal of asbestos containing components and structures*

The dismantling and removal of asbestos containing components and structures is strictly regulated. The works will be performed by a specialized company which has the needed permits prescribed in the regulations.

*Dismantling and removal of structures containing mineral fibres*

Mineral fibre materials are often used for building isolation, but also for the isolation of heating pipes. The dismantling of such material is regulated. These rules stipulate the procedures to be followed and the health protection measures to be taken.

*Gutting individual buildings*

The buildings are gutted which transforms them into a building shell again. The work will be done under consideration of the employment protection rules. The different fractions (wood, glass, metals etc.) will be carefully separated and recycled as far as possible. The specific rules for waste requiring special supervision and conditioning (such as fluorescent lamps, starters, condensers) will be considered.

*Removal of roofing membranes and tar-bitumen roof sheeting*

The roofing and the isolation will be separated carefully from the concrete structure. Where pebbles are used for the roofing, they can normally be recycled without problems. Pebbles sticking to the bitumen will be disposed of together with the bitumen.

*Removal of contaminated seals*

Special techniques and tools (like milling machines) will be used to remove tar or PCB containing seals in the buildings and in the surroundings. The waste will be removed and disposed of separately.

*Removal of contaminated areas (soil and surface sealing, floor pavement)*

If the surfaces or pavements fall into a different category (from a waste management point of view) than the concrete below it, they will be removed and disposed of separately.

### 4.1.6.4. Conventional dismantling of the building structures

The building structures will be dismantled with conventional techniques and procedures under consideration of the relevant technical rules and prescriptions. As far as possible the different waste categories will be separated (concrete, masonry, etc.). Moisture barriers will be separated from the mineral material so that the mineral material can be reused.


Figure 4-28: Conventional dismantling of the building structures

## 4.2. R&D program

R&D is at this moment not expected to be part of the D&D project. R&D involves the activities of research and development in the case where new specific data are needed for design and construction of special equipment for characterisation, decontamination, dismantling waste management and for safety aspects, for development of new procedures and techniques. Research and development activities may play an important role especially in decommissioning projects involving old facilities being dismantled long after shutdown, decommissioning of facilities following an accident, facilities with damaged spent fuel, and those having large amounts of historical and legacy waste in storage in the facility. In these cases, research and development may be needed to determine the precise status of the facility, for identifying or adapting solutions for characterisation, decontamination, dismantling, and waste management and for ensuring the safety of the post-accidental situations of systems and structures and in the event of using new or adapted procedures.

## 4.3. Planning

The following chapter gives first a basic presentation and description of the time schedule of the time critical path for the decommissioning activities for the Krško NPP site with its general arrangements of the working packages. In a second step the Work Breakdown Structure (WBS), which is the basis of the software program CALCOM, is explained whereby the costs for decommissioning are presented in chapter 15.

### 4.3.1. The sequence of D&D works

The basis for the preparation of the time schedule are the shutdown date of the plant as well as the operation periods of the Spent Fuel Dry Storage (SFDS) onsite provided by NEK for the base case and the sensitivity case (see Table 4-1). Using the given dates, NIS plans the D&D actions of the units and the site with their schedule dependencies by using the software program CALCOM.

**Final shutdown and SFDS operation periods**

| | | |
|---|---|---|
| Preparatory & licensing work | 2040 | Base case & sensitivity case |
| Final shut down NPP | 2043 | Base case & sensitivity case |
| Movement spent fuel to SFDS | 2048 - 2050 | Base case & sensitivity case |
| End of SFDS operation | 2103 | Base case |
| End of SFDS operation | 2075 | Sensitivity case |

Table 4-1: Final shutdown of Krško NPP and SFDS operation periods

NOTE: Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.

#### 4.3.1.1. General approach

The general approach, based on the comprehension of NIS, for the shutdown and immediate dismantling of nuclear sites can be basically represented by the following steps – site specific and strategic agreements excluded:

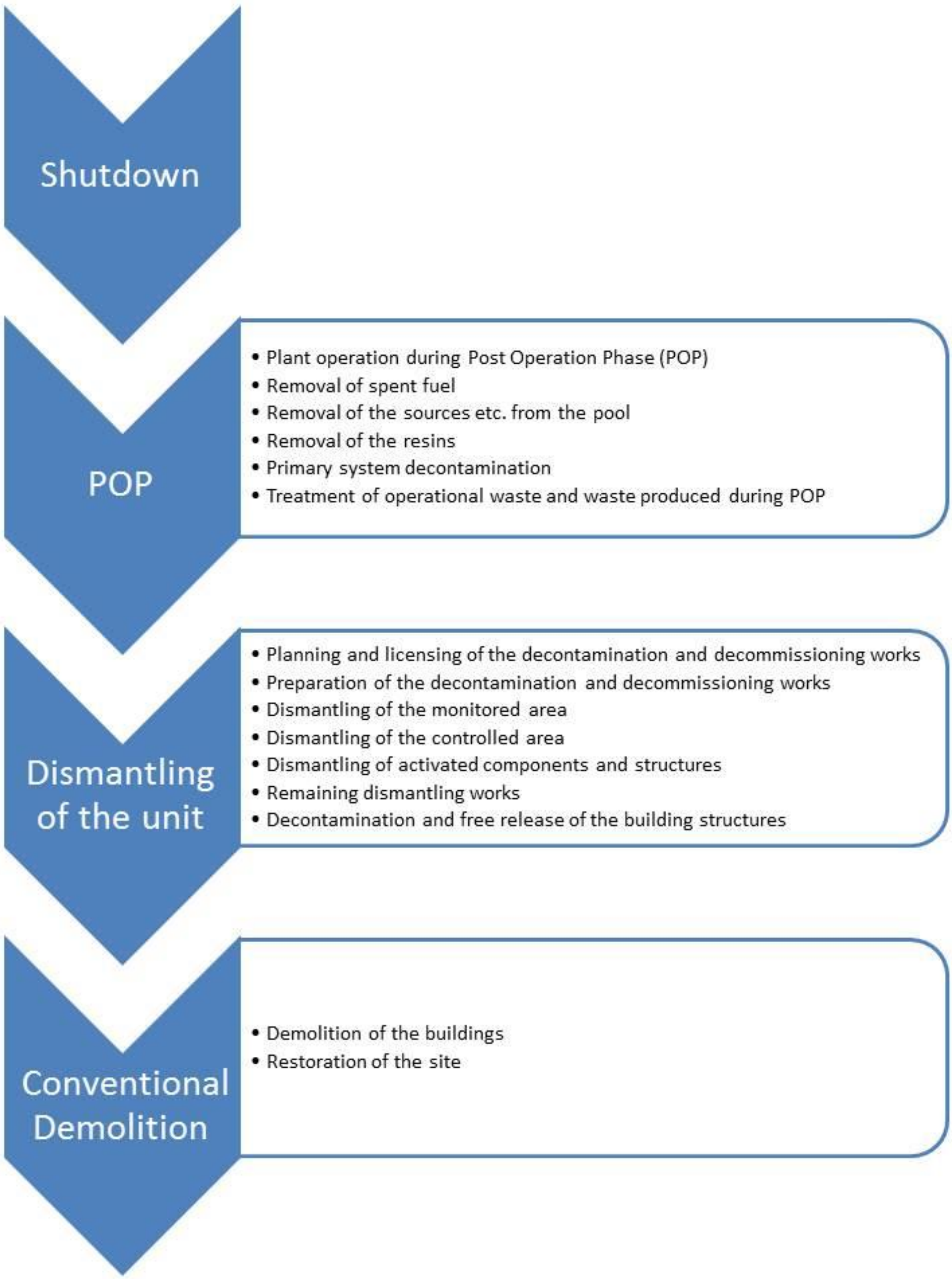



Figure 4-29: General approach for the D&D process

From NIS' point of view, the following considerations have to be taken into account as site specific and strategic conditions for the Krško site:

- The cutting of the removed and interim stored old SGs and RPV head in the DB
- The preparation of waste management area in the DB, IB, FHB and WMB
- The decommissioning license will be delivered on final shut down
- The nuclear and conventional dismantling works may only start after the D&D license is granted
- The dismantling in the controlled area buildings e.g. contaminated dismantling in the AB or RB are performed in parallel with the time critical path projects and are shown in Figure 4-39

The conventional demolition of the units and common buildings shall take place immediately after the free release of the SFDS, in order to avoid an increase of the overall project duration.

The further considerations are mainly focused on the presentation and description of the procedures taking place in the reactor building.

Only the durations that are relevant for the generation of the time critical path are described hereafter.

#### 4.3.1.2. Projects for the sequence of D&D works

This section gives an overview of the projects that are relevant for the critical path for a decommissioning project of a nuclear site. The overall arrangement of the working packages and the overall D&D time-schedule being is the topic of section 4.3.1.3.

As already described, the critical path is crucial for the planned completion of the final project end date. Therefore the modules of the critical path are listed and described hereafter, including their dependencies.

*Pre-decommissioning actions,*


Figure 4-30: Pre-decommissioning actions

The pre-decommissioning actions contain all activities up to the final shutdown of the plant.

Such D&D activities are:

- Collection of technical data (technical and radiological status of the plant)
- Project planning and engineering (actualization of the preliminary decommissioning plan – primary contractor selection – purchasing of installations and D&D equipment, like clearance measurement facility, cutting and packaging equipment)
- Licensing procedure, which covers the approval of one general license including the detailed technical concept and the accompanying D&D work of experts and authorities, like supervision of safe operation of remaining systems
- Final Shutdown of the plant

*Preparation of the D&D works:*

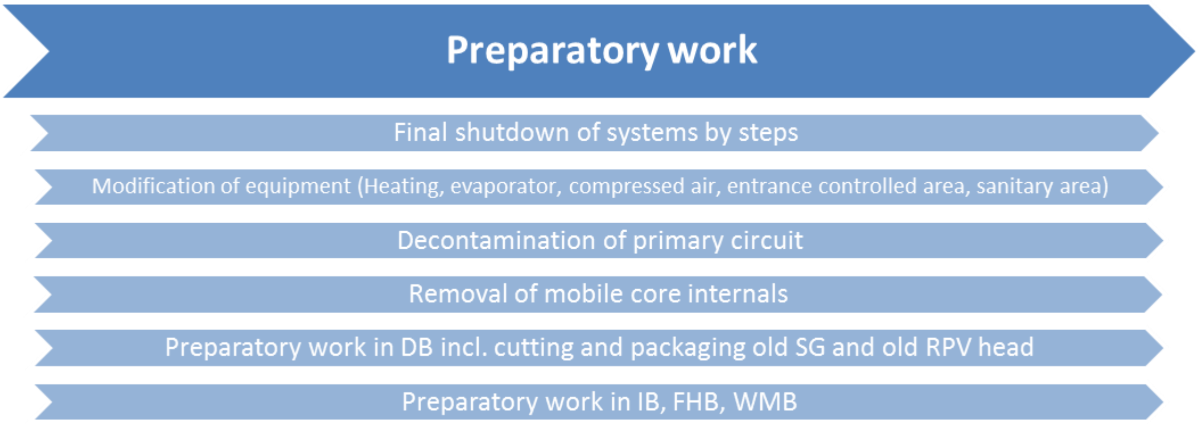



Figure 4-31: Preparatory work

After the final shut down, the preparatory work for the decommissioning project is performed.

It contains measures, which are prerequisite for the D&D work after final shutdown and continues the work of the package above after the D&D approval.

- Shutdown of the systems as well as modifications of equipment
- Decontamination of the primary circuit
- Removal of mobile core internals
- Modification of decontamination building (DB) as well as installation of new facilities
- Preparation of material treatment facility (auxiliary building)
- Cutting and packaging of stored (old) SGs and old RPV head

The shutdown of systems can be performed right after the D&D approval. This section is structured like follows:

- Creation of concepts and preliminary evaluation
- Discussions with external experts/agencies
- Performance of shutdown of systems
- Acceptance of shutdown

The shutdown can either relate to single systems or groups of systems. Modifications on systems still necessary for the remaining operation are to be performed in order to reduce the expenses for maintenance and periodic checks. The groups of systems to be modified are the heating, evaporation and pressurized air system.
The primary circuit is to be decontaminated to reduce the dose rate for further dismantling activities.

The removal of mobile core internals, like control rods, core instrumentation lances and fuel assembly channels. After shutdown they are cut into pieces in the spent fuel pit and packaged according to the final repository acceptance criteria.

*Dismantling of primary loop components:*

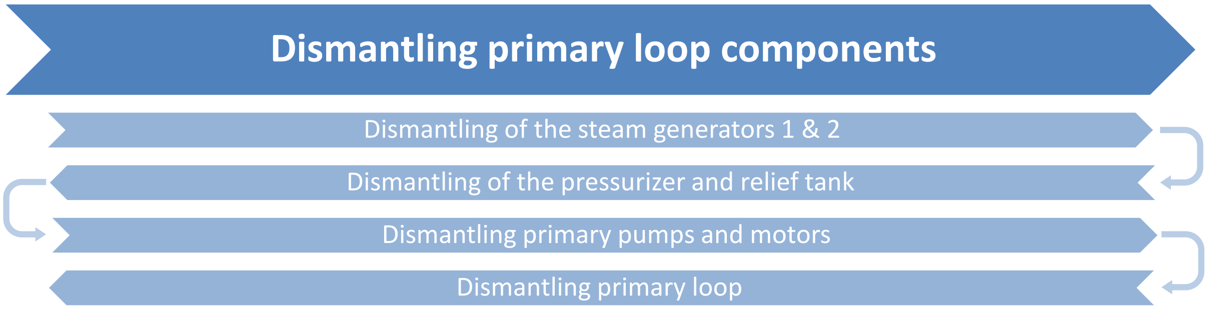



Figure 4-32: Dismantling primary loop components

This project covers the dismantling of the following main components of the primary loop:

- SG 1 & 2
- Pressurizer
- Pressurizer relief tank
- Primary pumps and motors
- Loop

*Dismantling of the RPV internals:*

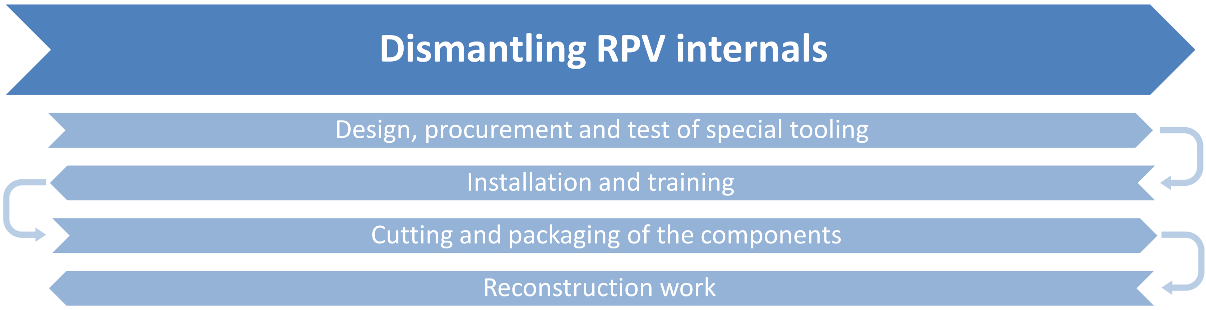



Figure 4-33: Dismantling RPV internals

The dismantling of the RPV internals is performed after the dismantling of the primary loop components. It contains the dismantling, cutting and packaging of the RPV internals. This includes:

- Design, procurement, and testing of special tooling/equipment for remote dismantling work
- Simulation of complicated work on models and training of personnel
- Preparation work
- Necessary reconstruction and rehabilitation work in the reactor pool area
- Preparation and reconstruction work on systems in operation

The internals will be cut and packaged in the reactor pool directly. An underwater technique is planned.

*Dismantling of the RPV:*

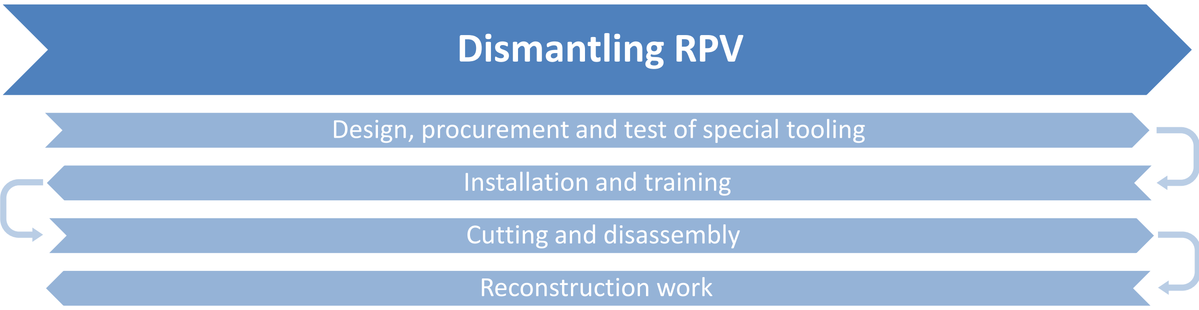



Figure 4-34: Dismantling of the RPV

The next project on the critical path is the dismantling of the RPV. The preparation work is linked to the end of the dismantling of the RPV internals and starts with the preparation of the reactor pool to install the dismantling equipment. The dismantling work can start as soon as the installation works are finished.

This project contains the dismantling, cutting and packaging of the RPV. This includes:

- Design, procurement, and testing of special tooling/equipment for remote dismantling work
- Simulation of complicated work on models and training of personnel
- Preparation work
- Preparation and reconstruction work on systems in operation

The RPV will be cut and packaged in the installed place. An underwater technique is not necessary.

*Dismantling of the biological shield:*

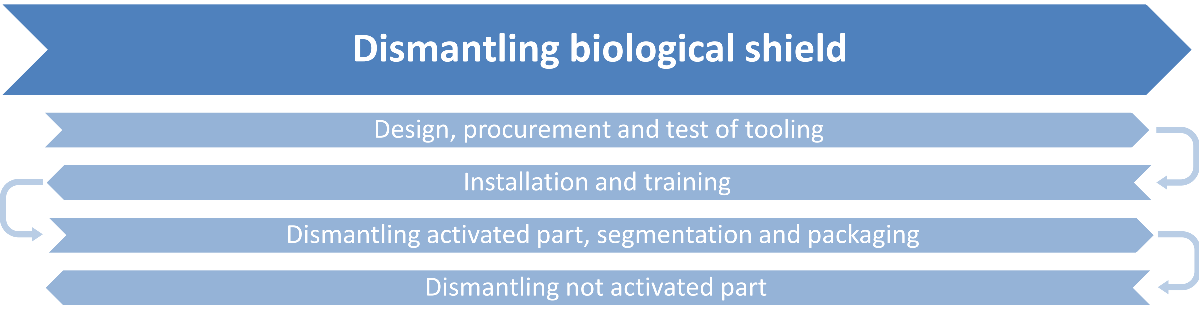



Figure 4-35: Dismantling of the biological shield

A further project on the critical path is the dismantling of the biological shield. The preparation work starts after the dismantling of the RPV is finished.

After finishing the preparation and the installation, the dismantling of the activated part starts. The biological shield will be cut into blocks of 5 to 10 Mg. Then these blocks will be segmented into smaller pieces suitable for packaging and final storage or clearance measurements in a cutting station outside the dismantling area.

*Dismantling remaining systems:*


Figure 4-36: Remaining dismantling work in the controlled area

The next project belonging to the critical path is the dismantling of the remaining components and systems in the controlled area. As a first step the preparation of the working places has to be performed. After finalization of the preparatory activities, the actual dismantling work can start. The remaining dismantling work in the controlled area can be subdivided in two steps – the dismantling of the systems and components and the remaining infrastructure in the controlled area.

The dismantling of the remaining components in the controlled area features components and equipment, like steel structures, lifting devices, cables and cable trays, ventilation ducts etc. The final dismantling of the infrastructure covers the removal of tools, scaffolding, steel girder boxes, etc., which are no longer needed.

*Clearance of building structures:*

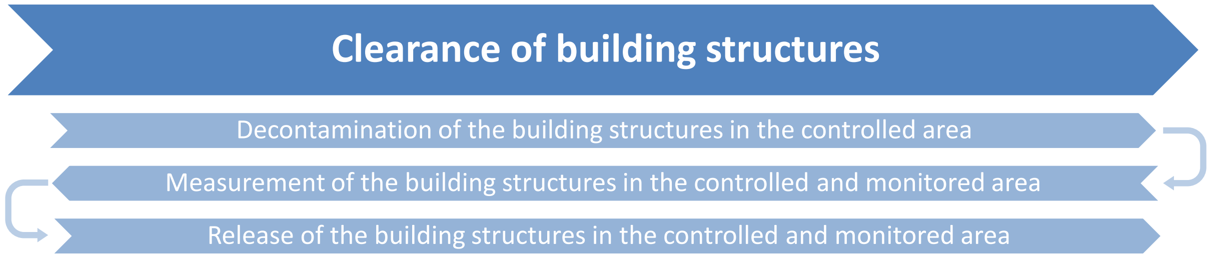



Figure 4-37: Decontamination and free release of the building structures in the controlled area

The last project on the time critical path to reach “brown field” is the decontamination of the building structures in the controlled area and the clearance of buildings in the controlled as well as in the monitored area.

This working package is separated in decontamination and clearance measurement activities to release the buildings from nuclear regulations. After an extensive radiological characterization, the decontamination of building structures includes the scarification of surfaces.

After the decontamination is completed, free release measurements of the building structures of the controlled and monitored area are performed, prior to the approval of the authorities.

*Conventional demolition and site restoration:*

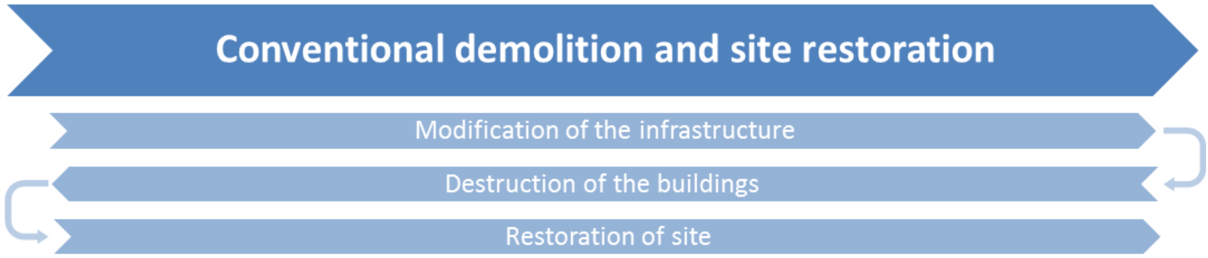



Figure 4-38: Conventional demolition and site restoration

After the end of the SFDS operation, the decommissioning of this last building concerned on nuclear constraints begins. The conventional demolition of the complete Krško site starts, when the SFDS is released. The working package includes the demolition of the buildings and the site restoration.

Infrastructural modifications e.g. the provision of sufficient access and exits for transportation purposes are performed before the actual demolition of the buildings starts. As soon as the demolition work is finished and the building pits are filled with building rubble the site restoration and landscaping is performed. "Green field" is reached.

#### 4.3.1.3. D&D time-schedule

The specific and strategic conditions on the Krško site, summarized before, lead to the sequence of the main activities on the critical path shown on Figure 4-39. The durations of the main activities were validated, in particular according to the durations necessary to deal with the quantities of primary masses and their radioactivity and with the quantities of (radioactive and conventional) waste.

In conclusion, as a result the overall milestones for the Krško decommissioning project are:

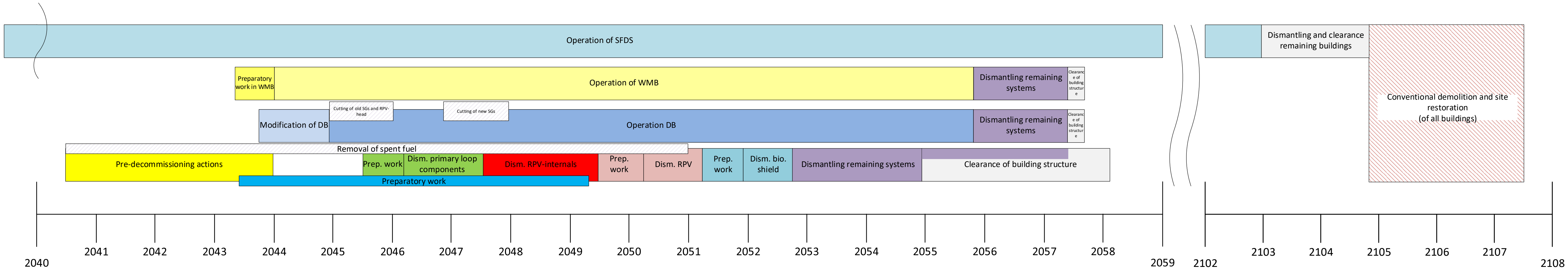
**Main milestones D&D project Krško NPP**

| | Base case | Sensitivity case |
|---|---|---|
| Start of project (Pre-decommissioning actions) | 07/2040 | |
| Final shut down / D&D approval | 12/2043 | |
| Old SG dismantled and packed | 12/2045 | |
| Finalisation primary loop | 07/2047 | |
| Finalisation RPV internals | 06/2049 | |
| Finalisation RPV | 03/2051 | |
| Finalisation biological shield | 10/2052 | |
| Building structures cleared (Brown field) | 02/2058 | |
| End of operation SFDS | 01/2103 | 01/2075 |
| Green field | 07/2107 | 07/2079 |

Table 4-2: Main milestones for the decommissioning project

Additionally a more detailed time schedule for the base case (SFDS operation until 2103) is shown in Figure 4-40. The difference to the sensitivity case is only the duration of the SFDS operation which ends in that case in 2075 (see Table 4-2).

<u>NOTE:</u> Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.



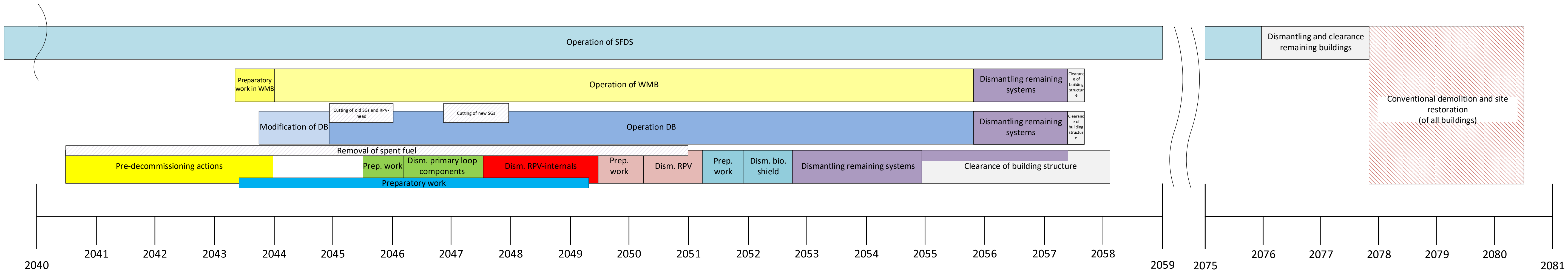
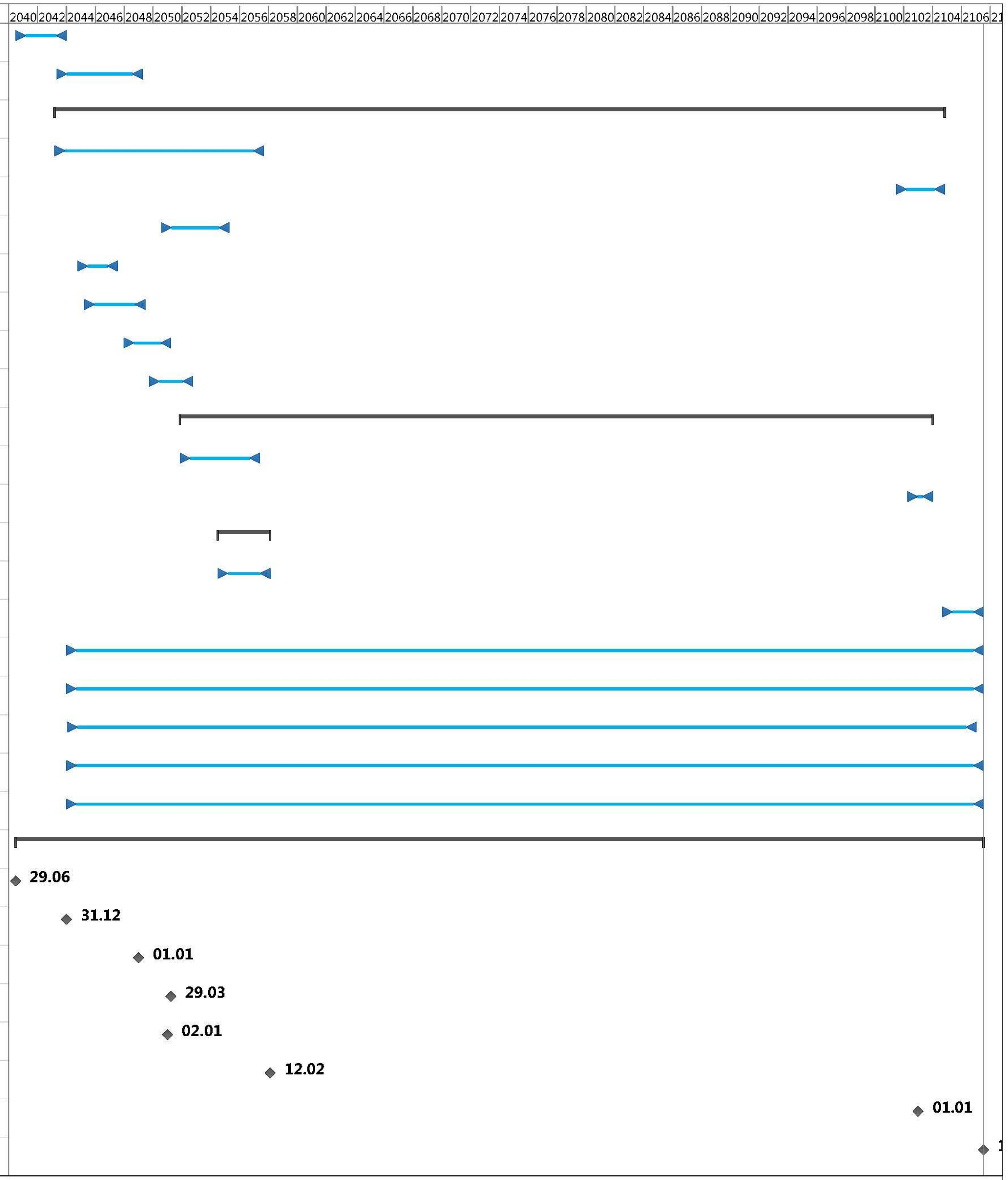




Figure 4-39: Time critical path for the D&D project Krško (first base and second sensitivity case)

| Nr. | PSP name | Start date | Finish date |
|---|---|---|---|
| 1 | PRE-DECOMMISSIONING ACTIONS | 29.06.2040 | 30.12.2043 |
| 2 | PREPARATORY WORK | 07.05.2043 | 13.04.2049 |
| 3 | **DISMANTLING OUTSIDE CONTROLLED AREA** | **12.03.2043** | **07.11.2104** |
| 4 | Decommissioning Phase "Brown field" | 12.03.2043 | 31.08.2057 |
| 5 | Decommissioning Phase "Green field" | 29.06.2101 | 07.11.2104 |
| 6 | DISMANTLING CONTROLLED AREA | 03.08.2050 | 09.04.2055 |
| 7 | DISMANTLING PRIMARY LOOP COMPONENTS | 13.10.2044 | 17.07.2047 |
| 8 | DISMANTLING RPV INTERNALS | 29.03.2045 | 25.06.2049 |
| 9 | DISMANTLING RPV | 27.12.2047 | 29.03.2051 |
| 10 | DISMANTLING BIOLOGICAL SHIELD | 29.09.2049 | 04.10.2052 |
| 11 | **DISMANTLING REMAINING SYSTEMS** | **15.11.2051** | **08.01.2104** |
| 12 | Decommissioning Phase "Brown field" | 15.11.2051 | 21.05.2057 |
| 13 | Decommissioning Phase "Green field" | 10.04.2102 | 08.01.2104 |
| 14 | **CLEARANCE OF BUILDING STRUCTURES** | **26.06.2054** | **12.02.2058** |
| 15 | Decommissioning Phase "Brown field" | 26.06.2054 | 12.02.2058 |
| 16 | DEMOLITION, SITE RESTORATION, CLEANUP AND LANDSCAPING | 12.09.2104 | 19.07.2107 |
| 17 | PROJECT MANAGEMENT, ENGINEERING AND SITE SUPPORT | 01.01.2044 | 19.07.2107 |
| 18 | SITE SECURITY, SURVEILLANCE AND MAINTENANCE | 01.01.2044 | 19.07.2107 |
| 19 | WASTE PROCESSING, STORAGE AND DISPOSAL | 01.02.2044 | 14.01.2107 |
| 20 | SFDS (FUEL, OPERATION, DECOMMISSIONING) | 01.01.2044 | 19.07.2107 |
| 21 | LOCAL INCENTIVES | 01.01.2044 | 19.07.2107 |
| 22 | **Milestones** | **29.06.2040** | **19.07.2107** |
| 23 | Start of project | 29.06.2040 | 29.06.2040 |
| 24 | Final shut down | 31.12.2043 | 31.12.2043 |
| 25 | Start movement SF from SFP to SFDS | 01.01.2049 | 01.01.2049 |
| 26 | Finalisation RPV | 29.03.2051 | 29.03.2051 |
| 27 | End of movement SF from SFP to SFDS | 02.01.2051 | 02.01.2051 |
| 28 | Finalisation Clearance Decommissioning Phase I | 12.02.2058 | 12.02.2058 |
| 29 | End of SFDS operation / Start of Decommissioning Phase II | 01.01.2103 | 01.01.2103 |
| 30 | End of project / Green field | 19.07.2107 | 19.07.2107 |




Page 1

Figure 4-40: Time schedule for the D&D project Krško (base case)

### 4.3.2. The work breakdown structure (WBS)

The decommissioning project of the Krško NPP is structured in a hierarchical organization in accordance (but not identical) with the IAEA “International Structure for Decommissioning Costing (ISDC) of Nuclear Installations” (see [13]). The used WBS reflects the experience of actual decommissioning projects and is used by NIS in all of their decommissioning cost estimates in Europe. Additional input concerning decommissioning cost estimates are given in [14] and [15].

The WBS is mandatory for the planning activities as well as for the cost estimate.

The WBS “describes” the project. The overall project is divided in subprojects, tasks, etc. until the lowest level is reached, where the individual activities can be calculated. The following table shows an example:

**Example**

| WBS Code | Title |
|---|---|
| 05 | Dismantling controlled area |
| 05.01 | Auxiliary building |
| 05.01.01 | Planning and engineering |
| 05.01.02 | Attendant measures |
| 05.01.03 | Preparation work |
| 05.01.04 | Execution project |

Table 4-3: Example for WBS

The WBS is adapted and the individual activities are defined according to the needs of the plant specific decommissioning plan.

#### 4.3.2.1. WBS level 1

The first level divides the decommissioning project in several separate projects defined also in the IAEA List but completed by some more working package items. Additionally the order of the working packages is following the course of a real decommissioning project (the projects allow a time schedule with reasonable time bars in the first level, IAEA list of projects have time bars all in the same length). Following table shows the used working packages:

**WBS structure Level 1**

| WBS Code | Title |
|---|---|
| 01 | Pre-decommissioning actions |
| 02 | Preparatory work |
| 03 | Nuclear material (operational waste) |
| 04 | Dismantling outside controlled area |
| 05 | Dismantling controlled area |
| 06 | Dismantling primary loop components |
| 07 | Dismantling RPV internals |
| 08 | Dismantling RPV |
| 09 | Dismantling biological shield |
| 10 | Dismantling remaining systems |
| 11 | Clearance of building structures |
| 12 | Demolition, site restoration, cleanup and landscaping |
| 13 | Project management, engineering and site support |
| 14 | Site security, surveillance and maintenance |
| 15 | Waste processing, storage and disposal |
| 16 | SFDS (fuel, operation, decommissioning) |
| 17 | Local Incentives |

Table 4-4: WBS level 1

### 4.3.2.2. WBS level 2, 3, etc.

A sub-project indicates the localization and/or gives more details to a project – e.g. buildings and rooms for dismantling places of contaminated material, single components of RPV internals for the dismantling of activated material.

#### 4.3.2.2.1 WBS level 3: Working task

A working task subdivides a sub-project into standardized tasks which are on principle used within all the Sub-Project to differentiate the different kinds of work and costs. The standardized (in NIS WBS, not IAEA) Working Tasks are:

- Planning and engineering: planning work performed mainly by NEK personnel which is necessary to negotiate and place an order to an external company; preparation studies are also considered
- Attended measures: working tasks related and parallel to a dismantling work, i.e. on-site engineering, detailed planning, supervision, on-site radiological protection, accompanying decontamination, internal transport, and approvals and expenditures by experts and authorities
- Preparation: preparation work before the intended work can be started, e.g. modification of existing systems, removal of disturbing items, installation of new equipment
- Execution: execution of the intended measure

#### 4.3.2.2.2 WBS level 4: Working object

Level 4 is used for the differentiation of a working tasks related to locations, techniques used and differentiation of personnel.

#### 4.3.2.2.3 WBS levels 5 to 8

The levels 5 to 8 are used to divide D&D measures into smaller, more detailed items as necessary for carrying out the planning and calculation work. The levels are:

- Level 5: Working package
- Level 6: Working step
- Level 7: Working activity
- Level 8: Working unit

### 4.3.3. Content of the projects

#### 4.3.3.1. Project 1: Pre-decommissioning actions

Project 1 contains all activities up to the final shutdown of the plant. The planned activities are:

- Collection of technical data (technical and radiological status of the plant)
- Project planning and engineering (actualization of the preliminary decommissioning plan, capacity calculation for installations and D&D equipment, personnel requirements and time schedule)
- Generation of the licensing documents, in particular the safety analysis and the environmental impact analysis; licensing procedure

#### 4.3.3.2. Project 2: Preparatory work for the D&D project

Project 2 contains preparatory activities for the D&D work. These preparations are required for the later dismantling work. The planned activities are:

- Shut down of systems not needed anymore
- Modification of equipment
  - Heating system
  - Evaporator system
  - Compressed air supply
  - Entrance controlled area
  - Sanitary area
- Decontamination primary circuit
- Removal mobile core internals
- Preparatory work in DB
  - Dismantling and packaging old SG 1 & 2
  - Dismantling and packaging old RPV head
  - Modification and installation to make waste treatment facilities in DB workable
- Preparatory work to make waste treatment facilities in IB workable
- Preparatory work to make waste treatment facilities in FHB workable
- Preparatory work to make waste treatment facilities in WMB workable

#### 4.3.3.3. Project 3: Nuclear material (operational waste)

The management of the remaining operational effluences, media, and wastes is placed in the Project 3. The planned activity is:

- Removal of operational waste
  - Planning and engineering
  - Preparation work
  - Packaging / Re-packaging of stored waste into repository containers

NOTE: The Project 3 is not considered in the main part of the present study. The results for the disposal of the operational waste are given in Attachment 4.

#### 4.3.3.4. Project 4: Dismantling outside controlled area

The non-radioactive part of the plant will be considered into the Project 4, i.e. cooling towers, workshops and other buildings outside controlled area. These facilities can be removed before, during or after the removal of the controlled area as needed and reasonable in the working sequence and time schedule. The dismantling work of installations and equipment is considered in the following buildings per decommissioning phase:

- Decommissioning phase “brown field”
  - Turbine building
  - Auxiliary boiler house
  - Decontamination building
  - Intermediate building
  - Component cooling building
  - Control building, rad. waste storage area
  - Waste manipulation building
- Decommissioning phase “green field”
  - Spent fuel dry storage
  - Cooling towers area
  - Circulating water intake structure
  - Dam area
  - Emergency diesel generators building
  - Essential service water building
  - Neutralizing sump house, water pre-treatment building, transfer pumps house, plant gas storage area
  - Simulator building, NEK environment, radiation controlled area access point, meteorological tower area, reception control (VKT)
  - Storage areas (AD1, AD2, AD3)
  - Switch yard area
  - Transformer stations, pump station (CPD)
  - Entrance building, NEK and fire protection yard
  - Bunkered building 1 &2, operational support centre

#### 4.3.3.5. Project 5: Dismantling controlled area

This project covers the dismantling of systems and components which are no longer needed for the remaining operation within the controlled area. It comprises the systems and components in the following buildings:

- Auxiliary building
- Reactor building
- Fuel handling building

All other buildings and some type of components, i.e. steel girders, stairs, doors, lightning, cable trays, will be considered in Project 10 “Dismantling remaining systems”. The dismantling of the components in the Project 5 will be carried out in the following sequence:

- Radiological characterization and zoning of working areas
- Radiological categorization of radioactive inventory
- Reconfiguration of systems, isolating and securing structures
- Removal and disposal of asbestos
- Removal of disturbing building structures, clearing of transport ways
- Preparation of the working area, in-situ decontamination to facilitate dismantling
- Dismantling of the components
- Clearing of the working site

#### 4.3.3.6. Project 6: Dismantling primary loop components

This project covers the dismantling of the following main components of the primary loop:

- SG 1 & 2
- Pressurizer
- Pressurizer relief tank
- Primary pumps and motors
- Loop

#### 4.3.3.7. Project 7: Dismantling RPV internals

The dismantling of the RPV internals is performed after the dismantling of the primary loop components. It contains the dismantling, cutting and packaging of the RPV internals. This includes:

- Design, procurement, and testing of special tooling/equipment for remote dismantling work
- Simulation of complicated work on models and training of personnel
- Preparation work
- Necessary reconstruction and rehabilitation work in the reactor pool area
- Preparation and reconstruction work on systems in operation

The internals will be cut and packaged in the reactor pool directly. An underwater technique is planned.

#### 4.3.3.8. Project 8: Dismantling RPV

This project contains the dismantling, cutting and packaging of the RPV (under dry conditions). This includes:

- Design, procurement, and testing of special tooling/equipment for remote dismantling work
- Simulation of complicated work on models and training of personnel
- Preparation work
- Preparation and reconstruction work on systems in operation

#### 4.3.3.9. Project 9: Dismantling biological shield

The dismantling of the biological shield is performed after the finalization of project 8 “Dismantling RPV”. It contains:

- Design, procurement, and testing of tooling/equipment for dismantling work
- Preparation work
- Dismantling, segmentation and packaging of the activated part of the biological shield
- Dismantling of the not activated part

#### 4.3.3.10. Project 10: Dismantling remaining systems

The dismantling of the remaining systems in the controlled and monitored area requires the following actions to be taken:

- Radiological characterization and zoning of working areas
- Radiological categorization of radioactive inventory
- Reconfiguration of systems, isolating and securing structures
- Removal and disposal of asbestos

- Removal of disturbing building structures, clearing of transport ways
- Preparation of the working area, in-situ decontamination of equipment to facilitate dismantling
- Dismantling of the components
- Clearing of the working site

#### 4.3.3.11. Project 11: Clearance of building structures

Project 11 contains the removal of the radioactive inventory from the building structures and the verification by measurements to release buildings and finally the site from nuclear constraints, i.e.:

- Building decontamination
- Release measurement in- and outside the buildings
- Environmental clean-up
- Final radioactivity survey

After finishing of Project 11 the so called “Brown filed” status is reached.

#### 4.3.3.12. Project 12: Demolition, Site restoration, clean-up and landscaping

Project 12 considers the non-radiological part of plant decommissioning. It involves the demolition of buildings and the final landscaping.

After finishing of Project 12 the so called “Green filed” status is reached.

#### 4.3.3.13. Project 13: Project management, engineering and site support

Project 13 goes along with the D&D project. In WBS project 13 the tasks cover expenditures needed for a smooth and secure operation of the pant after final shutdown. The tasks of operation during decommissioning include personnel and consumable costs.

It covers following functions and services:

- Management
- Engineering services
- Purchasing
- Finance
- General administration
- Business information system
- Hard- and software

A plant in decommissioning needs a management team, just like a plant in operation. This includes the plant management with secretary and a management personnel department. The management itself has administrative and representative duties and is supported by the secretariat. The management personnel department is responsible for the site planning and it is the interface between the site management and the decommissioning project team.

The duties of finance and accountancy are in principle the same as during operation. The monetary flows as well as the flows of goods and services must be systematically recorded, surveyed, summarized and consolidated. The flows of money and goods must be documented to give account versus third parties such as the financial authorities, the banks and the corporate controlling. The collected and documented data are needed for the control of the company.

The duties of project controlling are in principle the same as during operation. They use the collected and documented data from finance and accountancy as well as the reporting information from the decommissioning project to control the project and to keep track of the overall development.

During decommissioning, the personnel management has the following routine administrative duties for the personnel:

- Keeping personnel records
- Keeping track of working times, holiday times, absence times
- Personnel data administration
- Payroll accounting
- Social insurance accounting

The tasks stay the same as during the operation of the plant.

The duties related to documentation are in principle the same as during operation. As long as the plant or parts of the units are in operation, the normal documentation work must continue. The duties are the documentation of:

- The systems in operation
- Personnel radiation protection
- Plant radiation protection
- Management of waste
- External transportation of waste

During decommissioning, the operation of several management systems must continue. Such management systems are needed to ensure (internally) and to make evident (to third parties) that the rules, systems and methods established for the operation of the plant are either still valid or that they are adapted to the new situation for a plant under (partial) decommissioning.

This includes e.g. the following management systems:

- Quality management
- Knowledge management
- Environmental management
- Safety management

The duty of the QA / QC function is to make sure that the quality standards are observed. This is done by issuing quality documents and by performing internal checks and audits.

The duties of the data processing are in principle the same as during operation. They ensure the availability of the IT systems and keep the IT infrastructure up-to-date. During operation the IT costs had been external costs and the same situation will prevail during decommissioning. Therefore IT aspects are not considered in terms of needed personnel for plant operation.

Based on the actual operational requirements the NEK personnel is reduced with the end of the plant operation. To cover the above described activities after final shutdown the following numbers of persons have been taken into account as a starting point:

- Management: 6 persons
- Engineering services: 8 persons
- General administration (e.g. legal matters, HR, purchasing, finance): 40 persons
  (2 legal, 2 HR, 11 purchasing, 15 finance, 10 IT and other services)

During decommissioning these numbers are reduced further to reflect the progress of the decommissioning project. Main milestones for such a reduction are, e.g.:

- After removing of all spent fuel to the SFDS to 80%
- After dismantling of RPV to 50%
- After reaching “Brown field” status to 4% (only operation of SFDS, for more details see WBS project 16)

#### 4.3.3.14. Project 14: Site security, surveillance and maintenance

As project 13 the project “site security, surveillance and maintenance” lasts the D&D project. It contains the necessary measures for a safe post operation of the plant. Following functions and services are included:

- Technical operations unit
- Maintenance
- Engineering services
- Chemistry
- Radiological protection
- Industrial safety
- Quality and nuclear oversight
- Training
- Security
- Surveillance
- Provision of energy, water, steam, oil and gas
- Other operational costs

Compared with the situation during the normal unit operation for electricity production, the operation team during decommissioning will be smaller. This results from the lower number of operational systems that will be required after the end of electricity generation, after the end of the post operational phase, when all fuel is removed from the unit and all waste from operation has been removed.

The systems which are still needed must be operated, and the unit operation team is responsible for the operation of these systems until they are finally shutdown for dismantling.

For the mechanical maintenance the situation during decommissioning is comparable with the situation during normal operation of the unit. The systems which are still needed must be operated and maintained. The number of operating personnel will be less than during unit operation, and will decrease gradually during decommissioning as soon as the remaining operating systems will be shut down for dismantling.

The tasks/costs for mechanical maintenance include:

- The preparation of internal work orders
- The execution of maintenance and repair work
- The performance of periodic tests
- The acquisition / replacement of needed parts, tools and equipment
- The replacement of lifting and other mechanical equipment
- Tools and consumables for the mechanical workshop
- Scaffolding

With the start of the decommissioning project, the buildings have a lifetime of some decades. In our case, after 60 years of operation, the buildings will be nearly 60 or 70 years old when the decommissioning project starts. The decommissioning itself will also take several years.

As a consequence, repairs and maintenance will also be required for the buildings until they may be conventionally dismantled. In contrast to the mechanical maintenance, the work for civil structures maintenance will not be performed continuously.

The following list features typical tasks/costs for civil works maintenance:

- Inspection patrols looking for cracks, roof tightness, water puddles etc.
- Repair of de-contaminable coatings
- Cleaning and repair of building faces
- Repair of roofs; repair of waterproofing
- Repair of channels
- Repair of bottom coatings
- Painting work

Electrical maintenance work is comparable to mechanical maintenance in the sense that it is a permanent duty for the operation of the plant. The tasks/costs for electrical maintenance include:

- The execution of maintenance and repair work
- The performance of periodic tests
- The acquisition / replacement of needed parts, tools and equipment

Activities in the workshops to support the operation of the units will continue during decommissioning. The related tasks/costs include:

- The execution of maintenance and repair work
- The execution of adaptation work

As long as potentially contaminated systems are in operation, radioactive contamination (for example dust or liquids) will be removed by permanent cleaning actions (wiping of the surfaces) in the controlled area. This must be done carefully, to avoid spreading of contamination into clean areas and without interfering with the ongoing decommissioning work. The cleaning agents and media are collected and treated / disposed of as secondary waste.

The duties of the general health physics are the following:

- Caretaking of the automatic monitoring equipment of the plant
- Performance and evaluation of periodic measurements inside and outside the units in addition to the measurements needed for the decommissioning works, whose costs are covered by the decommissioning costs
- Surveillance of operation personnel and the environment
- Surveillance of the plant operation work
- Guidance of subcontractor's responsible persons in terms of health physics / radiation protection
- Surveillance of health physics / radiation protection systems and radiological measurements
- Reporting to the management and to the authorities

The aim of this work is to minimize the radiation exposure for the operational personnel and the environment and to demonstrate that the values are below the authorized limits.

The duty of the chemical and radiation protection laboratory is to control the water chemistry and radiochemistry. The remaining operating systems are surveyed with respect to purity and composition to discover abnormal events in due time. A significant part of the work consists of detecting radioactive activation and fission products, to specify them and to measure the quantities. The personnel take samples which are then analyzed chemically and radiochemically. This is done using modern computer supported equipment, and the results are recorded. The laboratory is responsible to perform controls of the releases to the environment via the air and the water pathways, and for the balancing of the releases.

The controlled area access must be surveyed. This must be continued when the controlled area is taken over by the decommissioning project. It ends when the controlled area is released from nuclear regulatory control.

Work and conventional safety is related to the safe working conditions such as wearing safety helmets, the handling of hazardous substances or noise protection. The working safety management must specify the necessary requirements and rules for working safety and health protection. This must be coordinated with the responsible persons from the subcontractors and inspected.

Fire protection must be ensured during decommissioning. This means that measures must be taken to prevent the onset of a fire and the propagation of fire and smoke, and to enable effective firefighting actions. During decommissioning, the fire load will be reduced, because combustible material will be removed (such as thermal insulation, lubricants, etc.), but this has few consequences for the fire protection costs which are mainly caused by personnel costs and the cost for repair and maintenance of the equipment:

- Fire protection personnel
- Training courses for fire protection, breathing protection
- Replacement of fire protection equipment
- Maintenance of fire traps, fireproof doors
- Maintenance for breathing protection, fire extinguishers

The necessary Housekeeping includes the following general duties:

- General services: management (operation, maintenance and administration) of the conventional facilities
- Caretaking of roads and green areas
- Car pool (lift trucks, carriages, company cars, etc.)
- Conventional buildings cleaning service

The main points of concern are the cleanliness and the functionality of the installations, the visual appearance of the plant, and the prevention of any danger. This remains important also during decommissioning, for example care must be taken that no dangerous situation arises by waste lying around, by failing lighting, black ice, etc. The related costs are mainly personnel costs.

Security/Guarding is needed until the site is released from nuclear regulatory control. The coordination and the control of the guarding remain under the responsibility of the plant operator. The guarding work including reception at the entrance of the site will be performed by plant personnel.

Based on the actual operational requirements the NEK personnel are reduced with the end of the plant operation. To cover the above described activities after final shutdown the following numbers of persons have been taken into account as a starting point:

- Technical operations unit: 2 persons
- Maintenance (mechanical, electrical, civil works, etc.): 81 persons
  (35 mechanical, 20 electrical, 12 I&C, 10 civil, 4 management)
- Operation (e.g. shift): 62 persons
  (7 shifts of 5 persons (RO, SF SS an 2 local operators) = 7x5=35,
  12 system engineers, 2 surveillance, 6 FP, 7 management)
- Chemistry: 25 persons
- Radiation protection: 18 persons
- Industrial safety: 2 persons

- Quality and nuclear oversight: 10 persons
  (optimised number of personnel)
- Security: 51 persons

During decommissioning these numbers are reduced further to reflect the progress of the decommissioning project (see WBS Project 13).

#### 4.3.3.15. Project 15: Waste processing and treatment

Project 15 comprises activities for the treatment and packaging of the dismantled components (primary waste) either for treatment and packaging of radioactive waste which will be generated during the decommissioning project (secondary waste). In particular Project 15 contains:

- Cutting
- Mechanical and wet decontamination
- Super-compaction
- Shredding of cables
- External treatment (melting, combustion)
- Conditioning of waste (without cementation)
- Release of materials
- Container costs (e.g. drums, Holtec HI-SAFE, N2d container, RCC)
- Landfill of conventional waste

#### 4.3.3.16. Project 16: SFDS (fuel, operation, decommissioning)

All SFDS related costs are presented separately in Project 16. The included and planned activities are:

- Spent fuel management
  - Purchase of 30 additional canisters (Holtec HI-STORM FW) for spent fuel (Phase 3 and 4 – for 1,098 spent fuel assemblies)
  - Packaging of the remaining 1,098 SF (in Phase III = 328 SF and in Phase IV = 770 SF) in Holtec containers and transportation to SFDS location
- Operation of the SFDS
  - Management/operational personnel (NEK): 1 On-site manager, 2 Technician
  - Security service (NEK): 365 days, 24 h per day, 2 guards per shift, 5 shifts
  - Non-personnel costs (lump sum): 50,000 € per year
- Decommissioning of the SFDS
  - Dismantling of equipment and components
  - Dismantling and packaging of the concrete shielding of the Holtec HI-STORM and Holtec HI-SAFE casks [16]
  - Measurements for release the building from nuclear constraints
  - Conventional demolition

#### 4.3.3.17. Project 17: Local Incentives

Project 17 contains the local incentives applying to [4]. During decommissioning with wet spent fuel pool it is 1,538,918 € per year, during decommissioning with SFDS it is 824,964 € per year.

# 5. Project Management

The project management involves all types of activities concerned with management of decommissioning activities, engineering, technical, safety and other relevant support, during all phases of the decommissioning project. One of the most important activities is to organise a smooth transition from operation to decommissioning and to establish a project organisation which reflects all requirements for a successful decommissioning.

The most common used organisation is that the plant owner is responsible for the overall project leading (including the operation of the site during decommissioning) and is supported by more or less external companies which are doing the real dismantling work, the treatment and disposal of the dismantled and demolished radioactive and non-radioactive materials.

An example of such a project organisation is shown in Figure 5-1.

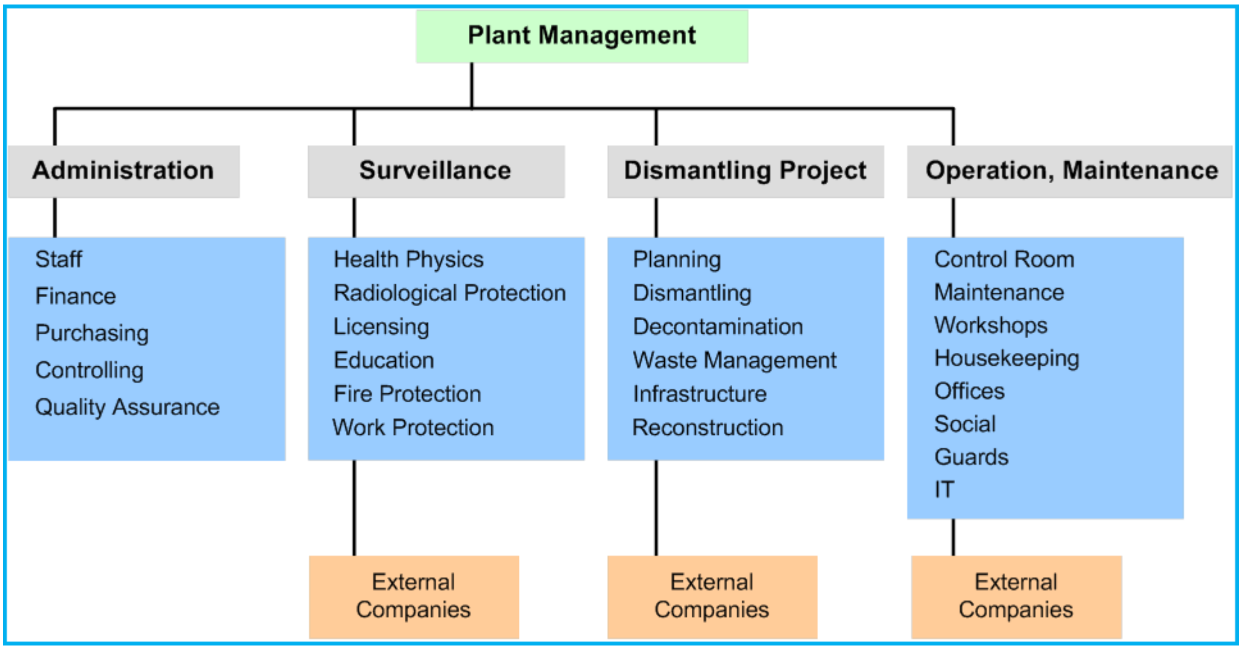



Figure 5-1: Example of a personnel organisation for a decommissioning of a NPP

There is no general solution existing from previous decommissioning projects. The decision what is the best for the own decommissioning project depends on a lot of different things, e.g.:

- The actual situation at the end of the operational life time of the NPP
- The strategy how to deal with the spent fuel
- The chosen decommissioning strategy
- The availability of a final repository
- The politics concerning nuclear electricity generation (i.e. building new plants or nuclear phase-out)

For the purpose of the present study it is assumed that the NEK personnel will be responsible for the project management and the operation of the site during decommissioning. The corresponding activities and the assumed number of personnel (at the beginning of the project after final shutdown) are described in WBS Projects 13 and 14 (chapters 4.3.3.13 and 4.3.3.14). Additionally, NEK personnel are accompanying the decommissioning activities (e.g. engineering, on site radiological protection).

The evaluation of the personnel costs for operating the SFDS (see WBS project 16, chapter 4.3.3.16) bases on NEK employee’s qualifications and hourly rates.

The real decommissioning work and waste treatment work will be carried out by external Slovenian and Western personnel. The Western personnel are considered for the remote controlled dismantling of the activated components (e.g. RPV and its internals).

The considered qualifications and the corresponding wages are given in chapter 15.4.2 (Table 15-2).

# 6. Inspections and Maintenance

The agreed operational regulations concerning inspections and maintenance are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

# 7. Waste management

During decommissioning and dismantling of a NPP a lot of components, structures and other residuals etc. with very different physical, chemical and radiological properties have to be treated, conditioned and packaged. The aims of all of the treatments are either:

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

To give a comprehensive description of the treatment of material and waste management, the following sections begins with some basic considerations and definitions. In a second step the masses to be processed related to the NPP Krško is described before the waste management strategy, management and treatment of the masses is described. Finally the results of the calculations are described.

## 7.1. Basic considerations and definitions

*Primary masses:*

The components and structures that constitute the NPP (including SFDS) at the time of final shutdown are called the primary masses. Most of them will be dismantled and removed from the site. Only a limited number of structures will be left in place, such as the building foundations.

NOTE: At the time of final shutdown there will be spent fuel elements in the unit – at least the last core which is in the RPV. Their removal and the costs associated with it are a part of the present study (WBS project 16). The packaging of spent fuel elements applies to [5].
There will be also operational waste stored at different locations and in different systems. The operational waste is considered as a primary mass within the CORA database of NIS, but they are not part of the present study DP rev.3.
The associated results for the disposal of that operational waste (WBS project 03) are presented in Attachment 4 of the present study for information only.

*Secondary masses:*

During dismantling of the units and treatment of the primary masses, additional masses will be generated which will have to be treated as well. These additional masses are called the secondary masses. Typical secondary masses are:

- Plastic foils used to prevent spreading of contamination
- Clothes for controlled area
- Air filters, worn tools
- Liquids from decontamination etc.

Special cases are:

- Chips from tooling (such as sawing)
- Material removed from the surface by decontamination (like blasting)
- Concrete rubble from building decontamination.

Although such material is properly speaking part of the primary mass, it is “generated” in the course of the treatment of the primary mass and the NIS software counts this material as secondary mass too.

*Tertiary masses:*

Another special case is the additional tools and equipment needed for the dismantling of the unit. First there are the small tools used by the dismantling crew (boring machine, boring bits) which are counted as secondary waste. But secondly there are the large special tools, e. g. for the dismantling of the RPV and its internals. Such material and equipment is sometimes called tertiary mass or additional masses. But as a matter of fact for the sake of the present study there is no real difference between this additional equipment and the primary masses. The additional equipment is a new primary mass. The NIS software makes no difference and treats the additional masses as primary mass.

To summarize, there are:

- Primary masses (components and structures of the unit, and new equipment needed for the dismantling of the unit). Primary masses are directly input in the database
- Secondary masses, generated during the dismantling and treatment of the primary masses. Secondary masses are calculated by the software

But from this status on no distinction is necessary anymore. All these primary or secondary masses (components, equipment, structures, and residues from dismantling or from treatment) must be dealt with – no matter what their origin is. To summarize: all of these masses have to be treated and conditioned with techniques mentioned in chapter 4. After treatment and / or conditioning there is the following output:

- Free material: this includes material that has never been suspected of being radioactive, or that has been free released from nuclear constraints. It is also free from conventional (non-nuclear) obligations
- Conventional waste: this is material that is free from nuclear constraints, but there are other (non-nuclear) reasons why this material must be treated as waste. Examples are: used lubricants, asbestos, coatings, etc.
- Radioactive waste: this is material that cannot be free released from nuclear constraints

The following figure shows a process flow chart of the above mentioned steps:

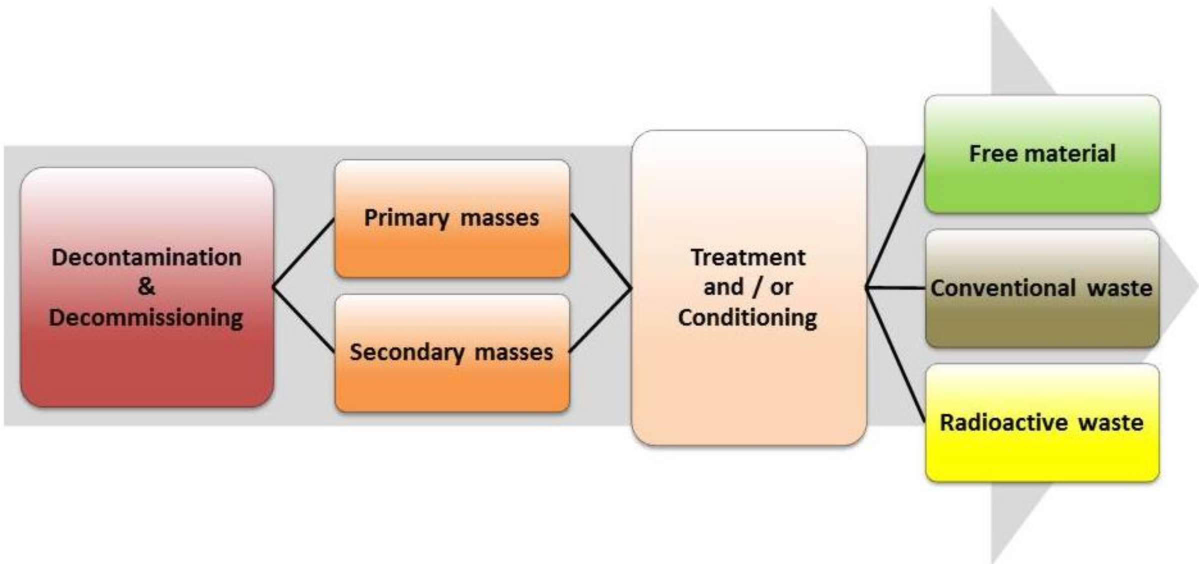



Figure 7-1: Treatment and conditioning between D&D and output streams

## 7.2. Masses of the NPP Krško to be treated

The masses of the NPP Krško which have to be treated are summarized in Table 7-1. They are separated by their origin type. For more details concerning the primary masses (e.g. separated by type of component) see Chapter 14.2.

**Treated masses and spent fuel of the NPP KRŠKO**

| Category | |
|---|---|
| **Number of spent fuel elements*3** | **1,098** |
| | |
| **Decommissioning material plant (primary) [Mg]** | **462,075.4** |
| Controlled area components and structures*1 | 164,206.5 |
| Monitored area components and structures*1 | 165,120.3 |
| Area inside the fence components and structures*1 | 132,748.6 |
| | |
| **Decommissioning material plant (secondary) [Mg]** | **4,366.1** |
| Generated secondary masses generated during D&D*2 | 4,366.1 |
| | |
| **Total mass (without spent fuel elements) [Mg]** | **466,441.5** |

*1 the areas are defined in Figure 2-3

*2 these masses are calculated by NIS

*3 information provided by NEK (considered in PDP rev.6 [1])

Table 7-1: Masses of NPP Krško to be treated separated by origin type

## 7.3. Waste management strategy

### 7.3.1. Waste management for the D&D project

The general waste management procedures are shown in Figure 7-2. It can be recognized that all the waste treatments will be accompanied by several decisions for the further treatment steps. Each decision will be supported by radiological characterizations or measurements.

Possible techniques for treatment, conditioning and packaging of the masses derived from the D&D can be summarized as follows:

- Further cutting / disassembling:
  - Not all dismantled components have the optimum dimensions for treatment and conditioning. Maybe the dimensions of the dismantled parts exceed the permissible dimensions for packaging and transportation, or maybe the internal surfaces are not accessible to the measurement tools or to the decontamination 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

  In some cases the contamination cannot be removed. Then one will try to separate the contaminated portion from the non-contaminated one, to minimize the amount of radioactive waste.

  A special case of a decontamination technique is melting. Selected radioactive material can be sent to specialized companies such as Siempelkamp (Germany), Studsvik (Sweden) or Energy Solutions (USA) where the material is molten. Nearly all contamination will be concentrated in the slag – which is radioactive waste – and the rest (steel) can be either free released or reused in the nuclear industry.
- Compaction, where two compaction techniques are used to reduce the waste volume:
  - Normal compaction (“pre-pressing”) is used for example to compact bales with combustible waste before they are sent to an incineration plant
  - Super-compaction is done to reduce the size (in m³) of radioactive waste, to get a better filling grade of the waste packages and thus to reduce the number of needed packages
- Incineration:
  - Combustible waste will be sent to an incineration facility. Incineration leads to a reduction in mass and in volume of the waste. After incineration the radioactive particles will be concentrated in the ashes and in the air filters. The off-gas is measured for control purposes before release into the environment
- Melting:
  - A part of the meltable material, which can be free released after melting, will be sent to a melting facility. Only slugs and filters generated during the melting pro-

cess will return as radioactive waste (assumption: 5% of the meltable material mass will return as slugs and filters).

- Concentration:
  - Concentration (e.g. evaporation) is applied to liquids to reduce their volume and to make them suitable for solidification
- Solidification:
  - Solidification is done to immobilize and fix concentrates and sludge using cement and additives
- Cementation:
  - Some types of waste and packages require an immobilization of the waste inside the package. This is done by filling the package with a liquid concrete so that the waste with the concrete becomes a monolithic block
- Packaging:
  - Radioactive waste will be packed in suitable waste packages. The packages must full-fill the waste acceptance criteria of the destination facility (external processing plant or waste interim storage facility and / or repository) but also the requirements for transportation over public roads

The following figure shows a process flow chart of the used waste management strategy. Also all above mentioned techniques for waste treatment and where they will take place at the NPP Krško site are shown.

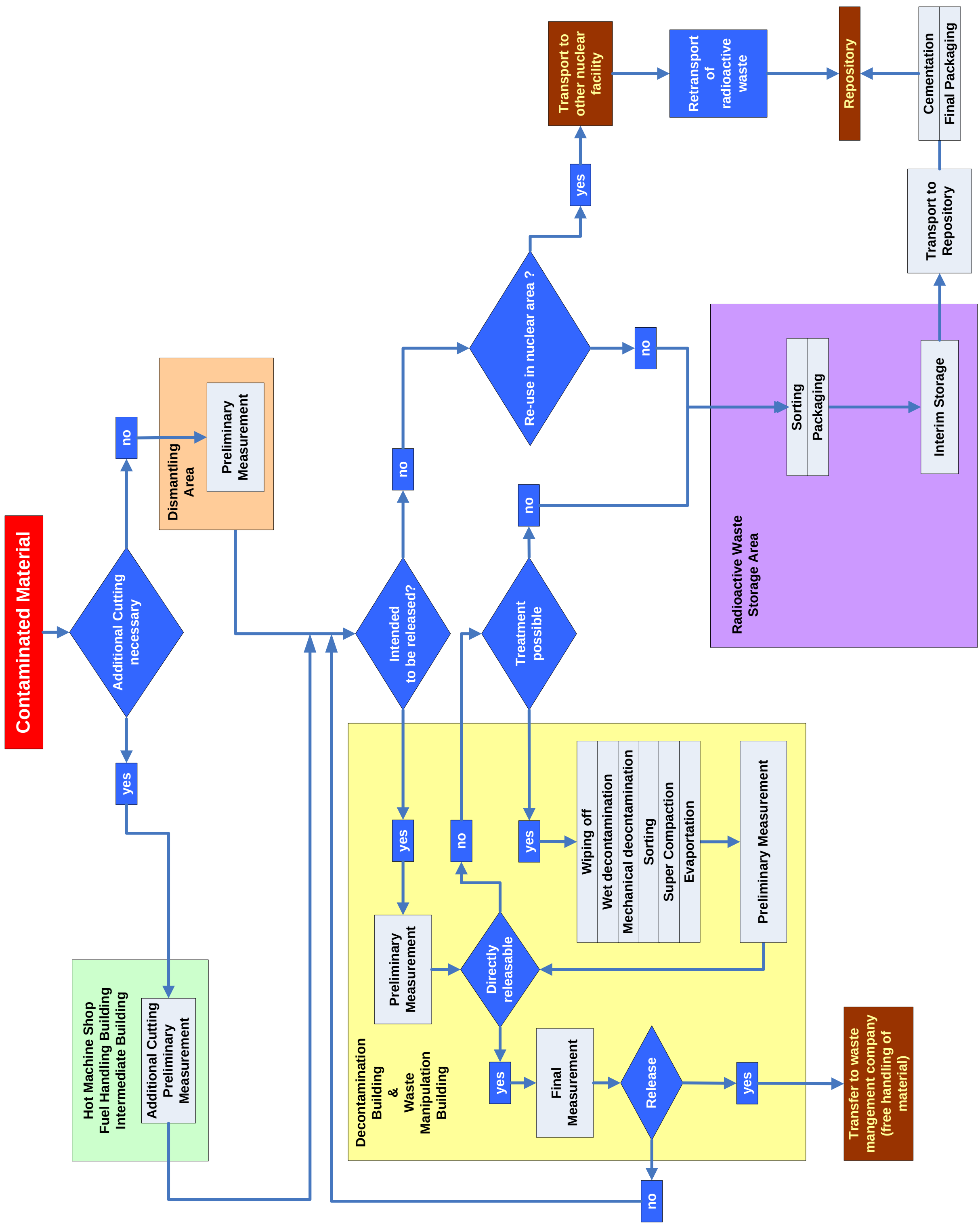



Figure 7-2: General procedure of waste management

According to the amount of the several masses to be managed a decision was made to use existing buildings and rooms for treatment, conditioning, and packaging. The existing plant site offers enough space and possibilities to perform the treatment actions.

The rooms and areas which were identified as appropriate for material treatment facilities are shown in Figure 7-3 to Figure 7-6.

In the intermediate building (IB) the rooms 011 – 015 will be used for additional mechanical cutting of dismantled components. These rooms contains components which are not necessary after the final shut down so they can dismantled first and the rooms can rebuilt into a workshop.

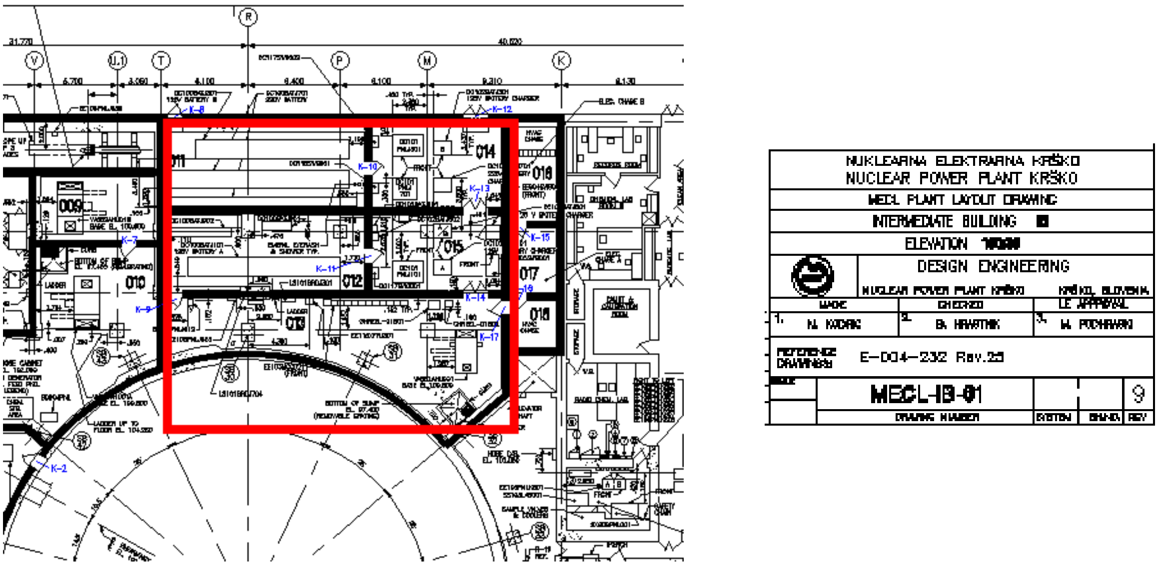


Figure 7-3: Workshop Intermediate building

The workshop in the fuel handling building, room FHB-01 Room 02 and 04 will be kept during the time of dismantling of the plant for additional cutting of the dismantled components and for the preparation of the components for transport outside of the controlled area.

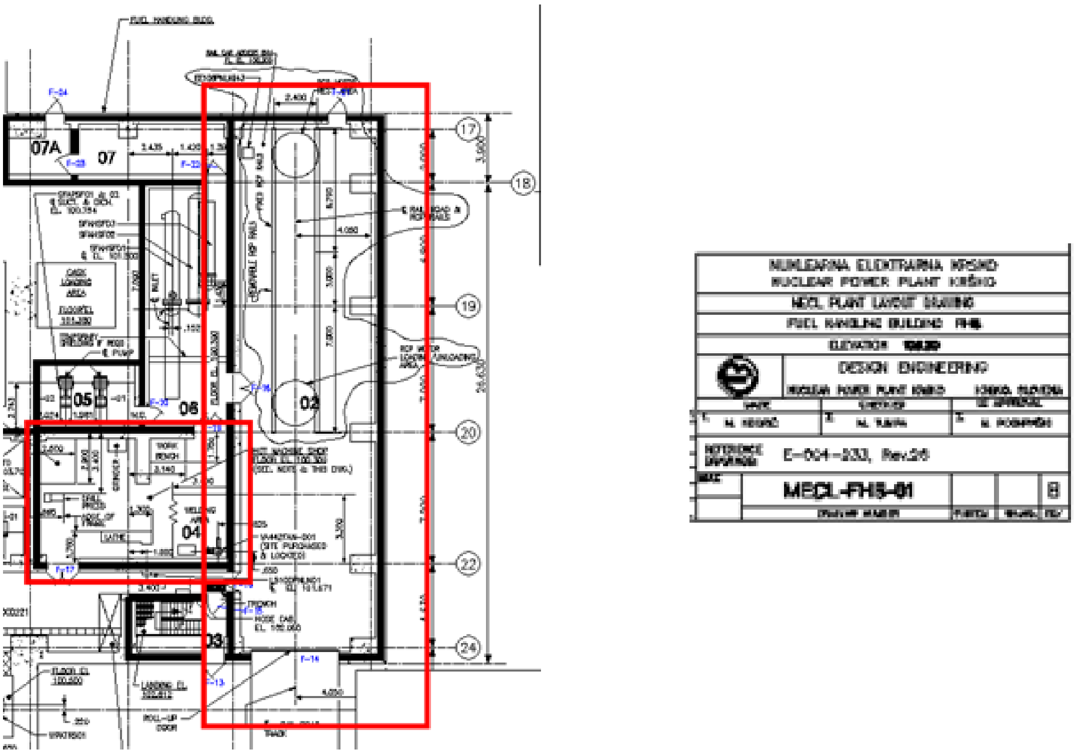


Figure 7-4: Workshop fuel handling building

The decontamination building will be used as waste management facility in different periods:

- First period: the already stored SG will be disassembled, cut and pack-aged
- Second period: the SG in operation will be disassembled, cut and packaged
- Third period: the decontamination building will be cleaned and reconstructed for treatment of waste, i.e. decontamination and release measurements

Improvements of the air conditioning system as well as some restructuring of the building walls and rooms might be necessary to enable an optimal use of the building.

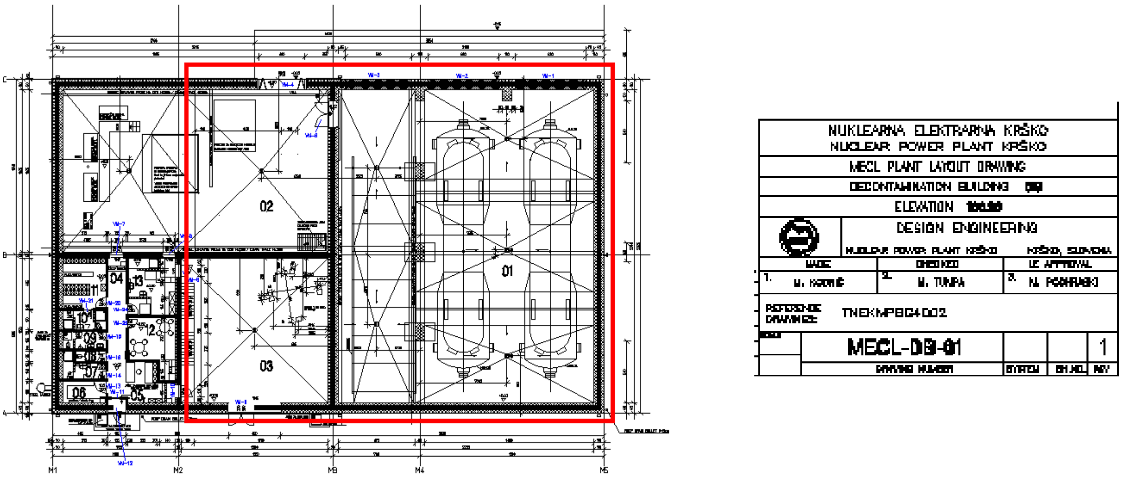



Figure 7-5: Workshop decontamination building

In addition to the use of the decontamination building, the waste manipulation building is also considered for the treatment of waste, i.e. decontamination, super-compaction, sorting and release measurements. Also storage areas for interim storage purposes are available in this building. Exemplarily, the ground floor of the waste manipulation building is shown in the fol-lowing figure. The super-compactor, which is currently in use, can be recognized (marked in red).

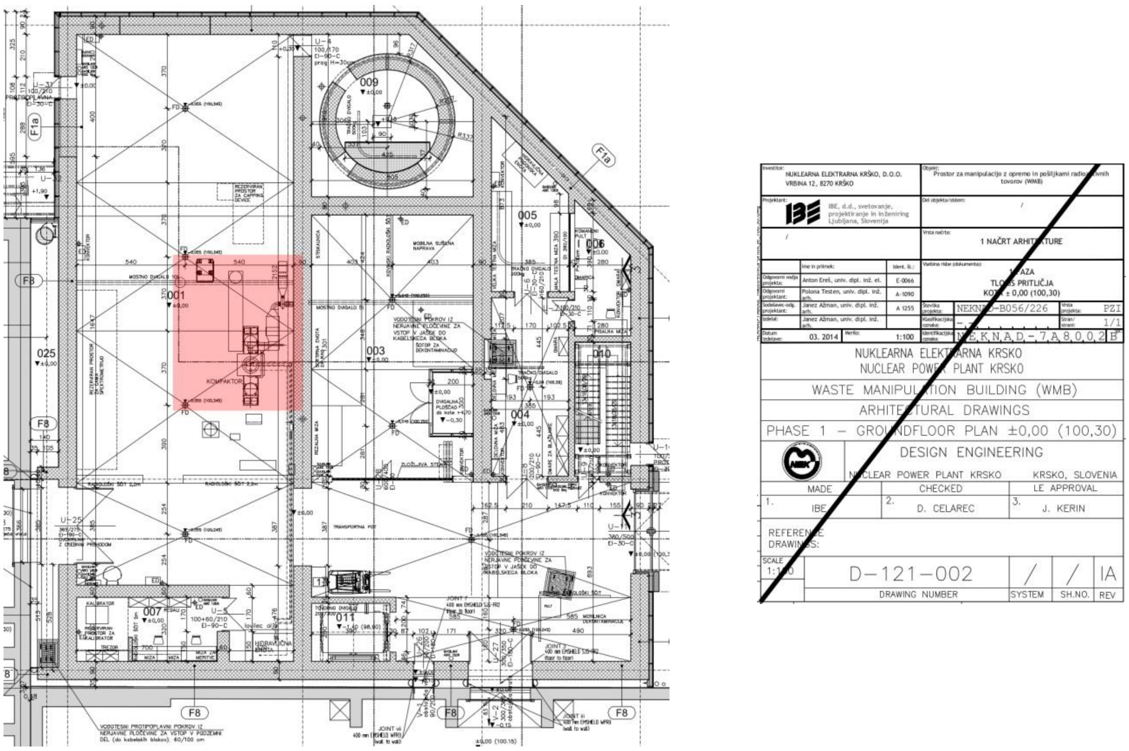



Figure 7-6: Waste manipulation building (ground floor)

### 7.3.2. Treatment of components

Based on the masses of the NPP Krško (see Table 7-1) and waste management strategy (defined and described in chapter 7.3.1) the treatment for each component has to be defined. This is done in the CORA database where the necessary definitions are deposited.

In a first calculation step the quantification of the decommissioning masses is done. This means for each of the component types it is decided which part of a component will be radioactive waste or non-radioactive material or can be treated by decontamination. The following component criteria have to be considered:

- Geometry
- Radioactivity
- Material

The decisions made are described in the chapters below.

#### 7.3.2.1. Primary circuit components

The whole primary circuit will be decontaminated by a full system decontamination process (see chapters 14.1.2 and 4.1.3.1) before dismantling. Afterwards the components are mainly dismantled in pieces and transported to the decontamination building or waste manipulation building for further cutting and packaging. At the decontamination building or waste manipulation building the components will be segmented in non-radioactive and radioactive; whereby radioactive parts, which can’t be released after decontamination, will be cut to suitable size and packaged for final repository. The processing methods which will be used for the dismantling of the components are described in Chapter 4.

##### 7.3.2.1.1 RPV, head and internals, mobile RPV internals

As the material for this type of components is activated, there are no further measures taken into account. The material is packaged in appropriate containers for final repository [17].

*Mobile RPV internals*

Mobile internals are components which could be reassembled during normal operational procedures, so as: control rods, neutron sources, in-core instrumentation, fuel assembly channels. Depending on the possible packaging and repository concept these components have to be packaged in:

- Holtec HI-SAFE with a minimum of cutting work and stored in the SFDS
- N2d containers and RCC after cutting to suitable size and stored in the LILW repository

*RPV internals*

The RPV internals (grid plates, core barrel, core structure, etc.) are not removable during normal operation procedures. These internals will be dismantled and packaged directly in repository containers without any treatment. The type of container is selected after several cost and shielding calculations and selected by the boundary condition of the LILW reposito-ry. The following figure shows the internals of a reactor exemplary:

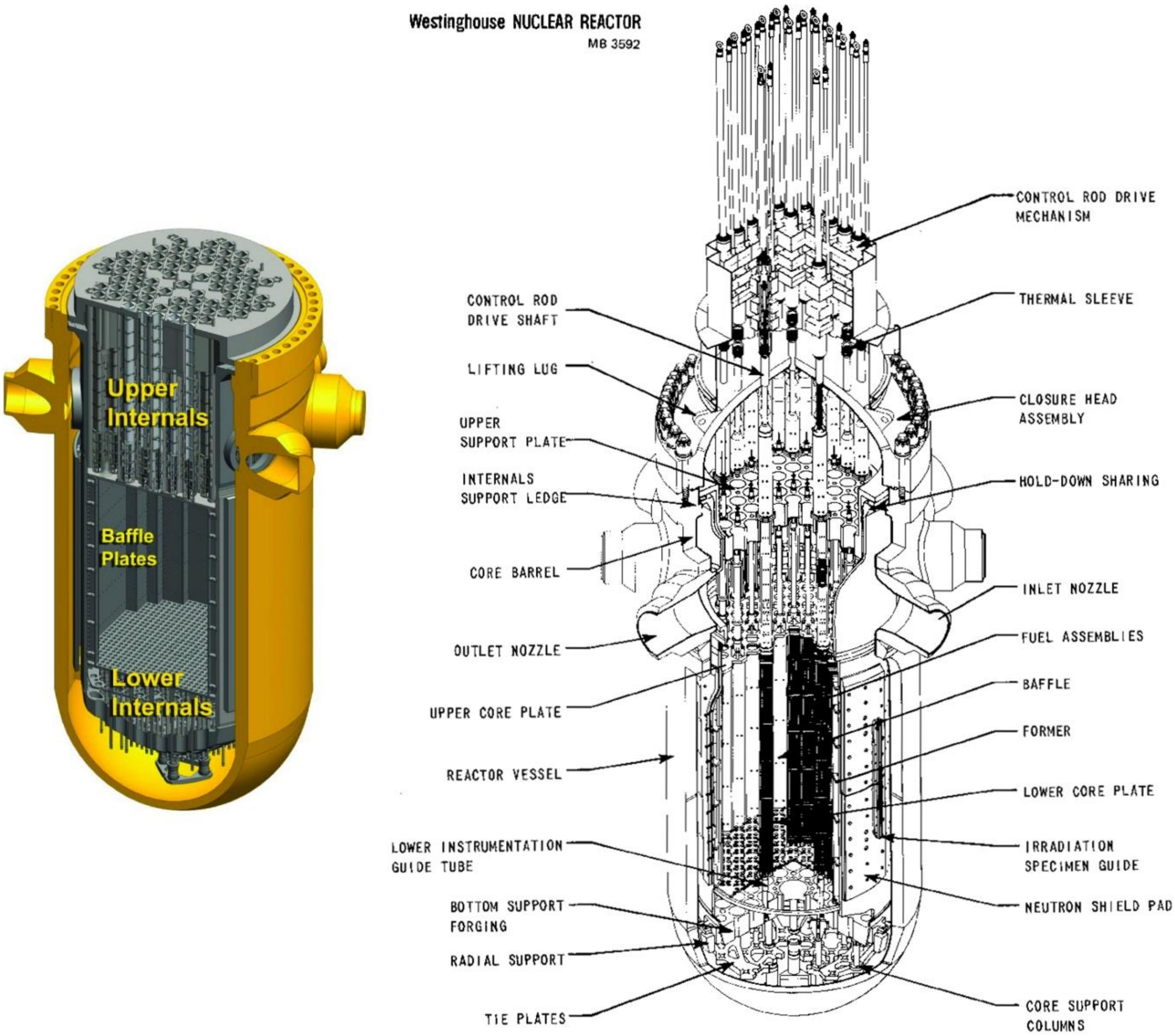



Figure 7-7: Examples of a RPV, head and internals

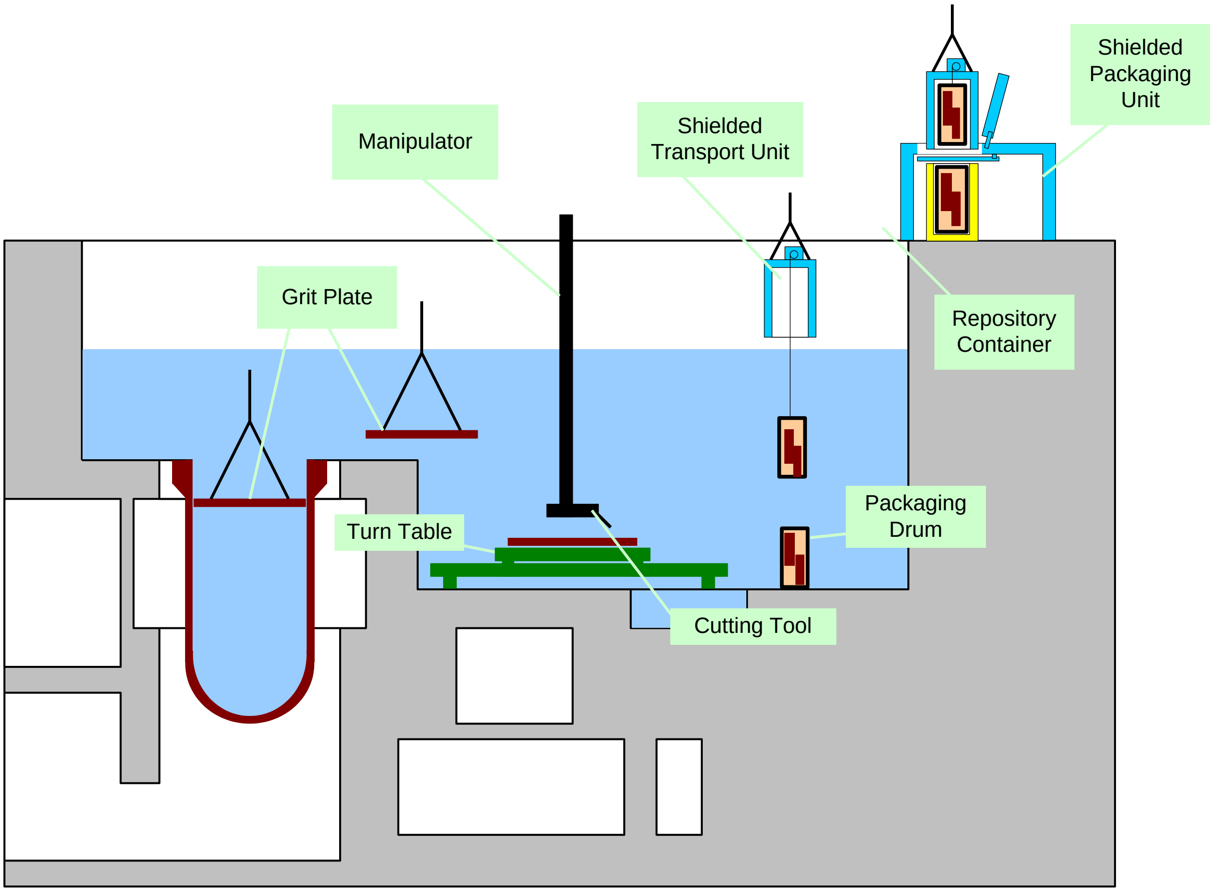



Figure 7-8: Dismantling and cutting of the RPV internals

The packaging concept affects the dismantling procedures and the sequence of work very strongly but not the dismantling techniques useable for the RPV internals. For the disassembling and the cutting action appropriate techniques are:

- WAS technique
- Acetylene burning
- Plasma burning
- Mechanical cutting such as sawing, milling, grinders, nibblers

The upper RPV internals are disassembled as far as possible respectively by cutting the fixing screws. The disassembled components will be transported from the RPV into the reactor cavity for additional cutting to suitable size for packaging. For the cutting procedure the WAS technique and mechanical sawing will be used.

The saw has to execute vertical and horizontal cuts to divide the thermal shield in several pieces.

To the beginning of the dismantling work substantial installation and preparation works are necessary on the reactor building operating deck and in the reactor vessel pit. The kind and expenditures of the preparation work depends on the storage container concept. General for the all the container concept are:

- Installation of remote control equipment and cutting tools comprising control panels
- Installation of cameras
- Improvement of the fuel loading machine
- Installation of mobile water filters in the reactor cavity
- Erecting of shielding elements as needed

Because of the selected packaging concept (use of Holtec HI-SAFE container) some additional preparations have to be fulfilled. The containers cannot be handled in the reactor building. Therefore the cut pieces will be packaged into an internal shielded transportation unit which will be transported to the fuel pool in the FHB. The packaging of RPV internals in the Holtec HI-SAFE will then be performed under water in the fuel pool. The in-site volume of the Holtec HI-SAFE will be dried by vacuum sucking. For packaging of all the RPV internals and high activated components approx. 7 Holtec HI-SAFE containers are needed.

<u>*RPV head*</u>

In the NPP Krško there is not only the operating RPV head which has to be dismantled, there is also an old RPV head stored in the DB. This RPV head will be dismantled after the dismantling of the old steam generators in the DB. The cutting is performed in the same way like the operating RPV head.

The operating RPV head and the control rod drive mechanism will be dismantled in the reactor cavity. The control rod drive will be disassembled manually; the RPV head will be cut in pieces fitting to the inner size of the repository container using an acetylene cutting device. The acetylene cutting is possible if the cut will be performed from the outside (basic material) but not from the cladded inner side.

The cut pieces will be packaged in N2d container and RCC.

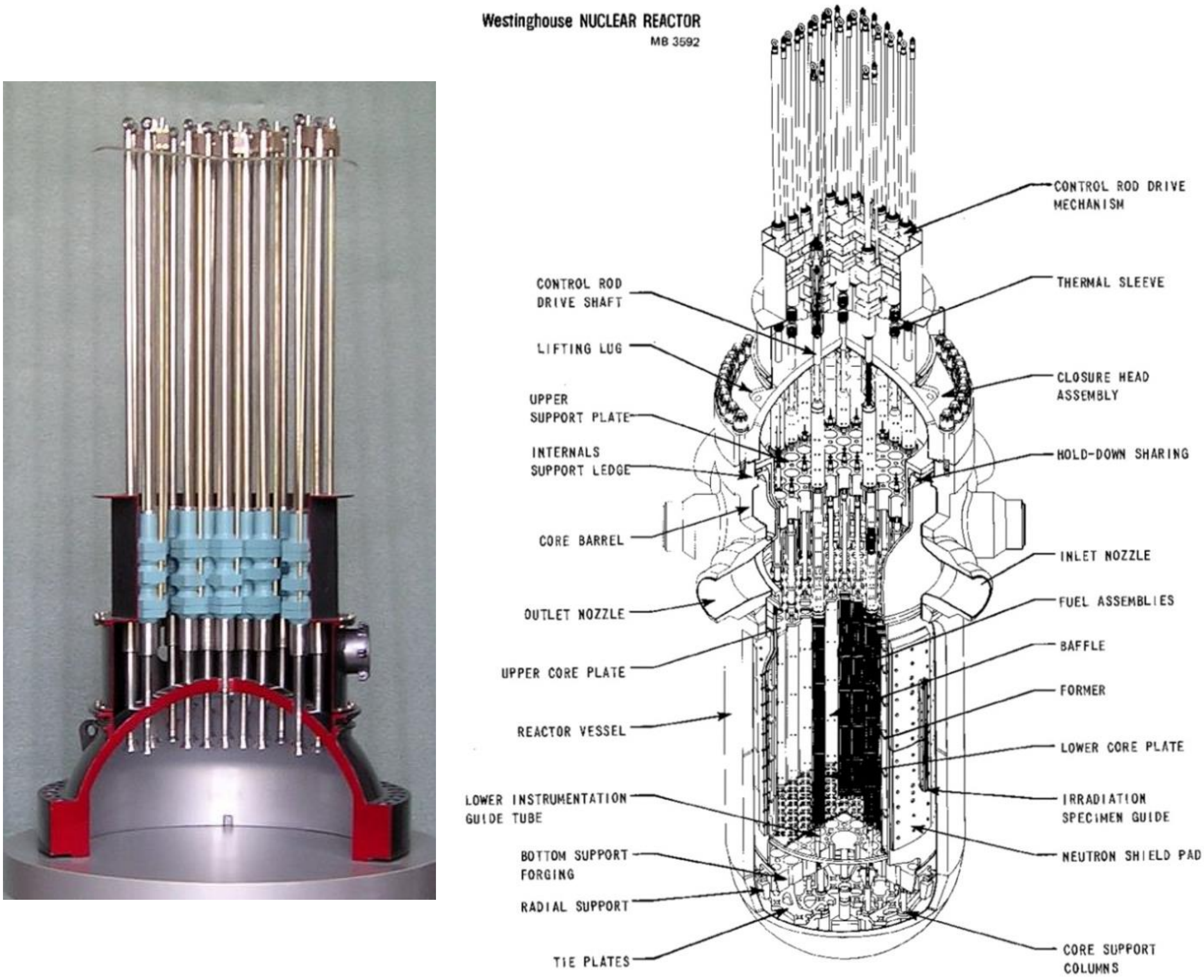



Figure 7-9: Example of a RPV head

*RPV*

The RPV has a body and a cover. The body consists of a vertical cylindrical shell and a hemispherical bottom that is welded to the shell. The cover is a hemispherical head that can be flanged to the body. A schematic overview of a comparable RPV is shown in the following:

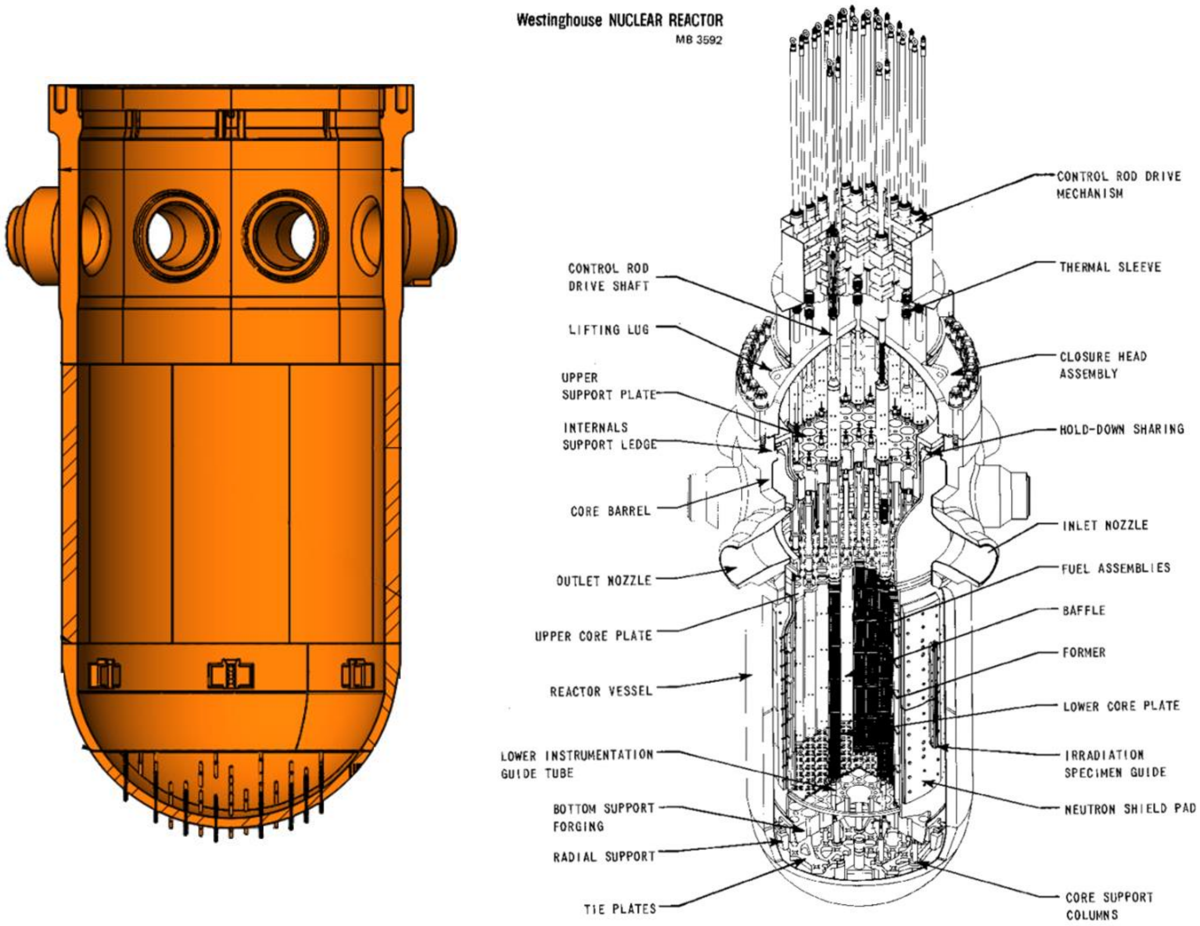



Figure 7-10: Example of a RPV

The dismantling of the RPV itself will be carried out in following steps which are illustrated by the figures. The main sequence is as follows:

- Cutting the loop pipes from inside with mechanical inside pipe cutters (Figure 7-11)
- Installation of a fixing equipment in the reactor cavity above the RPV
- Installation of a sawing equipment in the reactor cavity
- Disassembling of the RPV fixation
- Lifting the RPV for 1m into the reactor cavity by the reactor building crane (Figure 7-11)
- Fixing the RPV with the fixing equipment
- Cutting the RPV upper part
- Lifting the cut piece to the saw in the reactor cavity
- Cutting the upper part in suitable sizes for packaging
- In parallel lifting the RPV again for 1 m
- Cutting the next ring (Figure 7-12)
- And so on up to the RPV bottom

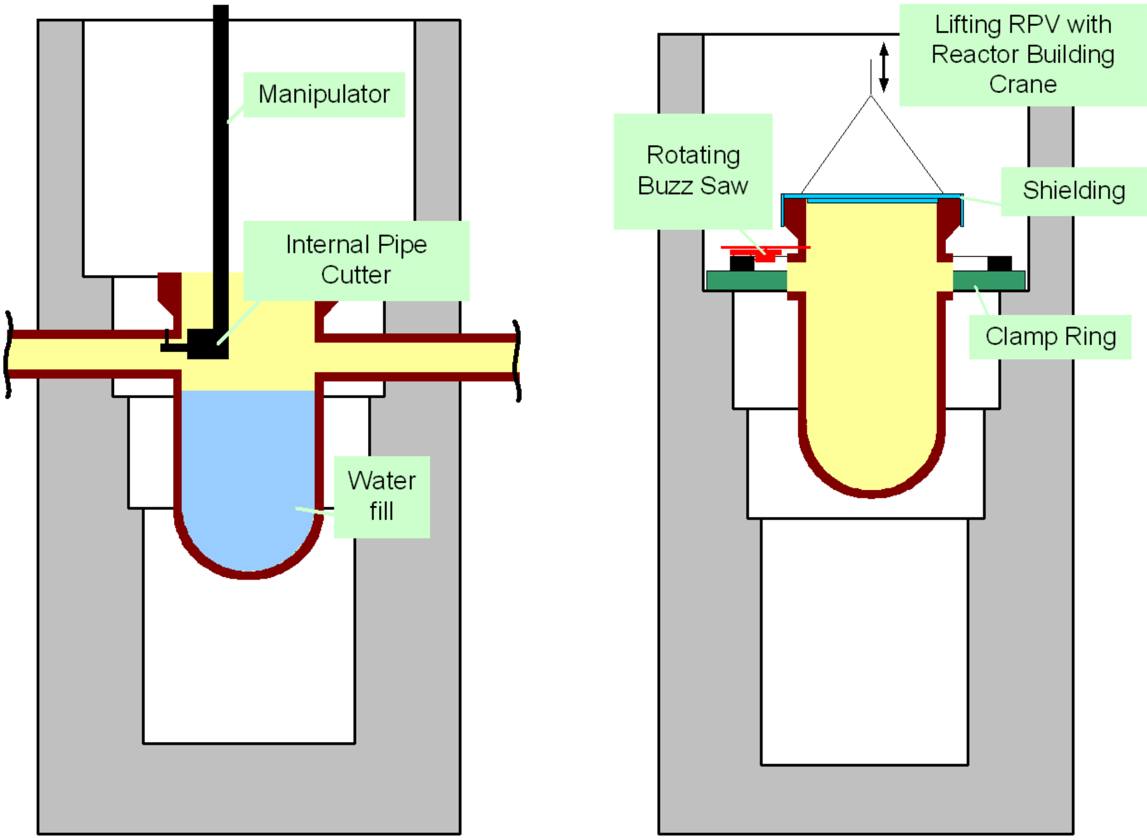



Figure 7-11: Cutting of the primary loop pipes and cutting first section of the RPV

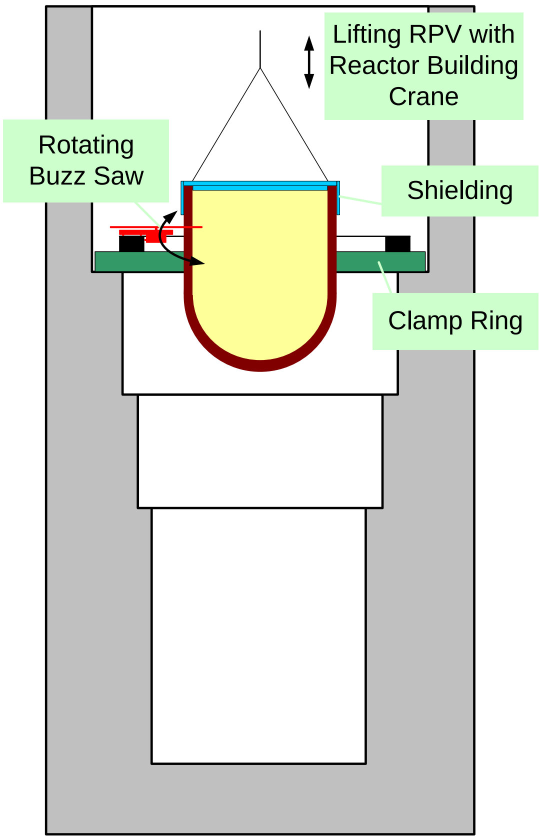



Figure 7-12: Cutting other sections of the RPV

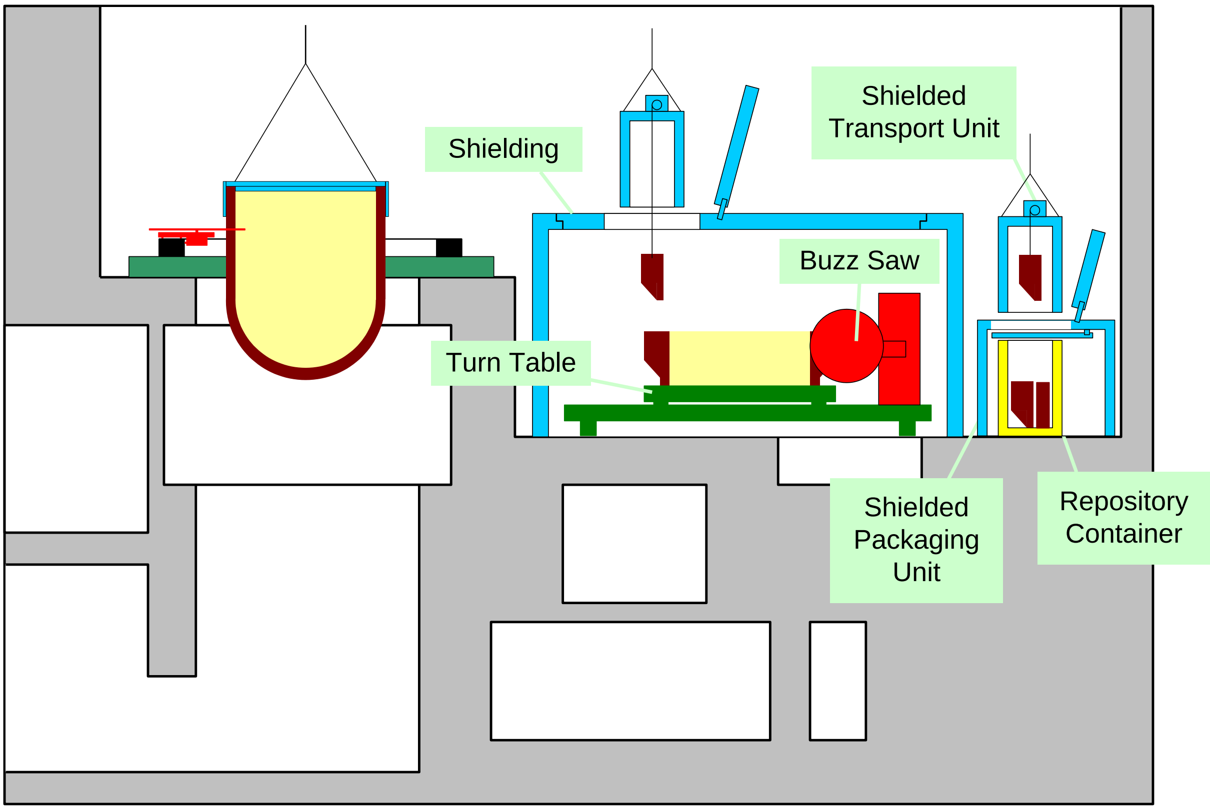



Figure 7-13: Additional cutting of RPV sections and packaging into repository container

The cut pieces will be packaged into concrete containers which are provided on the reactor operation level 105.55m. This work requires shielded transport equipment; the cut pieces and the content of a packaged container can be dried by vacuum sucking.

It is assumed that the RPV insulation is a part of the RPV and will be removed during the cutting of the RPV in a common working step.

### 7.3.2.1.2 Steam generators (SG)

In the NPP Krško there are not only the operating SGs which have to be dismantled. In the decontamination building also two old SGs are stored. The main goal of the dismantling of the SGs is to release most of the secondary part of a SG after decontamination. The secondary part covers all parts which are not part of the primary circuit like the primary in- and outlet, tube sheet, tubes and divider plate (see Figure 7-14).

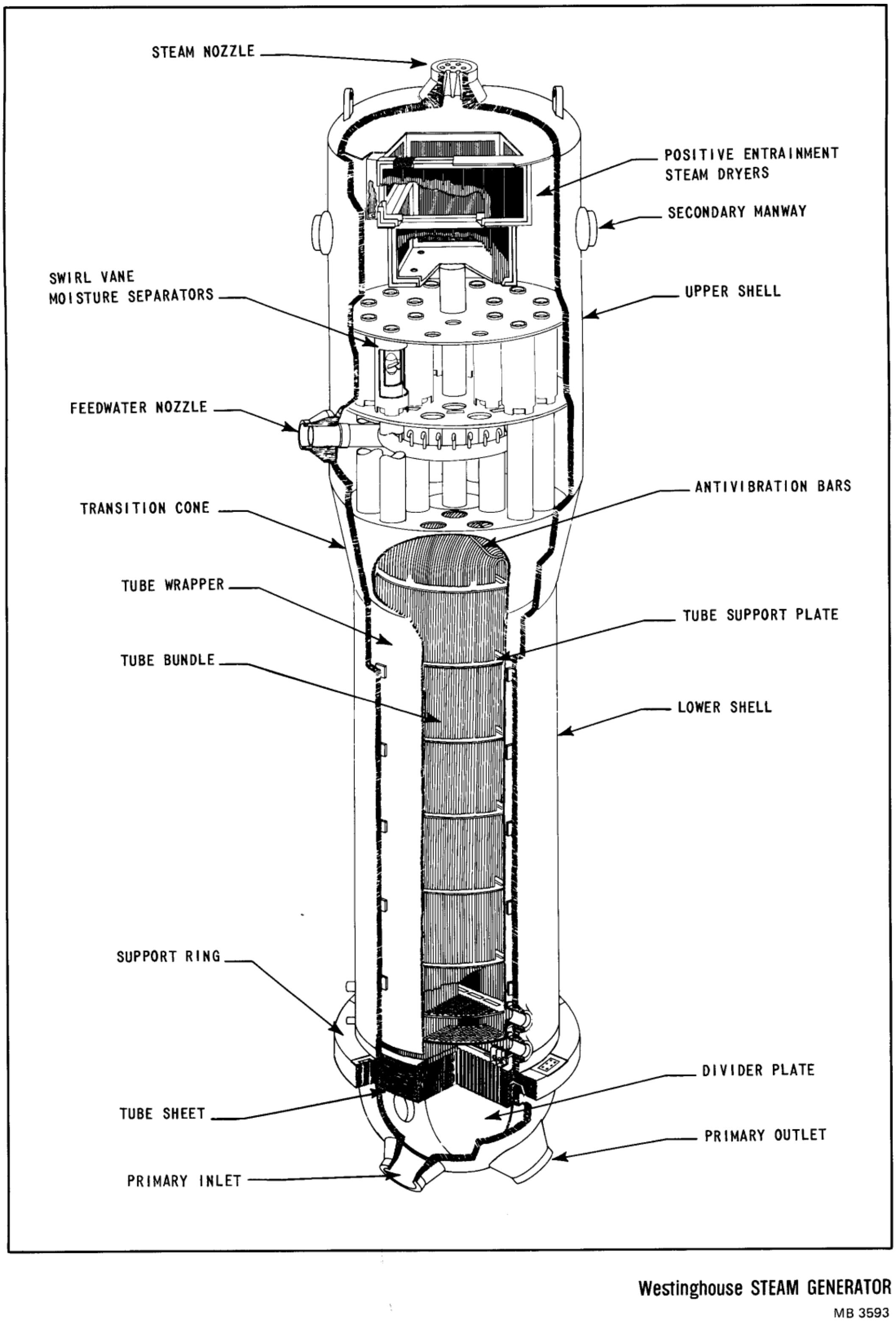



Figure 7-14: Example of a SG

Regarding this specific situation of the NPP Krško it is intended to proceed in the following sequence:

- The decontamination building will be improved with suitable equipment before final shut down as first step (see 7.3)
- The old SGs stored in the DB building will be disassembled, dismantled and cut suitable for release or packaging; a decontamination treatment for dismantled work pieces is planned
- After shut down the primary circuit will be decontaminated in-situ
- The SG will be dismantled in a one piece action and transported to the DB building
- The SG will be disassembled, dismantled and cut suitable for release or packaging; a decontamination treatment for dismantled work pieces is not planned
- The pressurizer, pressurizer relief tank, the primary pumps and the loop pipes will be dismantled and cut in transportable pieces and transported to the DB building for additional cutting and packaging respectively for release

Principle cutting processes applied are (exceptions are made if necessary):

- Cutting the SG into manageable pieces for the following working areas e.g. the decontamination in the blasting cabins. This process is performed by wire saw, as the handling is simple and a variable adoption to the different large components is possible next to space-saving build up. To avoid spreading of contamination, separate exhaust equipment is positioned next to the saw. The further treatment of the large component pieces is performed.
- Given the various large components to be processed, different types of cutting equipment are being considered e.g. hydraulic shears for the heat exchanger pipes, in some special cases grinders or acetylene burning for the secondary part.

### 7.3.2.1.3 Primary circuit pumps, pipes and the pressurizer

A general figure of the exemplary design of the reactor primary circuit is given in the following:

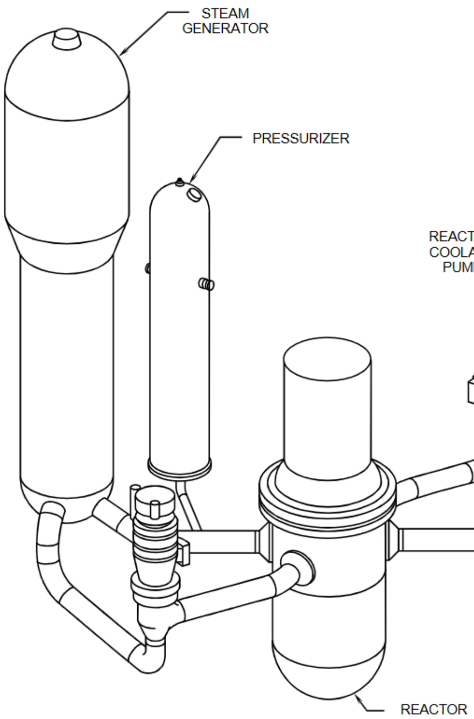



Figure 7-15: Example of primary circuit components

The primary circuit pipes as well as the pressurizer and primary circuit pump body (without motor) will be dismantled after the SGs.

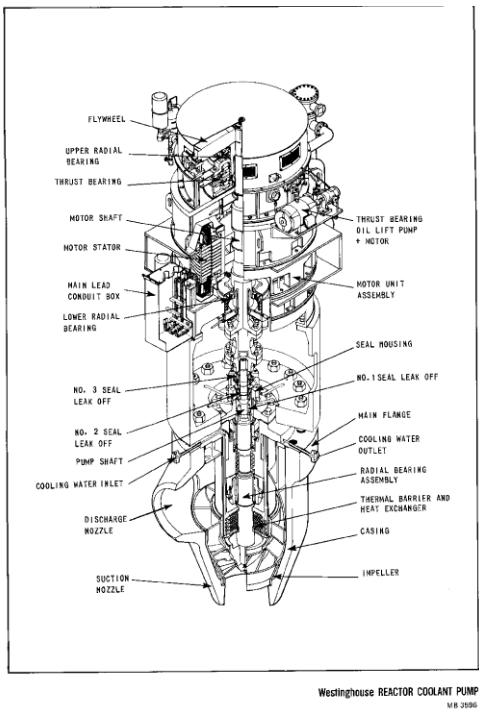



Figure 7-16: Example of a primary circuit pump

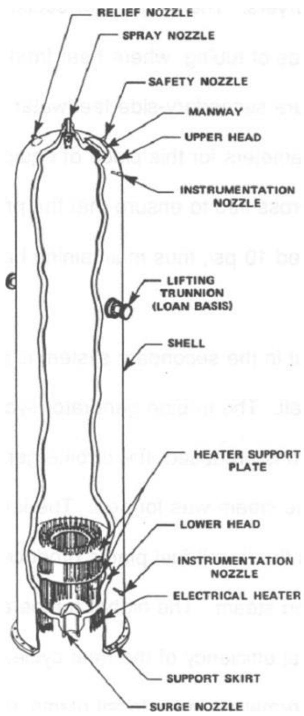



Figure 7-17: Example of a pressurizer

The principle cutting processes are the same then for the SGs, except for the motors of the primary circuit pump. These will be removed from the body and dismantled separately.

#### 7.3.2.1.4 Biological shielding

The activated (and potentially contaminated) part of the biological shield is cut on-site to transportable dimensions for internal transportation. An additional cutting to container sizes is performed in the radioactive waste storage area. The containers are put in storage awaiting their transfer to the final repository.

The radioactive part of the biological shield is dismantled by means of the rope sawing method.

With this technique a rope is pulled through holes drilled in the concrete. It reaches its sawing effect due to hard metal plates or the use of small natural diamonds which are attached to the ropes. This rope is led through deflection pulleys to a drive unit. There is the possibility to detach square meter large pieces which may then be demolished in a work shop using appropriate cutting tools.

### 7.3.2.2. Pipes

Pipes are separated in a first step into internally contaminated and not internally contaminated pipes. After this separation the internally contaminated pipes are classified by their diameter into three classes (<DN 50, DN 50 to DN 100 and >DN 100).

When dismantling the small pipes it is suggested to package immediately most of these in containers and prepare them for final repository – no additional measures like decontamination are proposed.

Large pipes are cut into transport size and moved to one of the workshops for further cutting and decontamination measures, if possible and necessary and prepared for radiological measurements. Otherwise these pipes are packaged into containers and directly prepared for final repository.

For the not internally contaminated pipes it is foreseen to release them after decontamination (wiping, mechanical or wet decontamination) of the outer surfaces.

### 7.3.2.3. Tanks, filters and heat exchanger

Tanks, Filters and Heat exchanger are separated into components with or without internal contamination. After this the tanks, filters and heat exchangers are separated into three classes (<100 kg, 100 kg to 1,000 kg and >1,000 kg).

As for small pipes most of the tanks, filters and heat exchanger smaller than 100kg are to be removed in one piece, packaged and send to the final repository.

Tanks, Filters and Heat exchanger larger than 1,000 kg are dismantled in one piece and cut to transport size in the workshops, if necessary. After that the heat exchangers will be transported to the decontamination building for further decontamination and additional cutting and release if possible or packaging into containers for final repository.

For tanks, filters and heat exchangers without internally contamination it is foreseen to release them. Some of these components could have some airborne contamination on the outer surface. In this case decontamination is necessary for release.

### 7.3.2.4. Pumps

For pumps with internal contamination and smaller than 50 kg mostly no measures after dismantling should be performed – these pumps should be packaged into the chosen container and be prepared for final repository.

Pumps with internal contamination and larger than 50 kg are dismantled, additionally cut to transportable pieces and transported to the decontamination building for further treatment.

Decontamination can be performed and parts of the pumps might be releasable – other parts might be packaged into containers and be prepared for final repository.

For pumps which are not internally contaminated it is foreseen to release them. As for the pipes some airborne contamination could appear on the outer surface, which makes an additional decontamination necessary.

#### 7.3.2.5. Valves

Valves are treated in the same way like pipes.

#### 7.3.2.6. Cables and cable trays

The cables will be collected to batches and transported in a skeleton transport box to the decontamination building for further treatment. It is suggested to separate the insulation from the copper. The copper will be measured and released as far as possible. The insulation will also be measured – the non-releasable cable insulation will be collected separately, compacted and then packaged into drums and containers for final repository.

Cable trays will be dismantled and cut to transportable size right away. As it is assumed that these components do only carry airborne contamination, they are packed in skeleton transport boxes and transported to the decontamination building for further decontamination and release measurement. The released material will become conventional waste – the non-releasable material will be packaged into containers and prepared for storage in the final repository.

#### 7.3.2.7. Electrical equipment

The electrical equipment is taken out in one piece as possible otherwise cut in transport size and packaged to the decontamination building for release measurement – a large amount of the electrical equipment will be free released as it is not contaminated – the other material is packaged into containers and prepared for final repository.

#### 7.3.2.8. Ventilation system

Air ducts are dismantled and cut to transport size – as it is assumed that the contamination is mainly airborne contamination some decontamination work in the decontamination building is foreseen. After decontamination and the release measurement the air ducts are either released or are packaged for final repository.

#### 7.3.2.9. Steel constructions and lifting devices

Steel constructions are removed last from the buildings as well as lifting devices as these might still be needed during dismantling of the plant.

Steel construction are removed and cut to transport size and transported to the decontamination building for further cutting and decontamination measures. The releasable part is released after measurement – the non-releasable part is packaged into containers and prepared for final repository.

The lifting devices are mainly seen as low contaminated and do carry mainly only air-borne contamination, therefore decontamination measures are taken after dismantlement and the components are released as far as possible – the non-releasable parts are packaged into concrete containers and are prepared for final repository.

#### 7.3.2.10. Motors

Motors will be dismantled in one piece, transported to a workshop and if reasonable additionally taken apart. In this working step releasable and non-releasable parts are separated. The parts that are good for decontamination measures are decontaminated and released as conventional waste, where possible. The others are directly measures and released or put into the equivalent container for final repository.

### 7.3.2.11. Hazardous materials

Hazardous material within the controlled area, which is non-radioactive, needs special attention during the dismantling activities, like for example additional protection measures, like e.g. protection masks and additional clothing and the regulations for packaging and release might be different from other material. If hazardous materials are radioactive material at the same time, the treatment procedures are the same as applied for radioactive material in this context as these are superior anyway.

Hazardous material which is released from nuclear regulations will still not be released completely; it is processed according to the Slovenian legal requirements, i.e. send to a landfill in a special packaging.

### 7.3.2.12. Secondary waste combustible

Combustible secondary waste, like clothing, paper and cleaning cloths, will be combusted as it is done during operation of the NPP Krško.

### 7.3.2.13. Secondary waste compactable

All secondary waste, like foils and filter material that can be compacted, are collected and transported to the decontamination building for measuring and release; the non-releasable material is filled in compressible drums and are compacted and then filled into TTC for packaging into N2d container or in the case of using RCC the drums will be packaged directly into the RCC for LILW repository.

### 7.3.2.14. Secondary waste liquid

Liquids are collected, pre-treated and neutralized. They are led to the evaporator. The condensates are measured in a release station. Free fractions are collected and measured again and released. Fractions of the condensate which are not free are fed back into the liquid waste stream. The concentrate is pre-treated for solidification. It is then filled in 200-l drums and fixed by dry filler. The filled drums are placed in concrete containers. Afterwards the concrete containers are filled with a filler material, if necessary, and put in a buffer store awaiting their transfer to the final repository.

### 7.3.2.15. Building rubble

The surfaces of the building structures inside the containment will be decontaminated by removing the surface layer where contamination is suspected. The building structures will then be dismantled under controlled area conditions and transferred to the decontamination building for measurement and release.

The surfaces of the building structures outside the containment but inside the controlled area will be decontaminated by removing the surface layer where contamination is suspected. The building structures will then be measured for release as a whole, in situ. After release the building structures will be dismantled under conventional conditions.

In CORA/CALCOM this is regarded as secondary waste which is generated during the process of building decontamination.

In the buildings and rooms in the controlled area where building decontamination takes place, there is only some simple equipment available for the transportation of the rubble:

- Individual cranes for overcoming different floor levels
- Transportation by manpower at the individual building levels
- Partial transportation in buckets from the decontamination position to the next drum

For that reason the maximum size for collecting the rubble at the decontamination place is a 200-l drum. These drums will be closed when they leave the controlled area. The drums are collected to batches and lead to the decontamination building for measurement and release.

Non-releasable drums are collected and packaged in concrete containers and prepared for final repository.

#### 7.3.2.16. Conventional concrete waste

After the abolishment of the controlled areas and the release of the buildings from nuclear regulations the building structures will be destroyed and removed. This work will be performed by a conventional demolition contractor.

In a first step all conventional hazardous matters will be removed. These hazardous matters are removed and disposed of in accordance with the pertinent rules. The structures above -1m are dismantled and crushed. The reinforcement steel is separated from the concrete and can be removed for reuse. The concrete rubble that cannot be reused will be transferred to a landfill. Structures below -1m are left in place. Floors remaining in place are destroyed to make them permeable. Remaining spaces are filled with crushed concrete.

#### 7.3.2.17. Conventional material

A part of the metallic material from conventional buildings and from nuclear release can be sold as scrap metal. This is true mainly for the reinforcement steel from the destroyed buildings and for a part of the physical inventory.

Large portions of the conventional material are mixed material and the revenues from selling it must be balanced against the costs for sorting and removal. A certain portion of the conventional and of the released material must be disposed of as conventional or even hazardous waste.

This will be done in accordance with the normal environmental protection rules.

Typical examples are:

- Paintings from walls
- Plastic material
- Lamps
- Electric and electronic material
- Asbestos
- Oil contaminated civil constructions or earth

#### 7.3.2.18. Waste from NPP operation

It is assumed that waste from operation is already conditioned and packaged into drums or TTCs and stored in the interim storage onsite NPP Krško (see Attachment 4).

The operational waste that is generated during the D&D will be treated like during operation – there is no other treatment used during dismantling. The super-compacted drums will be packaged into TTC. These TTC will be packaged then into N2d containers.
In the case of using RCC the drums will be packaged directly into RCC.

### 7.3.3. Packaging concept

#### 7.3.3.1. General assumptions

The packaging concept for radioactive waste is concerned by national and international requirements, rules and laws, e.g.:

- Regulations for the safe transport of radioactive material
- Preliminary radioactive waste acceptance criteria for storage and disposal
- The cementation of waste into the N2d or RCC containers is performed on the Krško NPP with regard to Attachment 3. The costs for a cementation facility and the cementation are not included in the DP, as they are part of the waste disposal program [4].

#### 7.3.3.2. Types of containers

Radioactive waste will be packaged into three different types of containers:

- Holtec HI-SAFE container
- N2d container
- RCC

The Holtec HI-SAFE containers are intended for packaging of the activated and high contaminated parts of the RPV [18]. Other contaminated components or equipment is packaged into the N2d containers and RCC. The assumption in the present study is to package 50 % of the radioactive waste mass into N2d containers and the other 50 % into RCC. The rules for loading the N2d container are given in the technical report [17] and for the RCC in [19]. The main boundary conditions are:

- The waste will be compacted and packaged in container in the NPP; if needed, additional shielding is foreseen inside the container
- Lead as an additional internal shielding in the containers is not allowed for the LILW repository
- The maximum allowable weight of N2d containers is 40 Mg or in case of RCC 15 Mg

<u>NOTE:</u> As options the packaging of 100 % of the radioactive waste masses into N2d container or 100 % into RCC are shown in Attachment 1 and 2 respectively.

The main dimensions of the containers which will be used are described in the following:

*Holtec HI-SAFE container:*

| Dimension | Nominal Value |
|---|---|
| Inner diameter | 1.8m |
| Representative inner height | 5 m (variable) |
| Representative inner volume | 13 $m^3$ (variable) |
| Wall thickness of inner and outer shells | 25 mm |
| Thickness of baseplate | 64 mm |
| Thickness of top ring plate | 25 mm |
| Variable concrete wall thickness | 200 mm to 760 mm |
| Lifting means | Must meets ANSI N14.6 |
| Lid securing methodology | Bolted |
| Lid lifting means | Threaded lifting holes or lugs |
| Example Curie content | 180,000 Ci |
| Calculated surface dose rate (conservative)<br>-180,000 Ci<br>-760 mm concrete shielding | 0.06 mSv |

Table 7-2: Representative Holtec HI-SAFE overpack characteristics [18]

Figure 7-18: Examples of Holtec HI-SAFE packages

*N2d container:*

| | |
|---|---|
| **Dimensions (mm)** | |
| Width x length x height outside: | 1,950 x 1,950 x 3,300 |
| Inside: bottom/top | 1,490/1,490 x 1,550/1,550 |
| Height before/after lid placement | 3,070/2,870 |
| Bottom slab thickness | 230 |
| Wall thickness (bottom/top) | 230/200 |
| Thickness of lid | 200 |
| **Volume of the container** | |
| Gross volume – outer dimensions | 12.28 $m^3$ |
| Net volume – after lid placement | 6.31 $m^3$ |
| **Weight** | |
| Empty container with lid | 14.92 Mg |
| Lid | 1.36 Mg |
| Maximum allowable weight of container | 40 Mg |

Table 7-3: Dimensions and weight of the N2d container [17]

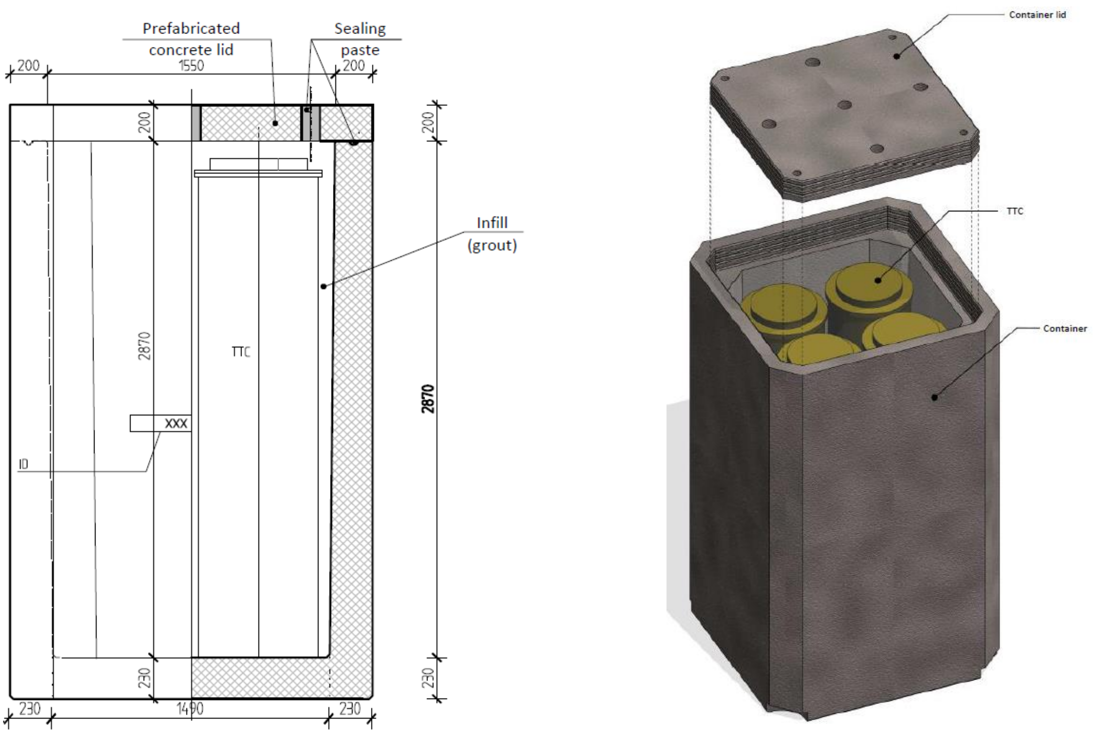



Figure 7-19: Drawings of the N2d container

*RCC:*

| | |
|---|---|
| **Dimensions (mm)** | |
| Outer height (H) | 1,700 |
| Outer width (W) | 1,700 |
| Outer length (L) | 1,700 |
| | |
| Useful height (H) | 1,430 |
| Useful width (W) | 1,450 |
| Useful length (L) | 1,450 |
| **Volume of the container** | |
| Gross volume – outer dimensions | 4.91 $m^3$ |
| Net volume – after lid placement | 2.85 $m^3$ |
| | |
| **Weight** | |
| Empty container with lid | Up to 7.5 Mg |
| Maximum allowable weight of container | 15 Mg |

Table 7-4: Dimensions and weight of the RCC [19]

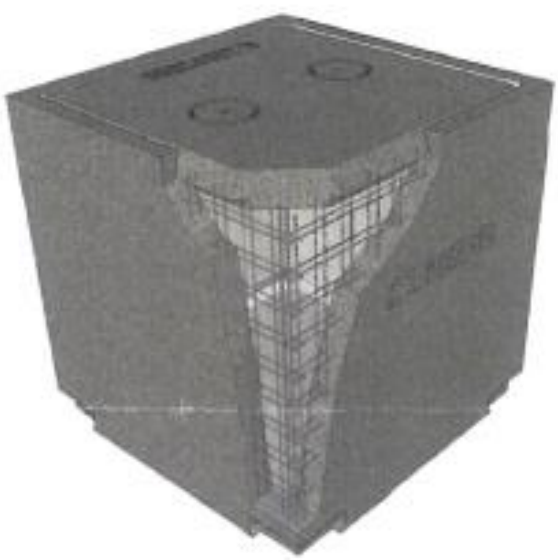


Figure 7-20: Drawing of the RCC

#### 7.3.3.3. Drums

One option to package components and treated liquids (concentrates) are drums. Mainly 200-l drums are used in decommissioning projects, because they are very well manageable and packable in containers for interim or final storage. Also there is the possibility to reduce the dose rates by the use of shielding within the drums.

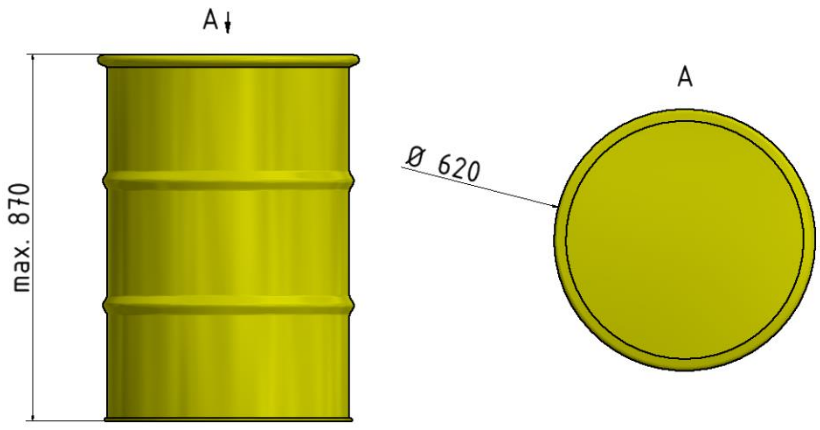



Figure 7-21: Press drum 200-l: schematic drawing

Figure 7-22: Shielded 200-l drum

#### 7.3.3.4. TTC

The TTC are like the 200-l drums currently used for storage of radioactive waste. In average ten super-compacted 200-l drums or three filled 200-l drums will be packaged into one TTC.

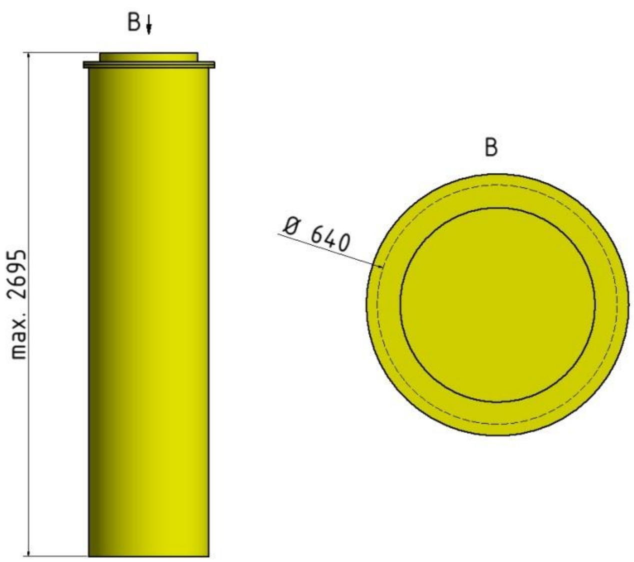



Figure 7-23: TTC: schematic drawing

Figure 7-24: Example of a TTC

### 7.3.3.5. Packaging of radioactive material

#### 7.3.3.5.1 Packaging of different waste materials

The different materials generated during the decommissioning of a NPP must be packaged in containers, sometimes manifold, e.g. using drums with overpack.

As the components are dismantled and cut into pieces, the component is no longer of interest and described, but the material is the relevant group to be considered in terms of packaging.

The following chapter shows the different material groups and the intended packaging strategy. The components in the containers will be immobilized. For the purpose of the present study it is assumed that the immobilization will be done by cementation in a new building to be erected on the Krško NPP site referring to Attachment 3. The costs for a cementation facility and the cementation are not included in the DP, as they are part of the waste disposal program [4].

#### 7.3.3.5.2 Contaminated materials

*Non-compressible material*

Non-compressible material from components is:

- Cut parts of thick walled components
- Components which are handled in complete i.e. motors, pumps, valves
- Steel girders
- Others

These materials will be packaged in N2d containers and RCC.

*Compressible material*

Compressible material will be super-compacted to reduce the needed volume. For this the material will be filled in 200-l press drums. The drum will be reduced in its height by the super-compactor. The reduction factors which could be reached are dependent of the pressing material and ranged from 3 to 5. The pressed drums (now called as pellet) will be filled in TTC and these TTC will be packaged into N2d containers. In the case of using RCC the 200-l drums will be packaged into the RCC directly.

*Insulation*

Insulation will be filled in a 200-l press drum. The mean filling grade is estimated to 50 kg per drum. These drums will be reduced by a factor of 5 and packaged into a TTC. The TTC will be put into N2d containers. In the case of using RCC containers the 200-l drums will be packaged into the RCC directly.

*Concrete rubble*

Concrete rubble will be directly packaged in the N2d containers and RCC.

### 7.3.3.5.3 Activated material

The packaging of the activated material is an important factor for the decommissioning cost. The containers must be shielded, the handling of the material has to be remote controlled, and the possible load per container is limited according to the level of activation. Therefore the selection of an appropriate and economical packaging of the activated material was done in the previous study. The conclusion was to take CASTOR casks and N3 container into account for storing activated materials. With regard to the current situation the packaging of the activated materials in Holtec HI-SAFE packages, N2d containers and RCC are foreseen. Thereby the Holtec HI-SAFE packages replace the CASTOR casks and the N2d container and the RCC replace the N3 container. As done in the previous study the radioactive values of activation and contamination are also taken into account for distributing the components to the packages or container.

For the optimization of the container loading an external dose rate of 0.1 mSv/h in 2 meter distance from the container surface (according to the transport regulations for radioactive materials) is used.

### 7.3.3.5.4 Activated concrete

Activated concrete from Biological Shield will be cut in situ - partially under remote control conditions to suitable dimensions. The material will be packaged in N2d containers and RCC.

### 7.3.3.5.5 Secondary waste

*Solids from mechanical decontamination*

Solids from mechanical decontamination are collected in 200-l drums or the waste is used as filling material in other containers. The drums will be packaged in N2d containers and RCC.

*Concentrates from decontamination liquids*

Concentrates from decontamination have been treated and evaporated. The concentrates will be collected in 200-l drums; the drums will be packaged in N2d containers and RCC.

*Slags and filters from melting*

Slags and filters which will be sent back from the melting facility are packaged in 200-l drums. The drums will then be packaged in N2d containers and RCC.

*Combusted wastes*

Combusted wastes which will be sent back from the incineration facility are super-compacted and packaged in 200-l drums. These 200-l drums will be packaged in N2d containers and RCC.

## 7.4. Results of the waste management and waste packaging calculations

The results of the calculations concerning waste amount and number and type of containers are strongly linked to the mass of the components and radioactive materials, expected during the decommissioning work. Therefore this important input is repeated in Table 7-5 below.

**Treated masses and spent fuel of the NPP KRŠKO**

| Category | |
|---|---|
| **Number of spent fuel elements*3** | **1,098** |
| | |
| **Decommissioning material plant (primary) [Mg]** | **462,075.4** |
| Controlled area components and structures*1 | 164,206.5 |
| Monitored area components and structures*1 | 165,120.3 |
| Area inside the fence components and structures*1 | 132,748.6 |
| | |
| **Decommissioning material plant (secondary) [Mg]** | **4,366.1** |
| Generated secondary masses generated during D&D*2 | 4,366.1 |
| | |
| **Total mass (without spent fuel elements) [Mg]** | **466,441.5** |

*1 the areas are defined in Figure 2-3

*2 these masses are calculated by NIS

*3 information provided by NEK (considered in PDP rev.6 [1])

Table 7-5: Input data for waste management calculations

### 7.4.1. Waste management results

For the nuclear power plant Krško, as a single working plant in Slovenia, it is not assumed to have facilities for the treatment of radioactive material in Slovenia – exception could be the final preparation of waste containers for the LILW repository. According to this it was at last supposed to do the treatment work as far as possible in the plant itself using both existing and new equipment. Treatment techniques which are not applicable in the plant will be avoided.

After the waste management and packaging concept is explained (see chapter 7.1 to 7.3) the results of the calculations made by CORA are shown. Table 7-5 shows the input data which are distributed to the disposal routes. In this a treatment objective and a treatment is combined. The used disposal routes in the case of this study are the following ones:

- Conventional waste (landfill) + no treatment
- Disposal HLW repository + no treatment
- Disposal LILW repository + evaporation
- Disposal LILW repository + no treatment
- Disposal LILW Repository + super-compaction
- External treatment + combustion
- External treatment + melting
- Release + mechanical decontamination
- Release + no treatment
- Release + wet decontamination

A selection of the disposal routes is combined within a distribution factor set. Every component in the CORA database has dedicated one distribution factor set. The assignment of distribution factors to the components is done with regard to their contamination (explained in chapter 2.4) and to the waste management strategy (explained in chapter 7.3). The distribution factor set for the SG, which is shown in the following, serve as an example:

**Distribution Factor Set**

| Portion [%] | Disposal Route | | | Mass Factor | SM Set | | Capacity [kg] |
|---|---|---|---|---|---|---|---|
| Steam Generators | | | | | | | |
| 30,00 | Release + Mechanical Decontamination | | | 100,00% | 9 (Decontamination - mechanical) | | |
| 25,00 | Disposal LILW Repository + No Treatment | | | 100,00% | 7 (Conditioning without supercompaction) | | |
| | *Packaging: Portion [%] Package* | | *Waste Type* | | | | *Capacity [kg]* |
| | 100,00 N2d Container - no shielding | | non compressible waste, metallic | | | | 9.906,7 |
| | *Interim Storage* ☐ | *Transportation:* | € / Package | *Repository:* | | € / m³ | |
| | *Final Repository* ☑ | *Transportation:* | € / Package | *Repository:* | | € / m³ | |
| 35,00 | Release + No Treatment | | | 100,00% | | | |
| 10,00 | External treatment + Melting | | | 100,00% | 11 (Melting) | | |
| | *Packaging: Portion [%] Package* | | *Waste Type* | | | | *Capacity [kg]* |
| | 100,00 Free Transport Container | | Waste for melting | | | | 17.270,0 |
| | *Interim Storage* ☐ | *Transportation:* | € / Package | *Repository:* | | € / m³ | |
| | *Final Repository* ☐ | *Transportation:* | € / Package | *Repository:* | | € / m³ | |

Figure 7-25: Example of a distribution factor set (SG)

Figure 7-25 shows also that packages are linked to the disposal route, where they are necessary e.g. for disposal LILW repository + no treatment or external treatment + melting.

By using the distribution factor sets the following results, separated in defined areas, occur:

**Disposal routes and treated masses of the NPP KRŠKO**

| Category | Controlled area [Mg] | Monitored area [Mg] | Area inside fence [Mg] |
|---|---|---|---|
| **Decommissioning material plant (primary)** | **164,206.55** | **165,120.31** | **132,748.56** |
| Conventional Waste (Landfill) + No Treatment | 147,896.31 | 163,004.24 | 132,748.56 |
| Disposal HLW Repository + No Treatment | 139.99 | | |
| Disposal LILW Repository + No Treatment | 1,970.71 | 744.15 | |
| Disposal LILW Repository + Super compaction | 28.43 | | |
| External treatment + Melting | 286.66 | 64.40 | |
| Release + Mechanical Decontamination | 776.78 | 193.20 | |
| Release + No Treatment | 12,116.20 | 1,083.07 | |
| Release + Wet Decontamination | 991.48 | 31.25 | |
| | | | |
| **Decommissioning material plant (secondary)** | **3,773.00** | **593.05** | |
| Conventional Waste (Landfill) + No Treatment | 366.74 | 73.34 | |
| Disposal LILW Repository + Evaporation | 2,478.96 | 341.64 | |
| Disposal LILW Repository + No Treatment | 385.20 | 79.39 | |
| Disposal LILW Repository + Super compaction | 24.59 | 4.67 | |
| External treatment + Combustion | 150.78 | 20.66 | |
| Release + No Treatment | 366.74 | 73.34 | |
| | | | |
| **Disposal mass (without fuel elements)** | **5,027.87** | **1,169.85** | |
| **Total mass (without spent fuel elements)** | **167,979.55** | **165,713.36** | **132,748.56** |

Table 7-6: Disposal routes and treated masses of the NPP Krško

NOTE: The given masses for secondary waste are masses before treatment, i.e. the radioactive waste masses for packaging might be lower (e.g. liquids vs. concentrates) after treatment.

A more detailed line-up of the above mentioned results is given in the following table:

**Disposal routes and treated masses of the NPP KRŠKO**

| Area | Monitored area [Mg] | | | | | | Controlled area [Mg] | | | | | | | | Area inside Fence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component type / Disposal route | Release + Wet Decontamination | Release + No Treatment | Release + Mechanical Decontamination | External treatment + Melting | Disposal LILW Repository + No Treatment | Conventional Waste (Landfill) + No Treatment | Release + Wet Decontamination | Release + No Treatment | Release + Mechanical Decontamination | External treatment + Melting | Disposal LILW Repository + Super compaction | Disposal LILW Repository + No Treatment | Disposal HLW Repository + No Treatment | Conventional Waste (Landfill) + No Treatment | Conventional Waste (Landfill) + No Treatment |
| AIR DUCTS | | | | | | 172.48 | 56.33 | 216.23 | | 2.08 | | 15.33 | | | 17.10 |
| BATTERY EQUIPMENT | | 14.61 | | | | 34.09 | 0.13 | 0.02 | 0.05 | 0.02 | | 0.09 | | 0.07 | 8.01 |
| BIOLOGICAL SHIELD | | | | | | | | 1,086.40 | | | | 513.60 | | | |
| CABLE | | 187.35 | | | | | | 71.75 | | | | 10.76 | | 96.86 | 482.72 |
| CABLE TRAY AND SUPPORT | | 93.67 | | | | | 35.87 | 26.90 | | 17.94 | | 8.97 | | | 243.36 |
| CONCRETE OF THE BUILDING | | | | | | 146,695.25 | | 6,790.00 | | | | 210.00 | | 138,293.87 | 121,978.00 |
| CONDENSER | | 127.27 | | | | 302.96 | 6.92 | | 4.22 | 1.74 | | 2.04 | | | 7.50 |
| CORE COMPONENT | | | | | | | | | | | | | 22.00 | | |
| CRANE | | | | | | 195.15 | 92.89 | 388.87 | 57.23 | 3.55 | | 1.88 | | | 97.23 |
| DOORS | | | | | | 25.50 | | 16.50 | | | | | | | 17.40 |
| ELECTRICAL EQUIPMENT | | 48.41 | | | | 487.07 | 1.26 | 14.15 | | | | 6.49 | | 45.10 | 1,204.71 |
| FILTER | | | | | | 42.42 | 3.93 | | 2.60 | 1.10 | | 1.70 | | | 16.98 |
| HANGER OR SUPPORT | | | | | | 255.70 | 225.38 | | 56.34 | 37.56 | | 56.34 | | | 20.58 |
| HATCH | | | | | | | | 80.00 | | | | | | | |
| HEAT EXCHANGE | | 225.40 | 193.20 | 64.40 | 161.00 | 489.76 | 36.09 | 246.38 | 233.76 | 80.40 | | 181.10 | | | 24.43 |
| INSULATION | | | | | | 546.50 | | | | | 28.43 | 28.43 | | 227.40 | 58.74 |
| LINER | | | | | | | 15.20 | 41.80 | 15.20 | | | 3.80 | | | |
| LUBRICATION | | | | | | | | | | | | | | | 285.00 |
| MOTOR AND DRIVE | | 243.86 | | | | 586.46 | 2.62 | 60.70 | 54.46 | 0.08 | | 59.14 | | | 291.11 |
| PIPE | | | | | | 2,397.50 | 337.06 | 382.12 | 194.13 | 104.75 | | 128.20 | | | 293.70 |
| PUMP | | | | | | 139.37 | 13.45 | 34.01 | 48.27 | 2.97 | | 34.71 | | | 129.92 |
| REACTOR PRESSURE VESSEL + INTERNALS + CONTROL ROD | | | | | 33.65 | | | | | | | 249.08 | 117.99 | | |
| REINFORCEMENT OF THE BUILDING | | | | | | 8,898.00 | | | | | | | | 9,233.00 | 6,310.50 |
| SMALL PARTS | 31.25 | 34.49 | | | | 151.06 | 40.00 | 40.00 | | | | | | | 434.50 |
| STEEL CONSTRUCTIONS | | 108.00 | | | 549.50 | 420.24 | | 2,578.36 | | | | | | | 147.07 |
| STORAGE RACK | | | | | | | | | | | | 390.74 | | | |
| TANK | | | | | | 206.65 | 72.36 | 1.12 | 92.07 | 26.08 | | 49.34 | | | 528.19 |
| TURBINE | | | | | | 406.82 | | | | | | | | | |
| VALVE | | | | | | 521.62 | 47.91 | 38.76 | 17.20 | 7.73 | | 18.02 | | | 143.61 |
| VALVE OPERATOR | | | | | | 29.66 | 4.08 | 2.13 | 1.25 | 0.65 | | 0.95 | | | 8.22 |
| **TOTAL** | **31.25** | **1,083.07** | **193.20** | **64.40** | **744.15** | **163,004.24** | **991.48** | **12,116.20** | **776.78** | **286.66** | **28.43** | **1,970.71** | **139.99** | **147,896.31** | **132,748.56** |

Table 7-7: Disposal route primary masses separated by unit and component type

### 7.4.2. Packaging results

A total mass of 3,391 Mg (see Table 7-9) from the components of the controlled area and monitored area including waste from secondary masses – calculated with the database software CORA – has to be stored in the HLW or LILW repository finally.

The calculation of the number of containers and the disposal volume needed is calculated by using specific packaging factors which are collected and evaluated by NIS during several decommissioning projects and which were updated for this study. The used factors are given in Table 7-8.

## Packaging factors

| Kind of waste | Capacity [kg] |
|---|---|
| **200-l-drums:** | |
| Ashes from combustion | 350 |
| Concentrates | 75 |
| Insulation waste | 50 |
| Melting waste | 450 |
| Mixed waste, lightweight materials | 110 |
| Solids from mechanical decontamination | 240 |
| **Transport container (Big bag):** | |
| Combustible waste | 300 |
| **Transport container (20'-container):** | |
| Combustible waste (Big bag) | 6,000 |
| Waste for melting | 17,270 |
| **TTC:** | |
| Insulation waste | 750 |
| Mixed waste, lightweight materials | 1,320 |
| **N2d container:** | |
| 200-l-Ashes from combustion | 4,200 |
| 200-l-Concentrates-drum | 900 |
| 200-l-Melting waste | 5,400 |
| 200-l-Solids from mechanical decontamination | 2,880 |
| Non compressible waste, concrete | 7,320 |
| Non compressible waste, metallic | 9,907 |
| RPV insulation | 2,477 |
| TTC-Insulation waste | 3,000 |
| TTC-Mixed waste, lightweight materials | 5,280 |
| **RCC:** | |
| 200-l-Ashes from combustion | 2,100 |
| 200-l-Concentrates-drum | 450 |
| 200-l-Insulation waste | 300 |
| 200-l-Melting waste | 2,700 |
| 200-l-Mixed waste, lightweight materials | 660 |
| 200-l-solids from mechanical decontamination | 1,440 |
| Non compressible waste, concrete | 3,306 |
| Non compressible waste, metallic | 4,475 |
| RPV insulation | 1,119 |
| **Holtec HI-SAFE cask:** | |
| RPV-Internals | 20,078 |

Table 7-8: Packaging factors for the calculation of the containers (N2d and RCC)

The amount of containers for storing all the radioactive waste is calculated by dividing the repository mass with the above described packaging factors. The necessary disposal volume is then calculated by the number of containers multiplied with the outer volume of the containers.

The results for the calculated amount of packages and for the related repository volume are given in the following table. The assumption in the present study is to package 50 % of the radioactive waste mass into N2d container and the other 50 % into RCC.

**NPP KRŠKO number and volume of repository container**

| Type of container: | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] |
|---|---|---|---|---|
| **Other container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| 200-l-drum | 57 | 1,137 | 0.14 | |
| Free Transport Container | 287 | 17 | | |
| TTC container | 28 | 38 | 0.08 | |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| Free Transport Container | 64 | 4 | | |
| | | | | |
| **Packaged secondary waste:** | | | | |
| 200-l-drum | 130 | 657 | 0.08 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 171 | 29 | | |
| TTC container | 12 | 9 | 0.02 | |
| | | | | |
| **Total:** | | | | |
| 200-l-drum | 187 | 1,794 | 0.22 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 522 | 49 | | |
| TTC container | 40 | 47 | 0.10 | |
| | | | | |
| **Repository container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| N2d Container | 1,000 | 121 | 1.28 | 1,485 |
| RCC | 1,000 | 342 | 2.05 | 1,678 |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| N2d Container | 372 | 38 | 0.40 | 461 |
| RCC | 372 | 83 | 0.50 | 409 |
| | | | | |
| **Packaged secondary waste:** | | | | |
| N2d Container | 254 | 46 | 0.49 | 571 |
| RCC | 254 | 112 | 0.67 | 549 |
| | | | | |
| **Total:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| N2d Container | 1,625 | 205 | 2.17 | 2,517 |
| RCC | 1,625 | 537 | 3.22 | 2,636 |
| | | | | |
| **Total for repository container:** | **3,391** | **748** | **16.29** | **5,390** |

Table 7-9: Detailed information about waste package results (N2d container and RCC)

The packaged waste masses for the repository in Table 7-9 are lower than the masses given in Table 7-6. The reason therefore is that after the evaporation of the waste water, combustion or melting it is assumed that only a few percent of the mass have to be packaged as waste.

NOTE: About 550 Mg of the packed waste mass are resulting from the SFDS decommissioning (incl. radioactive waste from the spent fuel storage containers).

A containers time schedule with the expected number and type of repository containers (for decommissioning waste) is provided hereafter.

**Yearly number of packages**

| Number of packages | Total | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | .... | 2103 | 2104 | 2105 | 2106 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200-l-drum | **1.794** | 0,0 | 39,2 | 58,2 | 135,3 | 38,0 | 7,5 | 1,3 | 10,0 | 323,2 | 34,9 | 960,1 | 66,2 | 67,1 | 30,4 | 19,1 | - | - | - | - | 3,4 |
| TTC container | **47** | 0,0 | 0,3 | 0,5 | 1,0 | 0,4 | 0,2 | 0,0 | 0,3 | 10,1 | 0,5 | 28,8 | 1,5 | 1,6 | 0,8 | 0,6 | - | - | - | - | 0,1 |
| N2d Container | **205** | 0,0 | 4,8 | 9,3 | 17,4 | 4,2 | 0,9 | 1,0 | 10,7 | 37,9 | 5,0 | 19,4 | 5,2 | 37,7 | 11,1 | 12,6 | - | 27,7 | - | - | 0,1 |
| RCC | **537** | 0,0 | 10,7 | 21,0 | 38,8 | 9,6 | 2,4 | 2,4 | 24,0 | 103,3 | 11,6 | 97,3 | 13,8 | 85,6 | 25,7 | 28,6 | - | 61,4 | - | - | 0,3 |
| **Total:** | **2.582** | **0,0** | **55,0** | **89,0** | **192,4** | **52,3** | **11,1** | **4,8** | **45,0** | **474,6** | **52,0** | **1.105,5** | **86,8** | **191,9** | **68,0** | **60,8** | **...** | **89,1** | **-** | **-** | **3,9** |

NOTE: For the purpose of the study it is considered that N2d container and RCC are also used for the storage of the radioactive waste from the SFDS decommissioning.

Table 7-10: Yearly number of packages

# 8. Safety assessment

The agreed operational regulations concerning the safety assessments are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant. The decommissioning planning will be supported by an appropriate safety assessment covering the planned activities and abnormal events that may occur during decommissioning. The assessment will address occupational exposures and potential releases of radioactive substances with resulting exposure of the public. The safety assessment will employ a systematic methodology to demonstrate compliance with safety requirements and criteria for decommissioning throughout the decommissioning process, including the release of material, buildings and sites from regulatory control. In addition, the safety assessment will be used to ensure that interested parties are confident of the safety of decommissioning.

Once developed by the operator, the final safety assessment for decommissioning of the NPP will be reviewed by the regulatory body to ensure compliance with the safety requirements and criteria.

# 9. Environmental assessment

The offsite radiological monitoring is being carried out since 1974 already and comprises surveillance of about 50 locations in local land environment. The following media are regularly monitored:

- Air
- Waters
- Precipitation
- Suspended matters
- Deposits
- Biota of the Sava river
- Underground waters

Dose calculations are compared to natural external dose rate and atmospheric deposits from preoperational monitoring. All the measurements are being carried out during plant operation as well as during later decommissioning.

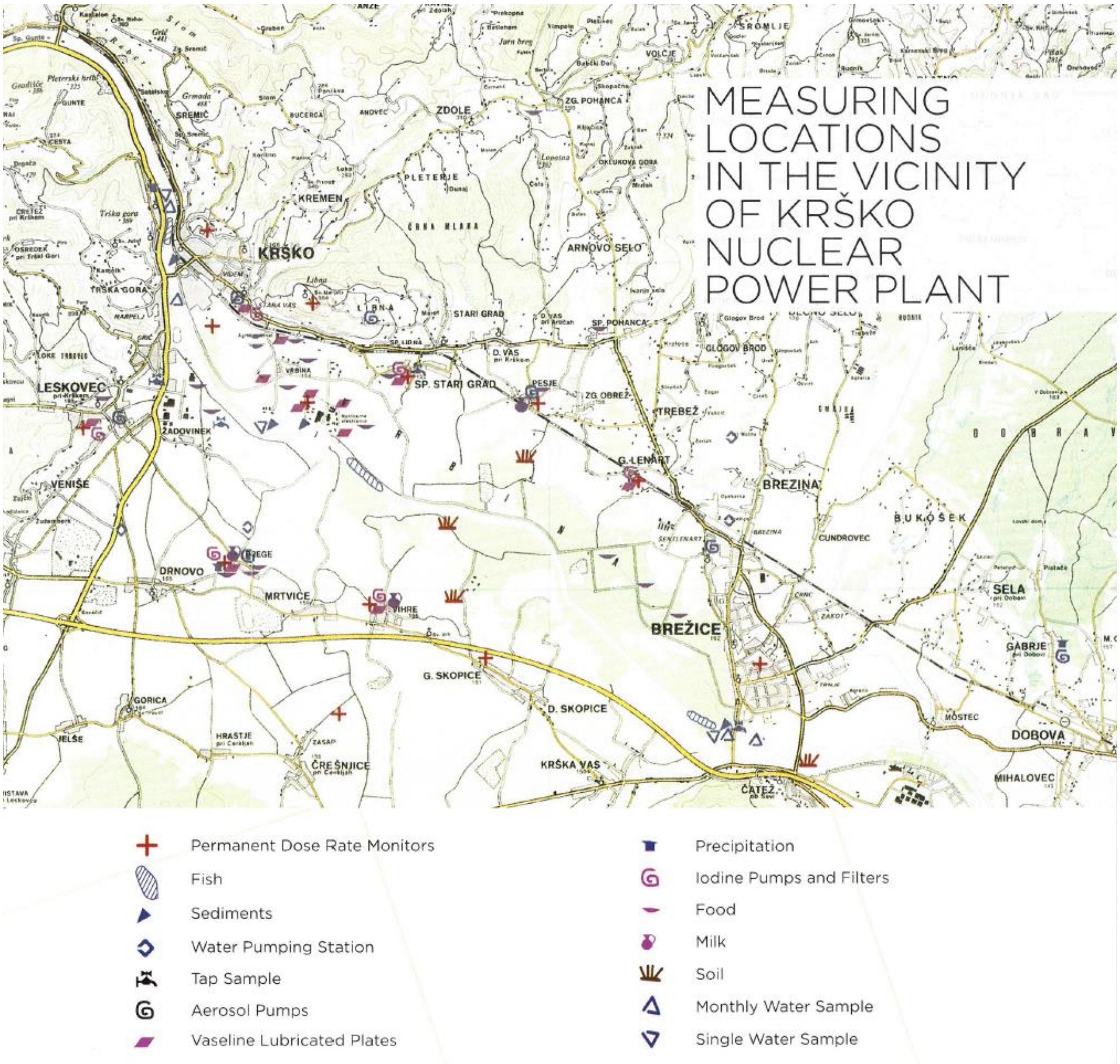



Figure 9-1: Measuring locations in the vicinity of Krško NPP

The agreed operational regulations concerning the environmental assessments are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the de-commissioning of the plant. Before the decommissioning of the NPP as well as for the SFDS an environmental impact assessment process is obligatory in Slovenia.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

# 10. Occupational safety

The agreed operational regulations concerning the occupational safety are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

## 11. Quality assurance

The agreed operational regulations concerning the quality assurance are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

## 12. Emergency plan

The agreed operational regulations concerning the emergency plans are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

# 13. Physical security and safeguards of nuclear and radioactive substances

The agreed operational regulations concerning the physical security and safeguards for nuclear and radioactive substances are still in force at the end of the operational life time.

Together with the planning and application for the decommissioning licence these regulations will be checked to what extent they are applicable for the terms and conditions of the decommissioning of the plant.

It is recommended to adapt the regulations in agreement with the authorities to the needs of the decommissioning.

# 14. Final overview of the radiological conditions

## 14.1. Radioactive inventory

The radioactive inventory of the Krško NPP, described in the following chapter for the components, systems and buildings (not for the operational waste and for the spent fuel elements), can be categorized within three groups:

- Activated components; situated in the area RPV internals, RPV and biological shield
- Contaminated components; inner contamination generated by contact with radioactive media
- Contaminated components and building structures; airborne contamination generated by radioactive particles and dust

The principal decrease of the total amount of radioactivity is shown in Figure 14-1. It shows that more than 99% of the radioactivity is concentrated within the spent fuel elements. This radioactivity will be removed with the packaging of the spent fuel in casks and therefore not more important for the decommissioning project.

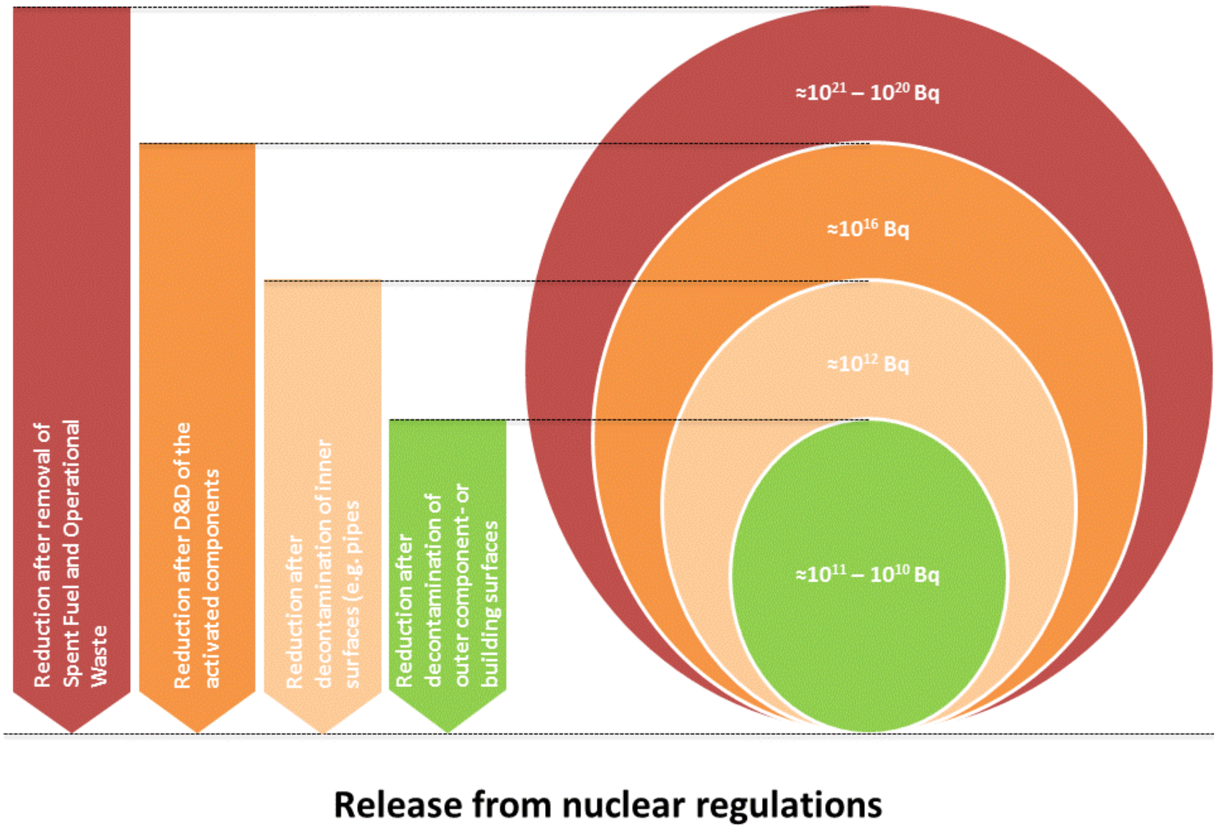



Figure 14-1: Radioactive inventory

The remaining radioactivity at the beginning of decommissioning and dismantling work is distributed in the categories mentioned above, whereby almost 100% of the remaining are contained in the activated material of the RPV internals and the RPV.

After dismantling the activated material, the contaminated components and building structures contain an expected radioactivity of about $10^{12}$Bq. Most of the radioactivity is distributed more or less on the inner surface of all systems, only minor radioactivity should be find on the outer surface of components, equipment's and building structures.

### 14.1.1. Radioactivity of the activated components

The following results of the activation calculation done by NIS in 2009 are reviewed for the present study and are still valid for the NPP Krško. The results of the review can be found in [20].

Based on the documents provided by NEK, the Monte Carlo Code System MCNP was used to model the Krško reactor core and the surrounding components relevant for activation analysis & decommissioning in 3D-geometry.

Figure 14-2 and Figure 14-3 show horizontal and vertical cuts of the MCNP-model.

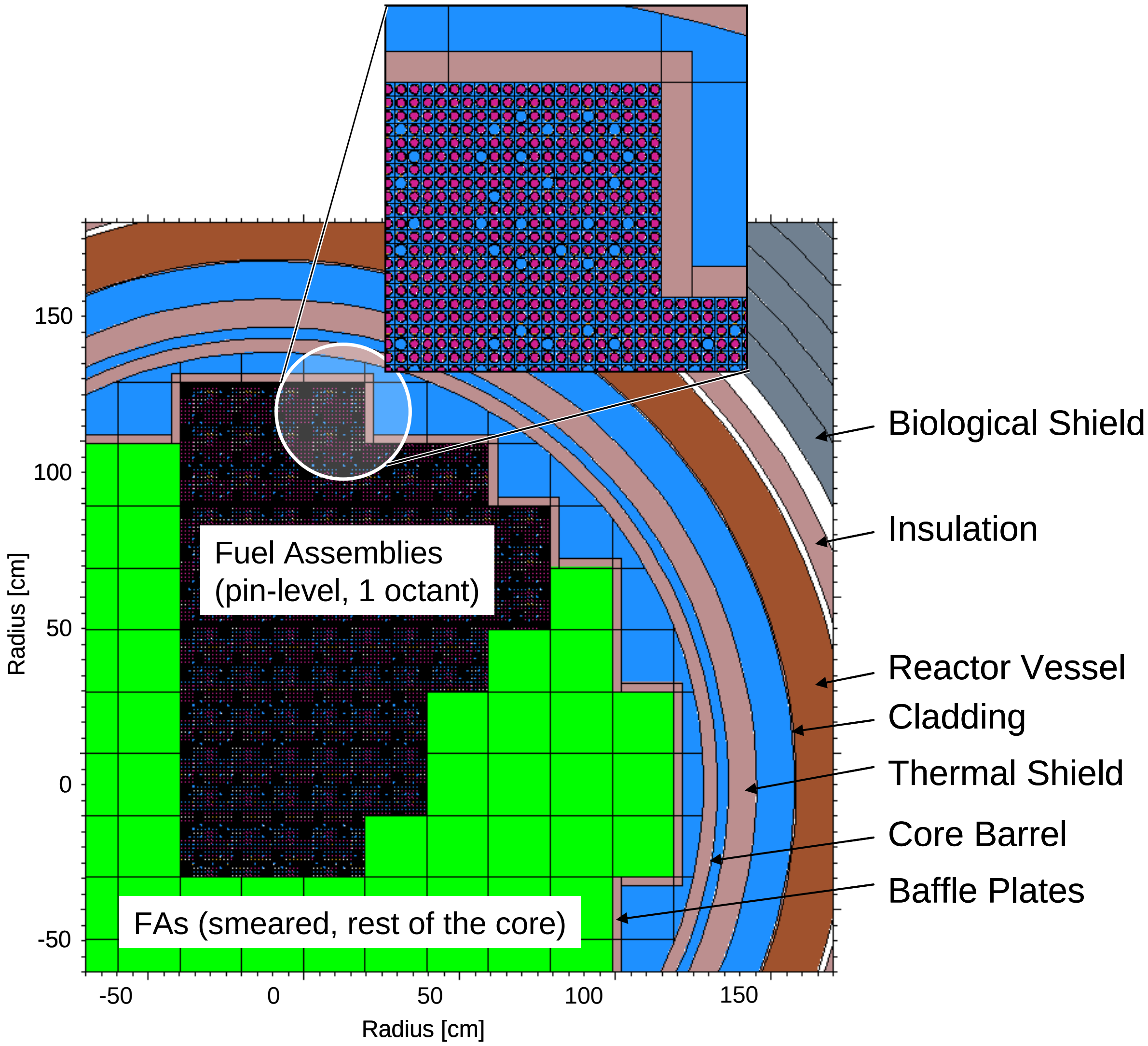



Figure 14-2: Horizontal cut of the MCNP-model

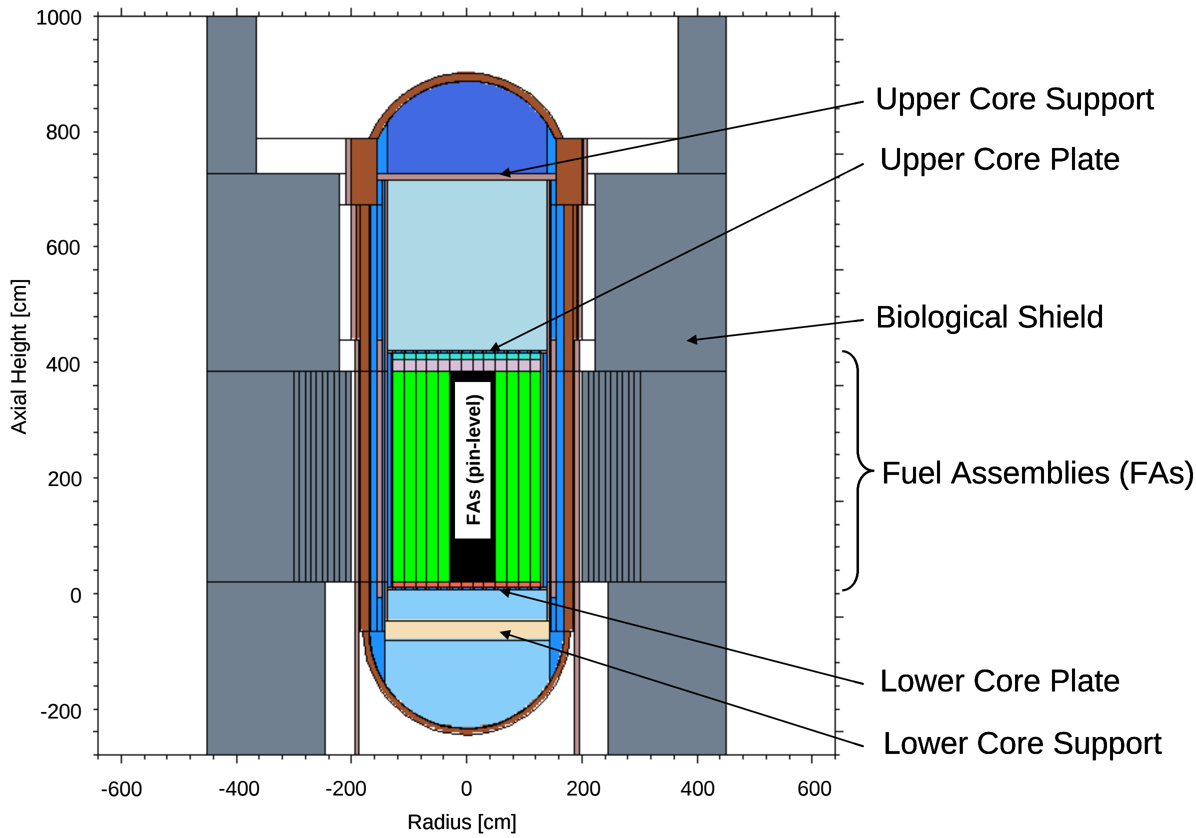



Figure 14-3: Vertical cut of the MCNP-model

Based on this model MCNP neutron transport calculations were carried out for the determination of the space dependent total neutron flux as well as the space dependent 1-group cross sections of the following nuclear reactions: Li-6(n, $\alpha$)H-3, Fe-54(n, $\gamma$)Fe-55, Fe-54(n, p)Mn-54, Fe-58(n, $\gamma$)Fe-59, Co-59(n, $\gamma$)Co-60, Ni-58(n, p)Co-58, Ni-58(n, $\gamma$)Ni-59, Ni-60(n, p)Co-60, Ni-62(n, $\gamma$)Ni-63, Cu-63(n, $\alpha$)Co-60, Cs-133(n, $\gamma$)Cs-134, Eu-151(n, $\gamma$)Eu-152 and Eu-153(n, $\gamma$)Eu-154. The reaction products are the radio-nuclides which contribute most to the activation of the reactor components and the biological shield.

The total neutron flux and the 1-group cross sections are input to the irradiation/activation calculations to be performed with ORIGEN-2.1, see below.

For the MCNP neutron transport calculations certain assumptions and simplifications had to be made, like octant symmetry of the core loading, 500 ppm average boron concentration and characteristic pin-power distributions derived from the NPP Biblis.

The MCNP results were stored in "mesh-tallies" (112 axial, 52 radial and 40 azimuthal mesh-intervals) covering the complete reactor geometry. Figure 14-4 shows the total neutron flux at 100 % reactor power as a function of radius in the core midplane.

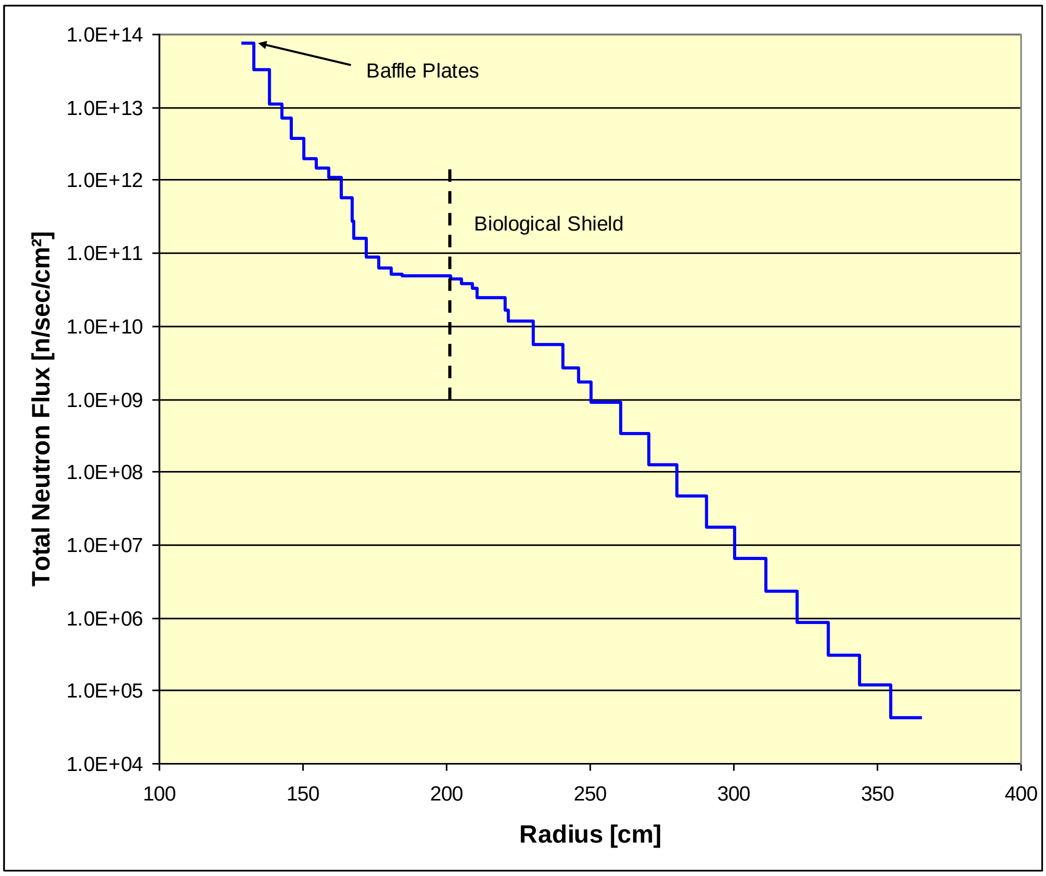



Figure 14-4: Total neutron flux at 100 % reactor power as a function of radius
(azimuthal average in the core midplane)

From the periphery of the reactor core up to about 2 m inside the biological shield the flux decreases by about 10 orders of magnitude.

The 1-group Co-59(n, $\gamma$) cross section, which is given in Figure 14-5, varies over 1 order of magnitude; this finding demonstrates the need for material dependent 1-group cross sections, in order to determine the material activations reliably.

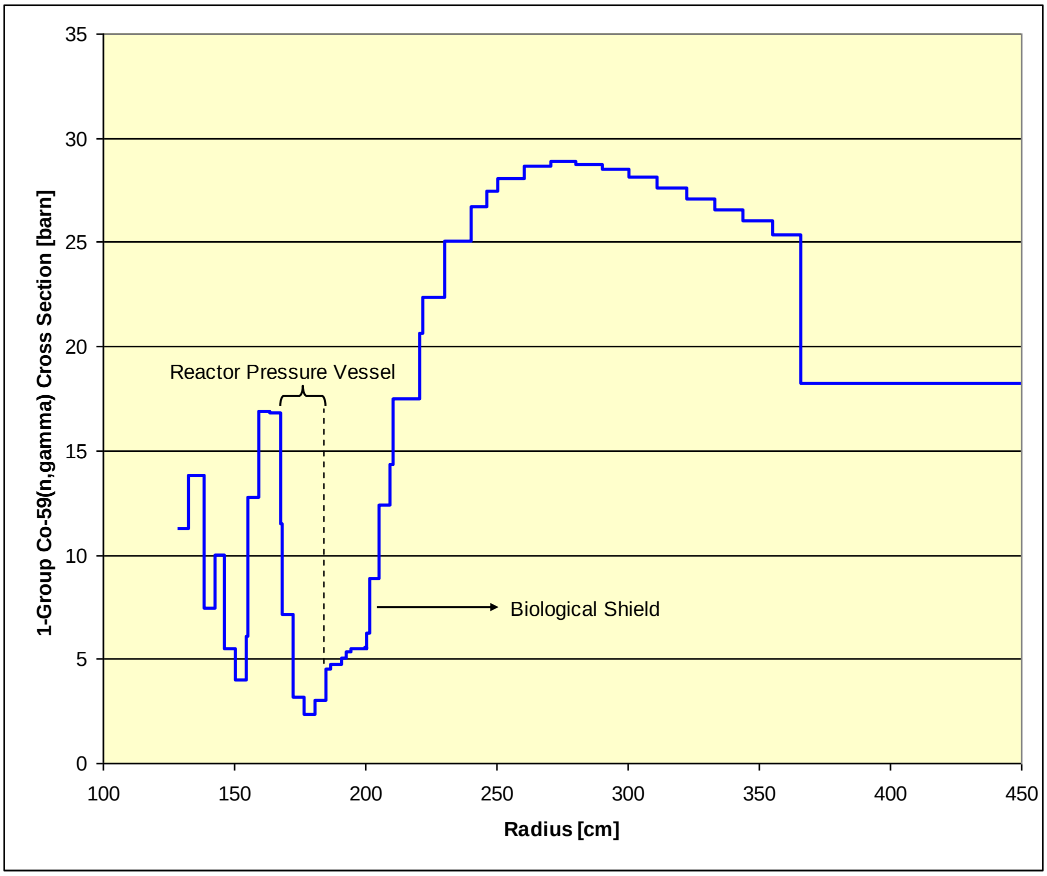



Figure 14-5: 1-group Co-59(n, $\gamma$) cross section as a function of radius (core midplane)

Based on the total neutron flux and 1-group cross section results, activation calculations with ORIGEN-2.1 were carried out for every single mesh interval; for those nuclear reactions which yield only negligible contributions to the activation no Krško specific 1-group cross section have been generated, data from a typical PWR fuel library were used.

Due to the saturation effect (for radioactive isotopes with a half-life less than 10 years, these isotopes are the important ones for decommissioning) there is almost no difference between 40 and 60 years of reactor operation. Nevertheless, for the present study the activation calculations were performed for 60 years of operation and are based on typical 18-months-cycles (17 months of 100 % reactor operation + 1 month outage).

Table 14-1 and Table 14-2 show the activation results for the most important radioactive isotopes in Bq/g in the azimuthally averaged axial/radial maximum values of the various components; given in several times after final reactor shutdown.

| Core Region | Material | Time after Shutdown*) [yr] | Specific Activity [Bq/g]**) of the Dominating Isotopes (azimuthal average at axial/radial maximum; contributions < 1 Bq/g deleted) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | H-3 | C-14 | Ar-39 | Ca-41 | Ca-45 | Mn-54 | Fe-55 | Co-58 | Co-60 | Ni-59 | Ni-63 | Zn-65 | Ag-110m | Sn-119m | Sb-125 | Cs-134 | Ba-133 | Sm-151 | Eu-152 | Eu-154 | total***) |
| | | | no γ | no γ | no γ | no γ | no γ | | no γ | | | no γ | no γ | | | | | | | no γ | | | |
| **Baffle Plates** | SS 304 | 2 | 1.052 M | 1.144 M | 1.118 k | 236 | 1.594 k | 128.3 M | 4.098 G | 713.8 k | 2.970 G | 4.876 M | 813.3 M | 1.802 M | 2.469 k | - | 2.100 k | 214.2 k | 95.72 k | 145 | 11 | 11.02 k | 8.020 G |
| | | 5 | 889.3 k | 1.144 M | 1.110 k | 236 | 15 | 11.29 M | 1.842 G | 16 | 2.001 G | 4.876 M | 795.1 M | 79.99 k | 118 | - | 991 | 78.12 k | 78.87 k | 142 | 10 | 8.656 k | 4.657 G |
| | | 10 | 671.7 k | 1.143 M | 1.095 k | 236 | - | 196.6 k | 485.7 M | - | 1.037 G | 4.875 M | 765.7 M | 446 | - | - | 284 | 14.55 k | 57.11 k | 136 | 7 | 5.785 k | 2.295 G |
| | | 15 | 507.3 k | 1.142 M | 1.081 k | 236 | - | 3.422 k | 128.1 M | - | 537.2 M | 4.875 M | 737.4 M | 2 | - | - | 81 | 2.709 k | 41.36 k | 131 | 6 | 3.866 k | 1.409 G |
| **Core Barrel** | SS 304 | 2 | 770.8 k | 165.1 k | 508 | 34 | 228 | 10.62 M | 883.4 M | 71.19 k | 780.6 M | 1.591 M | 199.2 M | 231.1 k | 7.799 k | - | 55 | 96.85 k | 14.30 k | 377 | 756 | 32.38 k | 1.877 G |
| | | 5 | 651.3 k | 165.0 k | 504 | 34 | 2 | 934.8 k | 397.0 M | 2 | 526.1 M | 1.591 M | 194.8 M | 10.26 k | 373 | - | 26 | 35.33 k | 11.79 k | 369 | 649 | 25.42 k | 1.121 G |
| | | 10 | 491.9 k | 164.9 k | 498 | 34 | - | 16.27 k | 104.7 M | - | 272.5 M | 1.591 M | 187.6 M | 57 | 2 | - | 7 | 6.579 k | 8.535 k | 355 | 503 | 16.99 k | 567.1 M |
| | | 15 | 371.5 k | 164.8 k | 491 | 34 | - | 283 | 27.61 M | - | 141.2 M | 1.591 M | 180.7 M | - | - | - | 2 | 1.225 k | 6.180 k | 341 | 390 | 11.35 k | 351.6 M |
| **Thermal Shield** | SS 304 | 2 | 228.7 k | 55.60 k | 209 | 11 | 77 | 2.960 M | 178.6 M | 20.59 k | 205.4 M | 333.5 k | 39.81 M | 76.76 k | 3.746 k | - | 6 | 36.08 k | 4.836 k | 381 | 5.178 k | 10.31 k | 427.6 M |
| | | 5 | 193.2 k | 55.58 k | 207 | 11 | - | 260.5 k | 80.28 M | - | 138.4 M | 333.5 k | 38.92 M | 3.408 k | 179 | - | 3 | 13.16 k | 3.985 k | 372 | 4.444 k | 8.097 k | 258.5 M |
| | | 10 | 145.9 k | 55.55 k | 204 | 11 | - | 4.535 k | 21.17 M | - | 71.71 M | 333.5 k | 37.49 M | 19 | 1 | - | - | 2.451 k | 2.886 k | 358 | 3.444 k | 5.411 k | 130.9 M |
| | | 15 | 110.2 k | 55.52 k | 202 | 11 | - | 79 | 5.582 M | - | 37.15 M | 333.4 k | 36.10 M | - | - | - | - | 456 | 2.090 k | 344 | 2.670 k | 3.616 k | 79.35 M |
| **Clad** | SS 304 | 2 | 44.08 k | 4.146 k | 17 | - | 6 | 162.0 k | 40.54 M | 1.109 k | 32.49 M | 78.99 k | 9.500 M | 5.686 k | 330 | - | - | 3.261 k | 361 | 59 | 9.060 k | 963 | 82.84 M |
| | | 5 | 37.25 k | 4.145 k | 17 | - | - | 14.26 k | 18.22 M | - | 21.89 M | 78.98 k | 9.288 M | 253 | 16 | - | - | 1.189 k | 298 | 58 | 7.775 k | 756 | 49.55 M |
| | | 10 | 28.13 k | 4.142 k | 17 | - | - | 248 | 4.804 M | - | 11.34 M | 78.98 k | 8.945 M | 1 | - | - | - | 222 | 216 | 56 | 6.026 k | 505 | 25.21 M |
| | | 15 | 21.25 k | 4.140 k | 17 | - | - | 4 | 1.267 M | - | 5.876 M | 78.98 k | 8.614 M | - | - | - | - | 41 | 156 | 53 | 4.671 k | 338 | 15.87 M |
| **Reactor Vessel** | Iron A-533-B | 2 | 31.61 k | 476 | 39 | - | 2 | 151.2 k | 17.04 M | 46 | 1.080 M | 1.458 k | 173.8 k | 717 | 191 | 141 | 397 | 1.125 k | - | 6 | 5.701 k | 590 | 18.49 M |
| | | 5 | 26.71 k | 476 | 39 | - | - | 13.31 k | 7.659 M | - | 728.0 k | 1.458 k | 169.9 k | 32 | 9 | 6 | 187 | 411 | - | 6 | 4.893 k | 463 | 8.605 M |
| | | 10 | 20.18 k | 476 | 38 | - | - | 232 | 2.020 M | - | 377.2 k | 1.458 k | 163.6 k | - | - | - | 54 | 76 | - | 6 | 3.792 k | 310 | 2.587 M |
| | | 15 | 15.24 k | 475 | 38 | - | - | 4 | 532.5 k | - | 195.4 k | 1.458 k | 157.6 k | - | - | - | 15 | 14 | - | 5 | 2.939 k | 207 | 906.1 k |
| **Biological Shield 0 ... 10 cm** | Krško region concrete and rebar | 2 | 474.9 k | 229 | 1.244 k | 2.487 k | 16.32 k | 895 | 425.7 k | - | 41.79 k | 8 | 1.001 k | 172 | 17 | 7 | 20 | 2.125 k | 121 | 132 | 33.21 k | 2.987 k | 1.004 M |
| | | 5 | 401.3 k | 229 | 1.235 k | 2.487 k | 154 | 79 | 191.3 k | - | 28.17 k | 8 | 978 | 8 | - | - | 10 | 775 | 100 | 129 | 28.50 k | 2.345 k | 657.9 k |
| | | 10 | 303.1 k | 229 | 1.219 k | 2.487 k | - | 1 | 50.45 k | - | 14.59 k | 8 | 942 | - | - | - | 3 | 144 | 72 | 124 | 22.09 k | 1.567 k | 397.1 k |
| | | 15 | 228.9 k | 229 | 1.203 k | 2.487 k | - | - | 13.30 k | - | 7.559 k | 8 | 907 | - | - | - | - | 27 | 52 | 119 | 17.12 k | 1.047 k | 273.0 k |
| **Biological Shield 90 ... 100 cm** | Krško region concrete and rebar | 2 | 1.216 k | - | - | - | 6 | - | 1.052 k | - | 73 | - | 2 | - | - | - | - | 1 | - | - | 85 | 4 | 2.442 k |
| | | 5 | 1.028 k | - | - | - | - | - | 473 | - | 49 | - | 2 | - | - | - | - | - | - | - | 73 | 3 | 1.630 k |
| | | 10 | 776 | - | - | - | - | - | 125 | - | 25 | - | 2 | - | - | - | - | - | - | - | 56 | 2 | 989 |
| | | 15 | 586 | - | - | - | - | - | 33 | - | 13 | - | 2 | - | - | - | - | - | - | - | 44 | 1 | 682 |
| **Upper Core Plate** | SS 304 | 2 | 337.9 k | 40.85 k | 158 | 8 | 56 | 4.245 M | 322.7 M | 28.28 k | 260.9 M | 616.9 k | 74.85 M | 56.28 k | 2.886 k | - | 3 | 27.23 k | 3.555 k | 354 | 5.736 k | 9.615 k | 663.8 M |
| | | 5 | 285.5 k | 40.83 k | 156 | 8 | - | 373.6 k | 145.0 M | - | 175.8 M | 616.9 k | 73.17 M | 2.499 k | 138 | - | 2 | 9.933 k | 2.929 k | 346 | 4.923 k | 7.550 k | 395.4 M |
| | | 10 | 215.6 k | 40.81 k | 154 | 8 | - | 6.503 k | 38.24 M | - | 91.09 M | 616.8 k | 70.47 M | 14 | - | - | - | 1.850 k | 2.121 k | 332 | 3.815 k | 5.046 k | 200.7 M |
| | | 15 | 162.9 k | 40.78 k | 152 | 8 | - | 113 | 10.08 M | - | 47.19 M | 616.8 k | 67.86 M | - | - | - | - | 345 | 1.536 k | 320 | 2.957 k | 3.372 k | 126.0 M |
| **Lower Core Plate** | SS 304 | 2 | 982.4 k | 363.8 k | 815 | 75 | 502 | 27.08 M | 3.333 G | 169.9 k | 2.132 G | 5.543 M | 731.2 M | 522.3 k | 9.025 k | - | 255 | 168.0 k | 31.30 k | 310 | 101 | 35.23 k | 6.232 G |
| | | 5 | 830.1 k | 363.7 k | 809 | 75 | 5 | 2.383 M | 1.498 G | 4 | 1.437 G | 5.543 M | 714.9 M | 23.19 k | 432 | - | 120 | 61.29 k | 25.79 k | 303 | 87 | 27.66 k | 3.659 G |
| | | 10 | 627.0 k | 363.5 k | 798 | 75 | - | 41.48 k | 395.0 M | - | 744.4 M | 5.543 M | 688.5 M | 129 | 3 | - | 34 | 11.41 k | 18.68 k | 291 | 67 | 18.49 k | 1.835 G |
| | | 15 | 473.6 k | 363.2 k | 788 | 75 | - | 722 | 104.2 M | - | 385.7 M | 5.542 M | 663.0 M | - | - | - | 10 | 2.125 k | 13.52 k | 280 | 52 | 12.35 k | 1.159 G |
| **Lower Core Support** | SS 304 | 2 | 2.114 k | 275 | 1 | - | - | 67.05 k | 1.748 M | 436 | 1.526 M | 3.319 k | 397.8 k | 377 | 22 | - | - | 313 | 24 | 2 | 723 | 57 | 3.747 M |
| | | 5 | 1.786 k | 275 | 1 | - | - | 5.901 k | 785.7 k | - | 1.028 M | 3.319 k | 389.0 k | 17 | 1 | - | - | 114 | 20 | 2 | 620 | 45 | 2.215 M |
| | | 10 | 1.349 k | 275 | 1 | - | - | 103 | 207.2 k | - | 532.8 k | 3.318 k | 374.6 k | - | - | - | - | 21 | 14 | 2 | 481 | 30 | 1.120 M |
| | | 15 | 1.019 k | 274 | 1 | - | - | 2 | 54.64 k | - | 276.0 k | 3.318 k | 360.7 k | - | - | - | - | 4 | 10 | 2 | 373 | 20 | 696.4 k |

*) shutdown after 60 years of operation

**) k ≡ $\cdot 10^3$, M ≡ $\cdot 10^6$, and G ≡ $\cdot 10^9$

***) total of all isotopes, including isotopes not shown in this table

Table 14-1: Specific activities (in Bq/g) of the most relevant isotopes and components as a function of time after shutdown

| Specific Activity [Bq/g], 5 years after shutdown*) | | Baffle Plates | Core Barrel | Thermal Shield | RPV-Cladding | Reactor Pressure Vessel | Biological Shield 0 ... 10 cm | Biological Shield 90 ... 100 cm | Upper Core Plate | Lower Core Plate | Lower Core Support |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SS 304 | SS 304 | SS 304 | SS 304 | A-533-B | Krško region concrete and rebar | | SS 304 | SS 304 | SS 304 |
| **C-14** | **no γ** | 1.71E+06 | 2.47E+05 | 8.33E+04 | 6.21E+03 | 7.13E+02 | 3.43E+02 | 1.29E-01 | 6.12E+04 | 5.45E+05 | 4.12E+02 |
| **Cl-36** | **no γ** | 2.68E+04 | 4.57E+03 | 1.57E+03 | 1.18E+02 | 3.89E+01 | 1.30E+01 | 4.89E-03 | 1.15E+03 | 9.73E+03 | 7.82E+00 |
| **Ar-39** | **no γ** | 1.62E+03 | 7.37E+02 | 3.03E+02 | 2.49E+01 | 5.70E+01 | 1.81E+03 | 6.80E-01 | 2.29E+02 | 1.18E+03 | 1.66E+00 |
| **Ca-41** | **no γ** | 3.53E+02 | 5.07E+01 | 1.71E+01 | 1.27E+00 | 5.40E-01 | 3.73E+03 | 1.40E+00 | 1.25E+01 | 1.12E+02 | 8.42E-02 |
| **Ni-59** | **no γ** | 7.31E+06 | 2.39E+06 | 5.00E+05 | 1.18E+05 | 2.19E+03 | 1.22E+01 | 3.07E-02 | 9.25E+05 | 8.31E+06 | 4.98E+03 |
| **Ni-63** | **no γ** | 1.12E+09 | 2.74E+08 | 5.47E+07 | 1.31E+07 | 2.39E+05 | 1.37E+03 | 3.43E+00 | 1.03E+08 | 1.00E+09 | 5.47E+05 |
| **Se-79** | **no γ** | 9.60E+02 | 1.26E+02 | 4.24E+01 | 3.16E+00 | 3.64E-02 | 1.40E-02 | 5.28E-06 | 3.11E+01 | 2.82E+02 | 2.09E-01 |
| **Kr-81** | **(γ)** | 7.21E+01 | 1.88E+00 | 2.18E-01 | 1.23E-03 | 1.74E-04 | 4.37E-05 | 6.19E-12 | 1.18E-01 | 8.71E+00 | 5.41E-06 |
| **Zr-93** | **no γ** | 3.93E+00 | 5.20E-01 | 1.66E-01 | 1.18E-02 | 6.88E-03 | 1.09E-02 | 4.10E-06 | 1.20E-01 | 1.20E+00 | 7.81E-04 |
| **Mo-93** | **no γ** | 3.26E+04 | 4.67E+03 | 1.57E+03 | 1.17E+02 | 1.51E+02 | 2.44E-01 | 9.18E-05 | 1.16E+03 | 1.03E+04 | 7.77E+00 |
| **Nb-94** | | 2.87E+04 | 4.92E+03 | 1.69E+03 | 1.27E+02 | 1.57E+01 | 1.04E+00 | 3.90E-04 | 1.25E+03 | 1.05E+04 | 8.44E+00 |
| **Tc-99** | **(γ)** | 5.77E+03 | 1.21E+03 | 4.26E+02 | 3.24E+01 | 4.46E+01 | 7.40E-02 | 2.78E-05 | 3.15E+02 | 2.47E+03 | 2.30E+00 |
| **Pd-107** | **no γ** | 6.01E-02 | 5.21E-03 | 9.48E-04 | 2.28E-05 | 1.31E-06 | 3.79E-04 | 1.42E-07 | 5.80E-04 | 1.56E-02 | 1.21E-06 |
| **Ag-108m** | | 3.38E+04 | 6.23E+03 | 2.16E+03 | 1.63E+02 | 9.41E+01 | 8.54E+00 | 3.21E-03 | 1.59E+03 | 1.31E+04 | 1.08E+01 |
| **Sn-121m** | | 7.14E-02 | 6.87E-03 | 1.34E-03 | 3.20E-05 | 1.65E+00 | 8.46E-02 | 3.18E-05 | 8.23E-04 | 1.91E-02 | 1.69E-06 |
| **Cs-135** | **no γ** | 1.25E+00 | 1.05E-01 | 2.04E-02 | 7.63E-04 | 4.83E-05 | 1.74E-04 | 6.45E-08 | 1.31E-02 | 3.33E-01 | 4.61E-05 |
| **La-137** | **no γ** | 2.97E+02 | 4.61E+01 | 1.57E+01 | 1.17E+00 | 1.82E-03 | 1.31E-02 | 4.92E-06 | 1.15E+01 | 1.00E+02 | 7.86E-02 |
| **Sm-146** | **no γ** | 6.95E-06 | 1.71E-06 | 6.26E-07 | 4.87E-08 | 5.62E-09 | 1.65E-07 | 6.20E-11 | 4.65E-07 | 3.27E-06 | 3.24E-09 |
| **Sm-151** | **(γ)** | 2.84E+02 | 5.41E+02 | 5.31E+02 | 8.16E+01 | 8.32E+00 | 1.80E+02 | 5.19E-02 | 4.91E+02 | 4.65E+02 | 3.13E+00 |
| **Ho-166m** | | 8.26E+03 | 1.55E+03 | 5.07E+02 | 3.59E+01 | 1.64E+01 | 5.43E+00 | 2.04E-03 | 3.69E+02 | 3.31E+03 | 2.37E+00 |
| **Pb205** | **no γ** | 2.43E-02 | 3.48E-03 | 1.17E-03 | 8.74E-05 | 6.17E-04 | 1.34E-05 | 5.05E-09 | 8.62E-04 | 7.68E-03 | 5.80E-06 |
| **U-233** | **(γ)** | 1.91E+01 | 1.35E+01 | 6.00E+00 | 5.13E-01 | 5.35E-02 | 3.15E-01 | 1.19E-04 | 4.58E+00 | 1.92E+01 | 3.44E-02 |
| **U-236** | **(γ)** | 9.72E-03 | 4.78E-03 | 2.11E-03 | 1.79E-04 | 1.04E-05 | 4.27E-05 | 1.61E-08 | 1.61E-03 | 6.86E-03 | 1.20E-05 |
| **Np-237** | | 3.23E-02 | 7.37E-03 | 2.01E-03 | 1.24E-04 | 7.08E-06 | 2.88E-05 | 1.08E-08 | 1.40E-03 | 1.65E-02 | 8.07E-06 |
| **Pu-239** | **(γ)** | 3.97E+01 | 2.97E+01 | 1.82E+01 | 1.97E+00 | 1.22E-01 | 5.05E-01 | 1.91E-04 | 1.48E+01 | 3.62E+01 | 1.42E-01 |

*) shutdown after 60 years of reactor operation

Table 14-2: Long-lived nuclides for final repository (5 years after shut down)

Figure 14-6 shows the azimuthally averaged, maximum specific Co-60 and Eu-152 activities as a function of radius, 5 years after shutdown. Co-60, by far is the most dominant γ-emitting isotope in the steel structures. On the other hand, in the biological shield the Eu-152 activity is somewhat higher than the one of Co-60.

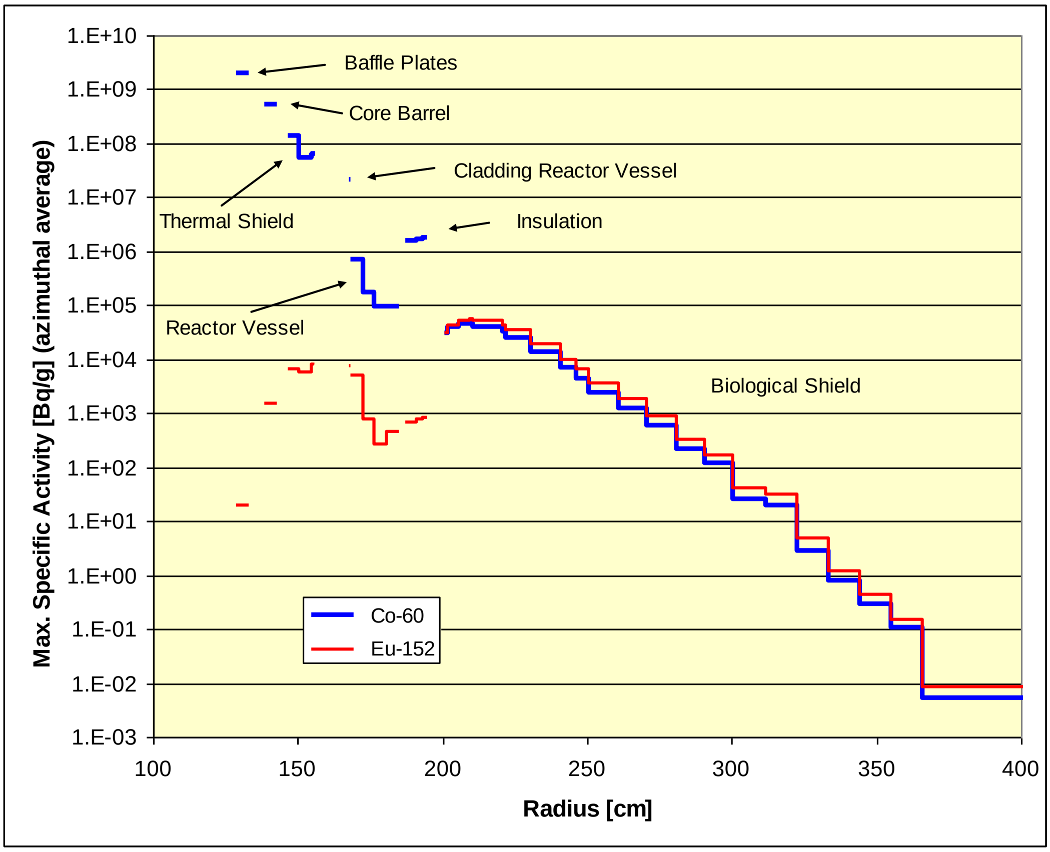



Figure 14-6: Azimuthally averaged maximum specific Co-60 and Eu-152 activity (in Bq/g) as function of radius (5 years after shutdown)

Figure 14-7 illustrates the radial dependency of the Co-60 activity in the upper and lower core plate as well as in the lower core support.

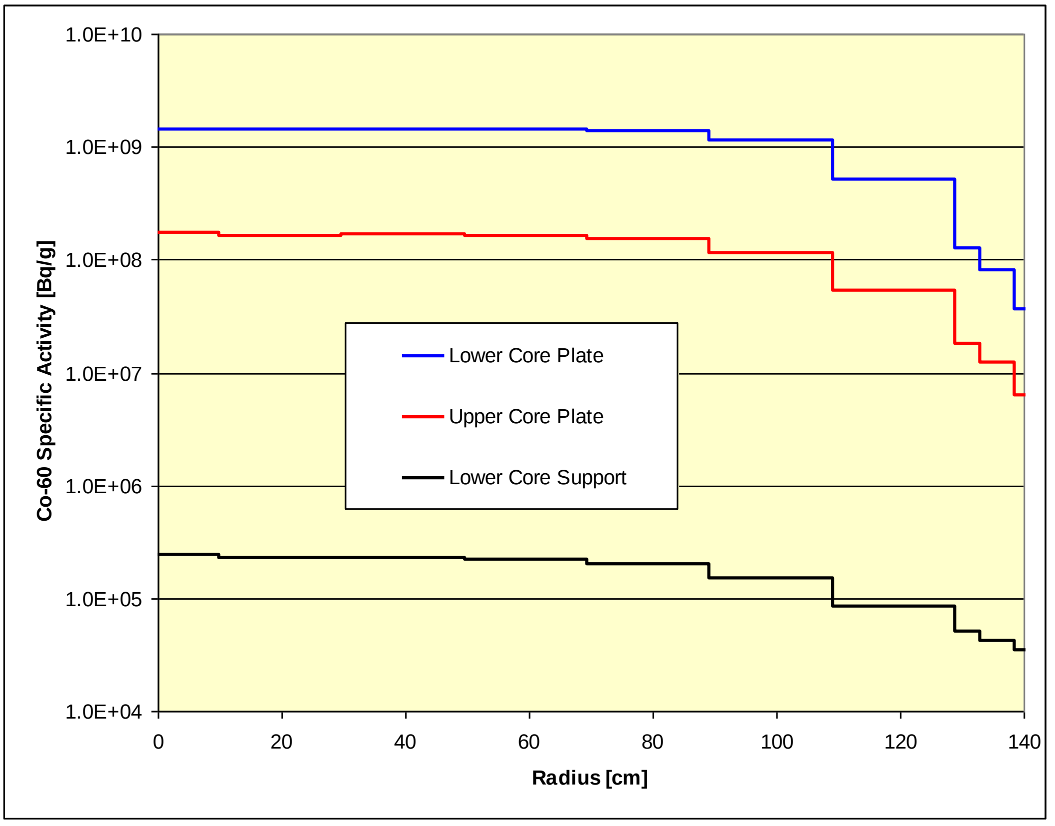



Figure 14-7: Azimuthally averaged specific Co-60 activity (in Bq/g) of the upper and lower core plate and lower core support as a function of radius (5 years after shutdown)

In Figure 14-8 (reactor components) and Figure 14-9 (biological shield), the axial dependency of the Co-60 activity is plotted as a function of the axial height. Above and below the upper/lower core plate there is a steep decrease of the activation levels.

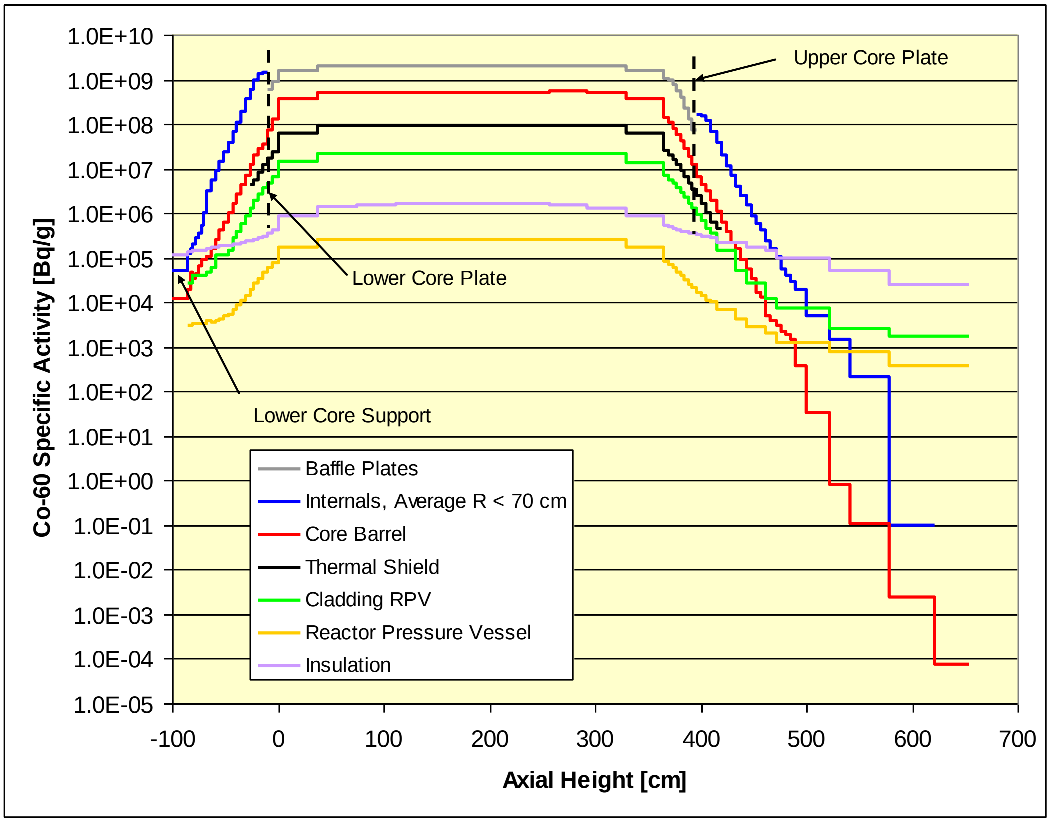



Figure 14-8: Azimuthally averaged maximum specific Co-60 activity (in Bq/g, 5 years after shutdown) as a function of axial height for reactor components

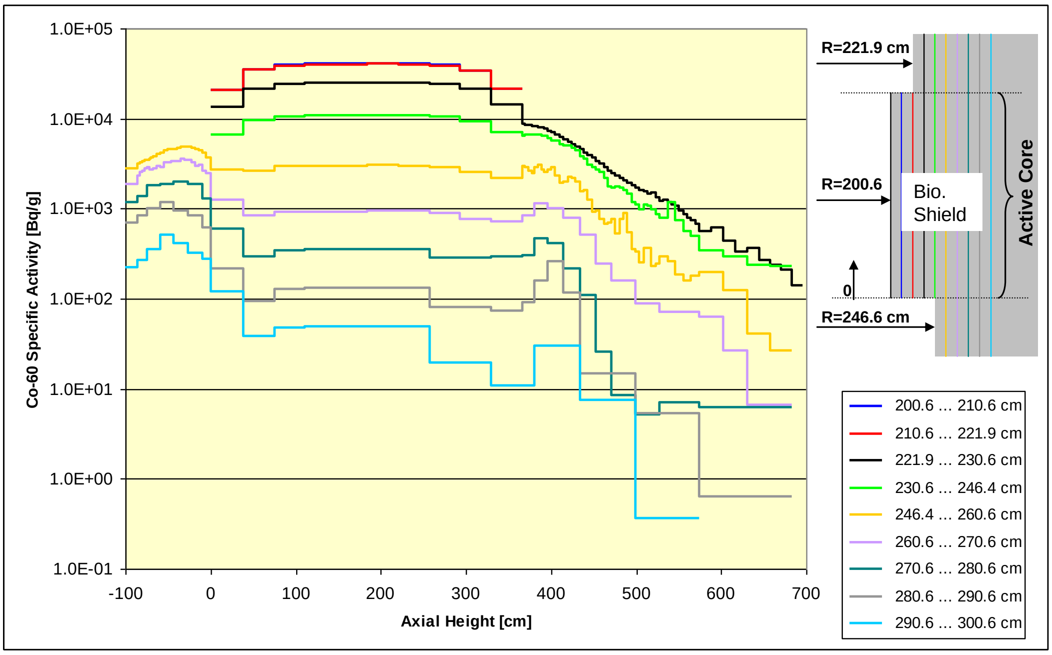



Figure 14-9: Azimuthally averaged maximum specific Co-60 activity (in Bq/g, 5 years after shutdown) as a function of axial height for the biological shield

From Figure 14-6 to Figure 14-9 the following conclusions can be drawn:

- As the stainless steel components (baffle plates, core barrel, thermal shield, RPV-cladding, insulation, lower/upper core plate, lower core support) have the highest Co contents – a factor 11 higher than for the RPV – and as they are much closer to the reactor core, it is evident that they show the highest Co-60 activation levels. In radial direction (core midplane) and in accordance with the distance from the core, the specific Co-60 activity drops from some $10^9$Bq/g to approx. $10^6$Bq/g (Figure 14-6). In axial direction (Figure 14-8) it decreases from the corresponding maximum value in the core midplane by 3 to 5 orders of magnitude at 100 cm above and below the upper/lower core plate. Axially, the insulation deviates from such a behaviour; due to neutron streaming (between the RPV and the biological shield) the activity decreases only by 1 order of magnitude over the same axial extent.
- For the RPV, the Co-60 activation in the core midplane varies over its thickness by almost a factor of 10, in the range of $10^6$Bq/g to $10^5$Bq/g (Figure 14-6). At 100 cm above and below the upper/lower core plate it is 2 orders of magnitude lower (Figure 14-8). For axial regions > 100 cm above/below the upper/lower core plate the decrease of activity is slower, showing a similar characteristics as in the case of the insulation.
- Considering the biological shield: along the first 100 cm, radially at core midplane (Figure 14-6), the activation level of the dominating isotopes Co-60 and Eu-152 decreases by ~3 orders of magnitude, from some $10^4$Bq/g to $10^1$Bq/g. Axially, above the upper core plate, the activities decrease much slower, approximately by a factor of 100 for the first 300 cm (Figure 14-9). Above and below the active core, where the concrete structures are recessed, there are local activation maxima due to neutron scattering/streaming processes.

The uncertainties of the activation calculations result from the Monte Carlo method, which was used for the neutron transport calculations, and from model simplifications and assumptions.

In the core midplane the statistical uncertainties of the Monte Carlo results (mesh-tallies) are typically ≤ 1 % at radii ≤ 300 cm and rise up to about 5 % for radii > 400 cm. In axial direction the uncertainties of the mesh-tallies increase more significantly so that the results of neighbouring mesh-intervals were merged to achieve adequate sampling; refer [20] for more details.

Model simplifications, which were necessary due to the complexity of the problem, are e. g. the use of a single fuel assembly loading pattern/axial power profile/pin power distribution and a mean boron concentration in the coolant. Moreover, assumptions had to be made due to the lack of material composition data like the unknown chemical composition of the stainless steel structures and the unknown trace elements and impurities of most of the irradiated materials. The knowledge of the trace elements and impurities is of essential importance, as most of the relevant radio-nuclides originate from neutron irradiation of nuclides only present in trace amounts. Therefore, typical elemental concentrations from literature were applied.

In comparison to the model simplifications, the unknown concentrations of the trace elements and impurities, by far, dominate the uncertainties of the activation results. In literature so-called Range Factors (ratio of the highest to lowest concentration measured) for various elements are compiled. Typical range factors for the Co content of reactor internals are ~ 11, but for concrete and for selected elements, these range factors can be as high as: 353 for Ba, 81 for Sb, 28 for Co and 11 for Eu. These findings underline the importance of measured trace element/impurity concentrations. Once Krško-specific measured data is available the activation results presented above can be rescaled accordingly.

### 14.1.2. Full system decontamination

One of the early tasks after reactor shutdown is to perform the decontamination of the primary system also called full system decontamination (FSD). This is not to be compared with the decontamination of dismantled components in the treatment facilities e.g. high pressure water: the technique is different, and the purpose is different. The FSD is performed in situ, with all pipes and components still installed. The system is flushed using a decontamination chemical. The purpose of the primary system decontamination is to reduce the radiation level during the preparation and the execution of the dismantling work.

The FSD experience of the primary coolant system after reactor shutdown shows that – depending from the local circumstances – a contamination reduction factor of up to 100 can be achieved applying a hard decontamination technique. For the purposes of the present study it is assumed that – as a conservative but guaranteed value – the decontamination factor will be 10 so that the system decontamination will remove 90% of the contamination of the primary system. This quantity of contamination will be collected as secondary waste and it is calculated separately.

In the calculations the primary mass of the decontaminated systems is replaced by the "primary mass after system decontamination" which has 100% of the mass (kg) but only 10% of the contamination (Bq). So the material from the primary system to be dismantled will have contamination data which is reduced by 90%. This is illustrated in Figure 14-10.

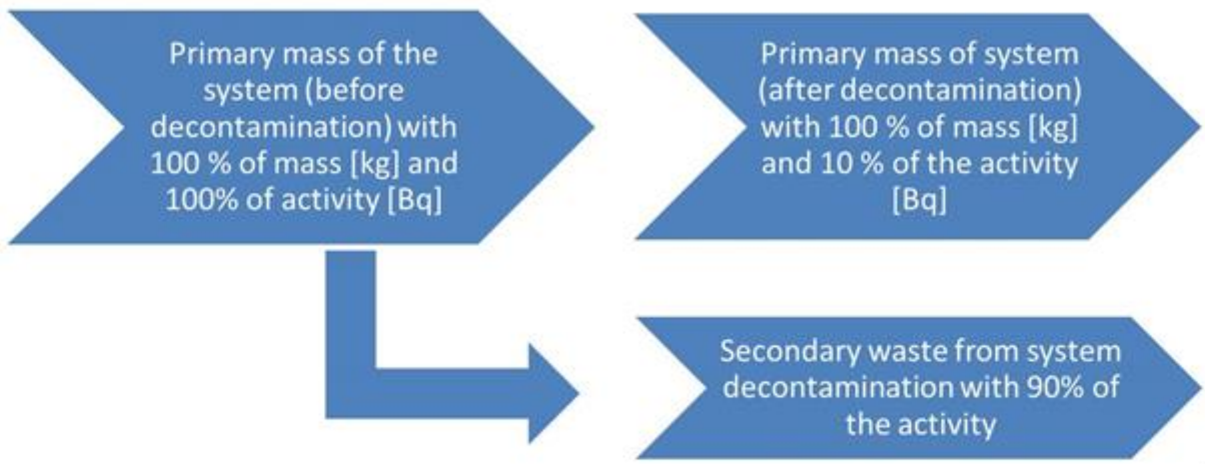



Figure 14-10: Influence of the reactor coolant system decontamination on the calculation model

### 14.1.3. Radioactivity of contaminated components

The radioactivity inventory in the systems and components at the date of plant shut down, generated during the operational time by contact with radioactive media is not calculable exactly. Also it is not possible within the performance of the DP to take samples and measurements on systems or components. Because of that the radioactivity content in the systems and components is acquired by following working steps.

*Step 1:*

In a first step a list of the relevant systems was developed. Therefore the NPP Krško system was categorized in classes with:

- No contamination
- Airborne contamination
- Low level contamination
- Medium level contamination
- High level contamination
- Activated

This work was done in the previous study in a common work between NEK and NIS. The result of this radiological classification is given in the following table.

**Radiological classification of systems**

| System description | No contamination | Airborne contamination | Low level contamination | Medium level contamination | High level contamination | Activated |
|---|---|---|---|---|---|---|
| AUXILIARY FEEDWATER SYSTEM | X | | | | | |
| CIRCULATING WATER SYSTEM | X | | | | | |
| CONDENSATE POLISHING SYSTEM | X | X | | | | |
| CONDENSATE SYSTEM | X | X | | | | |
| CONDENSER AIR REMOVAL SYSTEM | X | | | | | |
| CONDENSER AND ACCESSORIES SYSTEM | X | | | | | |
| COOLING TOWER SYSTEM | X | | | | | |
| EXTRACTION STEAM SYSTEM | X | | | | | |
| FEEDWATER CHEMICAL ADDITION SYSTEM | X | | | | | |
| FEEDWATER SYSTEM | X | | | | | |
| HEATER DRAIN SYSTEM | X | | | | | |
| HOT WATER SYSTEM | X | | | | | |
| MAIN GENERATOR & ACCESSORIES | X | | | | | |
| MAIN STEAM SYSTEM | X | | | | | |
| MAIN TURBINE AND ACCESSORIES | X | | | | | |
| STEAM DUMP CONTROL SYSTEM | X | | | | | |
| STEAM GENERATOR BLOWDOWN SYSTEM | X | X | | | | |
| TURBINE CLOSED CYCLE COOLING WATER | X | | | | | |
| TURBINE DRAINS | X | X | | | | |
| TURBINE GLAND STEAM | X | | | | | |
| TURBINE LUBE OIL SYSTEM | X | | | | | |
| TURBINE PLANT SAMPLING SYSTEM | X | X | | | | |
| VIBRATION MONITORING SYSTEM | X | | | | | |
| POWER TRANSFORMERS - ONLY main tranformer | X | | | | | |
| MISCELLANEOUS EQUIPMENT SECONDARY | X | X | | | | |
| FLOOR & EQUIPMENT DRAINS | X | X | | | | |
| RIVER DAM SYSTEM | X | | | | | |
| ENVIRONMENTAL MONITORING SYSTEM | X | | | | | |
| ABH HEATING STATION (TOPLOTNA POSTAJA) | X | | | | | |
| AUXILIARY STEAM HEATING SYSTEM | X | | | | | |
| AUXILIARY STEAM SYSTEM | X | | | | | |
| CHILLED WATER SYSTEM | X | | | | | |
| DIESEL FUEL OIL STORAGE SYSTEM | X | | | | | |
| DIESEL GENERATOR SYSTEM | X | | | | | |
| FUEL OIL SYSTEM | X | | | | | |
| POTABLE WATER SYSTEM | X | | | | | |
| SANITARY DRAIN SYSTEM | X | | | | | |
| SEWAGE DRAIN SYSTEM | X | | | | | |
| SIMULACIJSKO POSTROJENJE TO.VZ | X | | | | | |
| STEEL CONTAINMENT | X | X | | | | |
| SWITCHYARD SYSTEM BOP | X | | | | | |

## Radiological classification of systems

| System description | No contamination | Airborne contamination | Low level contamination | Medium level contamination | High level contamination | Activated |
|---|---|---|---|---|---|---|
| TB VENTILATION AND AIR CONDITIONING SYS | X | | | | | |
| TECHNICAL SECURITY | X | | | | | |
| WATER PRETREATMENT/POTABLE WATER SYSTEM | X | | | | | |
| POWER TRANSFORMERS | X | | | | | |
| IN-CORE INSTRUMENTATION SYSTEM | | | X | | | X |
| NUCLEAR INSTRUMENTATION SYSTEM | | | X | | | X |
| ATWS MITIGATION & ACTUATION CIRCUITRY | | | | X | | |
| CONTAINMENT SPRAY SYSTEM | | X | | | | |
| CONTAINMENT TESTING AND PRESSURIZING SYS | | | X | | | |
| HYDROGEN CONTROL AND MONITORING SYSTEM | | | X | | | |
| REACTOR PROTECTION SYSTEM | | | X | | | |
| ROD CONTROL AND POSITION SYSTEM | | | | X | | X |
| SAFETY INJECTION SYSTEM | | | | X | | |
| BORON RECYCLE SYSTEM | | | | X | | |
| BORON THERMAL REGENERATION SYSTEM | | | | X | | |
| CHEMICAL AND VOLUME CONTROL SYSTEM | | | | X | | |
| CHEMICAL FEED SYSTEM | | X | | | | |
| GASEOUS WASTE PROCESSING SYSTEM | | | X | | | |
| REACTOR COOLANT SYSTEM | | | | | X | |
| REACTOR MAKEUP WATER SYSTEM | | X | | | | |
| RESIDUAL HEAT REMOVAL SYSTEM | | | | X | X | |
| SAMPLING SYSTEM NUCLEAR | | | | X | X | |
| VACUUM PRIMING SYSTEM | | X | | | | |
| WASTE DISPOSAL SYSTEM (SOLID) | | | | | X | |
| WASTE ENCAPSULATION | | | | | X | |
| WASTE PROCESSING SYSTEM (LIQUID) | | | | | X | |
| FLOOR AND EQUIPMENT DRAIN SYSTEM | | | X | X | | |
| WATER TREATMENT SYSTEM | X | | | | | |
| COMPONENT COOLING SYSTEM | | X | | | | |
| DEMINERALIZED WATER SYSTEM | X | | | | | |
| FUEL HANDLING SYSTEM | | | | X | | |
| REFUELING WATER SYSTEM | | | | X | | |
| SPENT FUEL COOLING SYSTEM | | | | X | | |
| RADIATION MONITORING SYSTEM | | X | X | | | |
| VENTILATION AND AIR CONDITIONING SYSTEM | | | X | | | |
| SEISMIC DETECTION SYSTEM | X | X | | | | |
| PLANT GAS SUPPLY SYSTEM | X | X | | | | |
| ESSENTIAL SERVICE WATER SYSTEM | X | X | | | | |
| COMPRESSED AIR SYSTEM | X | X | | | | |
| FIRE PROTECTION SYSTEM | X | X | | | | |
| INSTRUMENT AIR SYSTEM | X | X | | | | |
| INSTRUMENT AND CONTROL SYSTEM | X | X | | | | |
| HANDLING EQUIPMENT SYSTEM | X | X | | | | |
| LIGHTING & UTILITY POWER SYSTEM | X | X | | | | |
| MISCELLANEOUS TOOLS AND MACHINES | X | X | | | | |
| PIPE HEAT TRACING SYSTEM | X | X | | | | |
| PIPING SYSTEM | X | X | | | | |
| PHONE AND COMMUNICATION SYSTEM | X | X | | | | |
| PROCESS INSTRUMENTATION AND CONTROL | X | X | | | | |
| WIRE WAY & CONDUIT SYSTEM | X | X | | | | |

Table 14-3: Radiological classification of systems

*Step 2:*

For each of the defined classes, except activated, average values from returned experiences in Europe are taken into account.

The total specific activity of each class of contamination is given in Table 14-4.

**Specific activity related to the contamination classes**

| Contamination classes | spec. surface contamination [Bq/cm$^2$] | spec. mass contamination [Bq/g] |
|---|---|---|
| No contamination | 0.00E+00 | 0.00E+00 |
| Airborne contamination | 3.00E+01 | 1.20E+01 |
| Low level contamination | 5.00E+01 | 2.00E+01 |
| Medium level contamination | 5.00E+02 | 2.00E+02 |
| High level contamination* | 3.70E+05 | 1.48E+05 |

*Reduction by a factor of ten, for systems which are involved in the full system decontamination

Table 14-4: Specific activity related to the contamination classes

The specific contamination for the airborne contamination is usually rather low. Experiences returned from Germany as well as from Switzerland showing that the obtained values are far below 100 Bq/cm$^2$, only for some special places e.g. in building draining sumps the contamination could reach this level.

For the present study, after evaluating the experiences from Germany and Switzerland, the specific surface contamination for the airborne contamination is set to 30 Bq/cm². This is the average value for the given contamination spheres (see [21]).

The defined value of 30 Bq/cm² for the airborne contamination is assigned to the systems mentioned in Table 14-3 and to:

- Components in the controlled area which are assumed to be not in contact with radioactive media
- Steel girder construction
- Inside building surfaces (controlled and monitored area)

The specific contamination for the inner contamination of systems is separated into the classifications

- Low level contamination
- Medium level contamination
- High level contamination

mentioned in Table 14-4 and are assigned to the systems in Table 14-3. The origin values for the High Level Contamination are reduced, for systems where the full system decontamination is performed (see chapter 14.1.2).

The activated systems (see Table 14-1) and components are described in chapter 14.1.1. For the activated systems the assumption is taken into account, that in comparison of contamination and activation values, the contamination of these systems is negligible.

In the case of contaminated systems or components the nuclide composition for each class was evaluated and provided by NEK. It is based on some operational experiences and is used for the decommissioning planning work and the cost estimation. The nuclide composition of each contamination class is defined to:

- Co-60 60%
- Cs-137 30%
- Cs-134 9%
- Sb-125 1%

The given nuclide composition is very approximately and can be verified only after effortful measuring which is not possible in the frame of the DP. Therefore it is assumed for the DP to have one nuclide composition related to a fixed date of 10 years after final shut down (related to the start of dismantling of contaminated material).

## 14.2. Results on the radioactive inventory

The radioactive inventory 5 years after final shut down resulting from activation, inner and outer contamination is calculated and stored in Cora for further use. In total the radioactivity inside the plant, based on CORA, is about 2.46 * $10^{16}$ Bq. The breakdown by the specific system classifications is given in the following table:

**Total activity breakdown**

| System classifications | Total activity [Bq] | Mass [Mg] |
|---|---|---|
| Airborne contamination | 4.23E+10 | 4,508.59 |
| Activated | 2.46E+16 | 1,457.84 |
| High level contaminated | 4.43E+12 | 2,136.97 |
| Low level contaminated | 1.86E+11 | 9,238.36 |
| Medium level contaminated | 1.57E+11 | 1,290.63 |
| No contamination | 1.86E+10 | 443,443.02 |
| **Total activated** | **2.46E+16** | **1,457.84** |
| **Total contaminated** | **4.83E+12** | **17,174.55** |

Table 14-5: Total activity for the NPP Krško site

The calculation of the inner contamination of systems and components results in a total amount of about 5.60 * $10^{12}$ Bq; the airborne contamination of systems, components and equipment is estimated to 4.23 * $10^{10}$ Bq. This includes also the building surfaces in the controlled area. It is estimated to a radioactivity amount of 1.86 * $10^{10}$ Bq.

The total amount of the radioactivity is very interesting information for radiological balances, packaging of the radioactive waste, and probably for the final repository. The planning of the D&D project and the cost calculation are more constrained by the masses in the Krško plant related to different radiological categories. Therefore these calculation results are also shown in Table 14-5.

Additionally to the above shown figure, the following figures show how the radiological category is distributed among the different material types:

**Material groups seperated after radiological classifictaion**

| Material group | No contamination | Airborne contamination | Low level contamination | Medium level contamination | High level contamination | Activated | Total [Mg] |
|---|---|---|---|---|---|---|---|
| Austenitic steel | 44% | 8% | 1% | 31% | 11% | 5% | **3,181.33** |
| Iron steel (ferritic) | 85% | 10% | 2% | 0% | 0% | 2% | **35,163.15** |
| Cable with insulation | 78% | 5% | 18% | | | | **849.43** |
| Mineral wool | 68% | 6% | 7% | 10% | 8% | 1% | **772.49** |
| Building rubble | 98% | 0% | 2% | 0% | | 0% | **415,389.13** |
| Conventional mixed waste | 77% | 23% | | | | | **20.05** |
| Mixed material (e.g. pumps, motors) | 81% | 9% | 0% | 1% | 7% | 0% | **3,876.21** |
| Galvanized steel (ventilation) | 35% | 2% | 63% | | | | **428.00** |
| Filters | 77% | 6% | 1% | 16% | 1% | | **65.08** |
| Lubrication (oil, grease) | | | | | | | **0.00** |
| Special waste (batteries, doors (hazadous); oil ) | 72% | 28% | | 0% | | | **523.51** |
| Mixed material (electric components) | 78% | 14% | 2% | 3% | 3% | 0% | **154.26** |
| Mixed material (ferritic/austenitic) | | | | | 84% | 16% | **1,652.78** |
| **Total** | | | | | | | **462,075.41** |

Table 14-6: Material groups separated after radiological classification

# 15. Costs estimate

## 15.1. Introduction

For almost 40 years now NIS has been involved in nuclear decommissioning projects and has analysed them from a technical and an economical point of view. These experiences have steadily been included in the NIS calculation program CORA & CALCOM to assure an up-to-date cost estimation with regard to modern techniques.

Today, CORA & CALCOM is used by NIS for the annual update of the decommissioning cost calculations for the German NPPs, and the operators of the actual decommissioning projects at e.g. Stade, Würgassen, Obrigheim and Karlsruhe use it for the ongoing projects.

Since the 1990s the NIS experience in this field led to several contracts in foreign countries, e.g. Belgium, The Netherlands, Slovenia, Switzerland and Lithuania.

Very important for the NIS are the decommissioning projects:

- KKN (Niederaichbach) prototype NPP (100 MWe, CO2 cooled and D2O moderated) with NIS as a member of the consortium for the decommissioning work
- VAK (Kahl) the first power NPP in Germany decommissioned by Nukem/NIS
- KWW (Würgassen), KKS (Stade), KWO (Obrigheim), KMK (Mülheim-Kärlich), and nowadays also the new decommissioning projects in KKB (Brunsbüttel), KKK (Krümmel), KKP (Philippsburg), GKN-1 (Neckarwestheim), KKG (Grafenrheinfeld) and KWB unit A and B (Biblis), whereby NIS is responsible for the decommissioning cost estimation, strategic planning and controlling purposes. The owners of KWW, KKS, and KWO have purchased the NIS software (CORA & CALCOM) which was adapted by NIS to the special needs of the D&D projects at the sites
- Dismantling of RPV in NPP Stade (2009)
- Dismantling of RPV and RPV internals of the two Zion units (2014) and today the two units in Songs (both plants are located in USA)
- WAK (Karlsruhe) fuel reprocessing plant works with CORA & CALCOM with technical and personnel support of NIS. Costs for the D&D of the reprocessing plant in Karlsruhe were calculated since 1995 and updated regularly, last in 2017. Moreover WAK bought the license for the use of CORA & CALCOM
- Other plants in the D&D stage in Germany are at Greifswald and at Rheinsberg. Here NIS has provided the know-how on D&D cost estimations and a series of computer tools to the owner EWN so that he is able to follow up his own D&D projects.

For all German NPPs, NIS prepares every year expert reports for liability purposes, relevant for the company balances.

As shown by the list before NIS does not only estimate the cost for future D&D work, it is also directly involved in the project management work for real projects. NIS people are integrated in the cost planning teams at the site and get a profound insight in the projects.

## 15.2. Audits

### 15.2.1. Quality assurance – regular audits

The NIS QA system is described in a QA manual. The NIS QA system is certified according EN ISO 9001.

The application of the QA rules is verified by regular internal and external audits.

### 15.2.2. Audits by external organizations

The cost estimation methods applied by NIS were checked by several external organisations and companies:

- November 1997: Audit by Bundesamt für Finanzen (German federal tax authority)
- December 1997: Audit by University of Delft, The Netherlands (in the course of D&D cost estimation for the Dodewaard NPP)
- November 1998: Peer review by IAEA (in the course of the D&D cost estimation for the Krško NPP)
- February 2002: Audit by HSK (Swiss authority) for cost estimations for Swiss NPPs
- January till September 2007: Extensive audit by PricewaterhouseCoopers (in the course of the year-end audit of two German utilities by PwC)
- August 2010: IAEA group of experts concerning decommissioning cost estimation of the Krško NPP
- August 2011: Audit by GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) concerning cost estimation for two WAK facilities (Multipurpose and compact sodium-cooled nuclear reactor)
- December 2013 and 2014: Extensive audits by an external German auditing and accounting firm concerning cost estimation of RWE, E.ON and VENE NPPs
- First half of 2017: Extensive audits by external American and Dutch auditing and accounting firms concerning cost estimation for the Swiss NPPs

## 15.3. Software tools and estimation models

The purpose of the following brief overview is to give a basic understanding of the software principles of CORA & CALCOM.

CORA & CALCOM are database applications which were especially developed by NIS for the decommissioning cost estimation of nuclear D&D projects. They are working on the base of either MS-ACCESS or ORACLE applications:

- CORA is used for the processing of the plant data: physical inventory, room data, radiological inventory, waste processing data, waste packaging data
- CALCOM is used for planning and estimation of the D&D project/costs

### 15.3.1. CORA: inventory tool

The NIS database CORA (Component Registration and Analysis) is used for the processing of the plant data for decommissioning purposes, especially for the determination of physical inventory, room data, radiological inventory, waste processing data, waste packaging data. CORA is developed on the platform of the Microsoft product MS-ACCESS.

For the Krško NPP almost ten thousand entities corresponding as components are listed. The following information is assigned to the registered components:

- Location (building and room for components corresponding to the controlled area)
- Type of component
- Type of material
- Radiological evaluation (radiological category, expected waste treatment including pro-posed interim and final storage containers, amount of secondary waste caused by dis-mantling and treating the component)

Based on these technical and radiological data CORA calculates results important for the evaluation of the waste management. Results used for the actual Krško NPP study are:

- Mass distribution to different waste treatment procedures
- Calculation of the expected secondary waste
- Packaging data – numbers of needed waste containers
- Calculation of the repository volume

### 15.3.2. CALCOM: project cost estimation and planning tool

CALCOM basically provides following tasks:

- Project planning
- Project management structure setup and maintenance
- Management of project schedule
- Resource management
- Cost estimates
- Data exchange with MS-PROJECT

All results of this study concerning time scheduling, costs and required personnel are calculated by CALCOM.

#### 15.3.2.1. Project management structure setup

The structure of a project management plan is hierarchical and is defined considering the needs of individual facilities and the actual boundary conditions for the D&D project. Here the WBS presented in chapter 4.3.2 is implemented. Additionally the sequence of tasks and their dependencies are transferred to the tool.

Due to the bottom up principle CALCOM can deliver results at any level of the WBS, but the calculation by means of evaluation and assignments takes place in the lowest. The superior level will then summarize the results for the subsidiary tasks.

#### 15.3.2.2. Project cost calculation and resource management

The base of the cost calculation is the technical and radiological inventory of the plant registered in CORA (see chapter 2.2). This includes the calculation of the decommissioning masses, of the radioactive waste and the reusable material, as well as the number and types of packages. The decommissioning cost calculation presupposes an existing project structure plan that identifies all necessary decommissioning activities from the beginning to the end. The cost estimation for a decommissioning task comprises the following types of costs:

- Personnel costs for internal and external personnel
- Investment costs
- Consumable costs
- Other costs (e.g. melting, interim storage, repository)

Different calculation models are available for each of the cost types:

- Manual calculation (all necessary data are given by the user, the module will calculate the cost; e.g. personnel cost are resulting from the duration of the task multiplied with the hourly wage rate of the involved personnel with its qualifications)
- Mass dependent calculation: a plant specific value, e. g. the mass (kg) of a component, or the mass (kg) of a set of components, or the surface ($m^2$) of a building area, will be used in combination with a specific working factor (man-hour/kg or man-hour/$m^2$) to calculate the decommissioning data (costs, duration, etc.)
- Time dependent calculation: the duration of a decommissioning task will be defined by other decommissioning tasks, e.g. radiological protection in parallel to the dismantling work
- Expenditure of labour dependent calculation: the labour for one task is related to the labour of other tasks, e. g. the expenditure of labour for site management is a percentage of the expenditure of labour for dismantling activities; the relation is represented by a specific factor (man-hour/man-hour)

Since mass, time and labour dependent calculation use specific factors, the module provides for the possibility to store and maintain these factors. Due to growing practical experience in a D&D project these factors may need to be updated. During task calculation correction parameters are available for specific factor; taking different working conditions into account (e.g. work under radiation protection measures, work on scaffoldings).

Along with the calculation of the personnel cost this module will provide for the possibility of a resource management (separated by own and external personnel). For this purpose several management and analysis functionalities are implemented.

Since this module uses data from the registration module it will be possible to assign cask cost and storage cost, which can be estimated in the Registration Module, to a decommissioning task.

All rates or prices for personnel, equipment, consumable and other costs are stored in the CALCOM database. For realistic results in case long-term calculations these prices can be escalated with inflation rates (average rate or rates for every year separately).

For cost comparison purposes the module will provide for the possibility to store actual task cost.

### 15.3.2.3. Definition and use of specific factors

Specific factors allow the transmission of experiences on decommissioning work from one project to another project using some plant specific reference indicators which is in the most relevant cases mass, radioactivity or surface of an item.

CALCOM use such specific factors in different ways:

- Working factors e.g. kg-dismantling / man-hour factors can be used for the calculation of the dismantling effort; factors for man-hour (radiation protection) / man-hour (dismantling) defines the relation between different kinds of work and allows an easy way to calculate the cost.
- Cost factors for consumables and investment cost, e.g. €/kg provides also an appropriate way for the cost estimation.

The CALCOM database contains the needed specific factors which are collected by NIS during more than 40 years experiences. Besides the use of different specific factors, CALCOM allows also adapting the specific factors to the local circumstances directly in the calculation file. So it is possible to use the same specific factor for similar activities, but to make a fine-tuning for each individual activity depending on the different circumstances.

## 15.4. Basic assumptions for the decommissioning calculation

The cost estimation for the decommissioning of the Krško NPP refers to future activities and costs. This future is still far away and so many factors and boundary conditions are not known yet. The calculations must use reasonable assumptions.

The following gives these definitions separated in assumptions with and without costs.

### 15.4.1. Non-cost assumptions

The following assumptions not directly referring to costs are made in the actual study:

- The first goal of the decontamination and dismantling activities is to reach the “brown field” status. This means the release of all buildings of the controlled and the monitored area from nuclear regulatory. Only the SFDS remains in operation. So, second goal is to reach “green field” status after the end of the SFDS operation. This means the removal of all buildings listed in Table 2-2. Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.
- Concerning the SFDS DP rev. 3 provides costs related to construction and operation of this facility until the end of NEK operation. This includes the relocation of 1,184 fuel assemblies in 16 containers. All later costs after 2043 related to the SFDS, like spent fuel movement (additional approx. 1,098 fuel assemblies in 30 canisters shall be moved in 2048 – 2051), operation of the SFDS after 2043 and decommissioning are costs related to the RW and SF disposal program. The total number of spent fuel elements to be stored in the SFDS is 2,282 (1,184 until 2028 and 1,098 after 2043). Based on existing Slovenian-Croatian bilateral agreement [1] and conclusions from 10th Meeting of Intergovernmental Commission held in July 2015 [2], SFDS facility can only be operated at NPP Krško site under domain of NEK until the end of NPP operation (year 2043, for the storage of Slovenian and Croatian part of spent fuel). Further operation of SFDS at NPP Krško site is subject of additional negotiation and potential further agreement between Slovenian and Croatian government.
- The dismantling plan bases on component, equipment and building masses listed in Table 2-1, Table 2-2 and Table 2-3.
- Referring to [5] the dismantling of the NPP starts immediately after the final shutdown. A deferred dismantling after an enclosure period is not taken into account. So, there are the advantages that on the one hand operation staff familiar with the operation history is still available, infrastructure and systems from operation can be still used and the site can be reused earlier. On the other hand the amount of waste could be higher due to the radiological decay as well as the dismantling effort due to a reduction of radiation exposure.
- The final shut down is planned on 31$^{st}$ December 2043.
- The plant will be decommissioned after a normal operation life without accidents; the decommissioning is planned and well prepared. In the period between the last and the actual study no incidents occurred having an impact on the actual study.
- The D&D project considers all necessary measures after the final shutdown and the measures before shutdown if such measures serve the preparation of the D&D project.
- As in Slovenia no storage or repository facility exist all spent fuel from the operation time and all the operational waste is stored on site. It is assumed that the spent fuel elements will be stored in storage containers in the SFDS building. After final shutdown the spent fuel will remain in the reactor building till it will be transported to the SFDS in the period 2048 – 2050.

- At the beginning of the decommissioning activities all systems and installations at the site are in function. The equipment and facilities to be used for decommissioning work comply with the state of the art.
- For external treatment of radioactive waste (e.g. melting) it is assumed that suitable plants are available and acceptance criteria are in place.
- All parts and materials which were exposed to neutron radiation during operation are activated and / or contaminated.
- Parts and materials exposed to neutron radiation during operation are activated and contaminated. All other non-activated parts and materials from the controlled area are assumed to be contaminated unless measurements reveal that there is no contamination above the clearance limits. The specific clearance levels are those specified in the Slovenian regulations [12].
- On all buildings and site areas outside of the controlled and monitored area a measuring program is carried out; it is considered that no contamination will be found outside these areas.
- The radiation exposure is kept ALARA. In any case the permissible occupational radiation exposure to the personnel is limited to 15 mSv/12 months
- All radioactive transports are carried out in accordance to IAEA regulations.
- Along with the dismantling of the site all buildings are demolished. Non-radioactive concrete rubble is used to the greatest possible extend e.g. for filling arising pits. The rest is stored in a conventional repository.
- The buildings are dismantled including their basements up to a depth of one metre below the ground surface. As far as the reactor buildings are concerned, their internal structures are completely demolished up to the metallic containment, in order to be able to check for absence of any contamination of the remaining parts of the building.
- The work will be carried out by the personnel on site and external companies. External companies are charged if it is required for specific decommissioning activities or if the capacity of the personnel on site is not sufficient.
- The containers presented in chapter 7.3.3 with its packaging factors defined in Table 7-8 are used.
- The immobilization will be done by cementation in a new building to be erected on the Krško NPP site referring to Attachment 3. The decommissioning costs and the DP do not include these costs, as they are part of the waste disposal program [4].
- To estimate the working effort the working factors in Table 15-1 are used. To respect the local circumstance concerning size of component, accessibility, need for protective measures, hoisting or lifting devices as well as scaffoldings adaptions are done. The working factors were reviewed and adapted if necessary relying on gained experiences since the last study.

### Working factors

| Factor | Value |
|---|---|
| Dismantling biological shield | 66.7 kg / man-hour |
| Dismantling concrete controlled area | 75.0 kg / man-hour |
| Dismantling controlled aera | 45.0 kg / man-hour |
| Dismantling monitored aera | 90.9 kg / man-hour |
| Dismantling primary circuit | 90.9 kg / man-hour |
| Dismantling RPV | 20.0 kg / man-hour |
| Dismantling RPV insulation | 2.0 kg / man-hour |
| Dismantling RPV internals | 2.0 kg / man-hour |
| Wastemanagement cable treatment | 75.0 kg / man-hour |
| Wastemanagement conditioning | 246.9 kg / man-hour |
| Wastemanagement cutting | 58.8 kg / man-hour |
| Wastemanagement cutting concrete | 235.3 kg / man-hour |
| Wastemanagement decont dry blasting | 166.7 kg / man-hour |
| Wastemanagement release components | 250.0 kg / man-hour |
| Wastemanagement release concrete | 1,000.0 kg / man-hour |
| Wastemanagement supercompaction | 60.0 kg / man-hour |
| Wastemanagement wet superjet | 200.0 kg / man-hour |
| Decontamination surface abrasion | 1.1 m² / man-hour |
| Preliminary survey | 21.7 m² / man-hour |
| Release measures inside building | 3.6 m² / man-hour |
| Release measures outside building | 13.3 m² / man-hour |
| Accomp. decontamination | 15 % of dismantling |
| Detailed planning | 25 % of dismantling |
| Engineering | 20 % of dismantling |
| Internal transport | 5 % of dismantling |
| On site radiological protection | 15 % of dismantling |
| Projectmanagement | 20 % of dismantling |
| Supervision | 15 % of dismantling |

Table 15-1: Working factors

### 15.4.2. Cost assumptions

The following assumptions referring to costs are made in the actual study:

- Price basis of the cost estimation is 2018.
- For the net present value of the estimated costs the real discount rate is $i_r$ = 3.2% per year (ref. [22], [23])
- When costs including VAT are presented, they are in accordance with Slovenian VAT regulations
- The personnel costs are calculated considering the hourly wages listed in Table 15-2.
- Investment items consumable materials are estimated on West European price bases. The investment costs are already presented in Table 15-5. The specific cost factors needed for the calculation of consumables and other non-personnel costs given in Table 15-3 are used.
- Local incentives are considered until the end of decommissioning of the NPP (brown field status) applying to [4]. During decommissioning with wet spent fuel pool it is 1,538,918 € per year, during decommissioning with SFDS it is 824,964 € per year.
- The costs for containers are presented in Table 15-4.
- The estimation is performed as a best estimate strategy. Risks and contingencies are calculated separately (see chapter 16).

| NEK personnel | | Slovenian foreign companies | |
|---|---|---|---|
| **Qualification** | **Cost per man-hour €/Mh** | **Qualification** | **Cost per man-hour €/Mh** |
| Project leader | 27.57 | Project leader | 42.40 |
| Health physics engi-neer | 17.65 | Health physics engi-neer | 34.71 |
| Project engineer | 20.29 | Project engineer | 34.71 |
| On-site manager | 30.31 | On-site manager | 34.71 |
| Health ph. technician | 16.86 | Health ph. technician. | 20.55 |
| Technician | 16.86 | Technician | 20.55 |
| Foreman | 16.09 | Foreman | 20.55 |
| Accountant | 14.04 | | |
| Technical designer | 15.19 | | |
| Health physicist | 14.41 | | |
| Craftsman | 12.39 | Craftsman | 13.15 |
| Labourer | 13.10 | Labourer | 13.15 |
| Guard | 13.37 | Guard | 13.15 |

| Western standard companies | | Western standard companies | |
|---|---|---|---|
| **Qualification** | **Cost per man-hour €/Mh** | **Qualification** | **Cost per man-hour €/Mh** |
| Project leader | 250.00 | Health ph. technician, Technician, Foreman | 125.00 |
| Health ph. engineer Project engineer, On-site manager | 185.00 | Craftsman, Labourer, Guard | 63.51 |

Table 15-2: Qualifications and wages of the personnel

## Specific factors for consumables and other non-personnel costs

| Factor | Value |
|---|---|
| Assurance | 421,000 € / year |
| Car park | 33,767 € / year |
| Chem laboratory | 76,075 € / year |
| Consumable workshop civil | 7,100 € / year |
| Consumable workshop elec. | 153,900 € / year |
| Consumable workshop mechan. | 187,000 € / year |
| Education | 70,333 € / year |
| Fire protection brigade | 208,350 € / year |
| International experts | 171,650 € / year |
| IT hardware | 37,367 € / year |
| IT hardware-maintenance | 101,867 € / year |
| IT software | 598,000 € / year |
| Mail, communication | 68,800 € / year |
| Medical service | 29,600 € / year |
| Officematerial | 64,267 € / year |
| Operation SFDS | 50,000 € / year |
| Provision energy | 245,280 € / year |
| Provision steam, oil, heating | 609,200 € / year |
| Provision water | 47,900 € / year |
| Recurring safety checks | 420,000 € / year |
| | |
| Local incentives during decommissioning with wet spentfuel pool (2044 - 2050) | 1,538,918 € / year |
| Local incentives during decommissioning with SFDS (2050 - 2058) | 824,964 € / year |
| | |
| Consumable costs demolition | 3.50 €/Mg |
| Consumable/material costs analysis, release - inside [€/m²] | 15.31 €/m² |
| Consumable/material costs analysis, release - outside [€/m²] | 6.12 €/m² |
| Consumable/material costs analysis, release - survey [€/m²] | 3.06 €/m² |
| Consumable/material costs decont./surface abr. [€/m²] | 26.62 €/m² |
| Consumable/material costs demolition in contr.area [€/kg] | 0.33 €/kg |
| Consumable/material costs dism. bioShield [€/kg] | 0.92 €/kg |
| Consumable/material costs dism. contr.area [€/kg] | 0.82 €/kg |
| Consumable/material costs dism. contr.area [€/Mh] | 36.74 €/Mh |
| Consumable/material costs dism. mon.area [€/kg] | 0.19 €/kg |
| Consumable/material costs dism. mon.area [€/Mh] | 16.97 €/Mh |
| Consumable/material costs dism. primary circuit [€/kg] | 0.53 €/kg |
| Consumable/material costs dism. primary circuit [€/Mh] | 47.71 €/Mh |
| Consumable/material costs dism. RPV [€/kg] | 5.42 €/kg |
| Consumable/material costs dism. RPV [€/Mh] | 108.40 €/Mh |
| Consumable/material costs dism. RPV-int. [€/kg] | 27.43 €/kg |
| Consumable/material costs dism. RPV-int. [€/Mh] | 54.85 €/Mh |
| Consumable/material costs WM conditioning | 0.10 €/kg |
| Consumable/material costs WM cutting | 0.69 €/kg |
| Consumable/material costs WM cutting concrete | 0.17 €/kg |
| Consumable/material costs WM decont. cable treatm. | 0.47 €/kg |
| Consumable/material costs WM decont. dry blast. | 0.99 €/kg |
| Consumable/material costs WM decont. wet superjet | 0.47 €/kg |
| Consumable/material costs WM evaporation | 0.45 €/kg |
| Consumable/material costs WM incineration | 13.50 €/kg |
| Consumable/material costs WM Landfill | 0.01 €/kg |
| Consumable/material costs WM melting | 3.50 €/kg |
| Consumable/material costs WM supercompaction | 0.15 €/kg |
| | |
| Repacking of operational waste (only for RCC container) | 4,800.00 €/container |

Table 15-3: Values for estimating the consumable costs

<u>NOTE:</u> The amount of local incentives is defined in [4].

## Drum, container and cask costs

| Factor | Value | Dimension |
|---|---|---|
| 200-l-drum | 120 | €/drum |
| TTC | 2,000 | €/container |
| N2d container | 10,600 | €/container |
| RCC | 6,000 | €/container |
| Packaging Holtec HI-SAFE container | 1,563,711 | €/cask |

Table 15-4: Cask and container costs

## 15.5. Investment plan

This chapter contains the investments needed for the Krško NPP decommissioning project.

Table 15-5 shows the investments and its costs estimated based on NIS experiences. The sum of investments has an amount of 13 Million €. Costs for containers are not included in this sum.

The biggest part of the investment costs are spent for the preparatory work at the beginning of the decommissioning project. The facilities and infrastructure have to be modified to enable the later dismantling work as well as the waste treatment. This includes the modifications, upgrades as well as investments for new equipment, as already existing equipment and facilities will be used as far as possible.

To reach brown field and green field status a small amount of 0.8 Million € is invested in release measurement equipment, which will be used for a longer period. It does not seem to be efficient to rent this equipment.

### Basic Data for investments

| Included tools and equipment | Cost [k€] | Timeframe |
|---|---|---|
| **02 PREPARATORY WORK** | **11,970** | |
| Heating system, heat vessel | 175 | 2044 |
| Evaporator system, evaporator | 1,100 | 2044 |
| Air supply | 385 | 2044 |
| Entrance controlled area | 165 | 2044 |
| Sanitary area | 165 | 2044 |
| Cutting and packaging equipment for old steam generators and old RPV head | 1,600 | 2044 |
| Cutting and packaging equipment for new steam generators | 400 | 2046 |
| Reconstruction in decontamination building (DB) | 220 | 2047-48 |
| Waste treatment equipment in decontamination building (DB) | 880 | 2048 |
| Clearance measurement facility in decontamination building (DB) | 880 | 2048-49 |
| Waste treatment equipment in intermediate building (IB) | 1,500 | 2046 |
| Packaging equipment for activated components in fuel handling building (FHB) | 4,400 | 2045-46 |
| Waste treatment equipment in waste manipulation Building (WMB) | 100 | 2044 |
| **11 CLEARANCE OF BUILDING STRUCTURES** | **833** | |
| Release measurement equipment for decommissioning phase "brown field" | 667 | 2056-58 |
| Release measurement equipment for decommissioning phase "green field" | 167 | 2104 / 2076* |
| **Total investments:** | **12,803** | |

*2076 for sensitivity case

Table 15-5: Investment costs

## 15.6. Results

The present chapter gives the results. It contains the costs and required personnel for the base case as well as for the sensitivity case. The important resulting milestones and schedules are presented in chapter 4.3.1.

### 15.6.1. Total cost

The total costs without VAT for the base case of the D&D project have an amount of **417.6 Million €**. For VAT additional 56.4 Million € are calculated.

The total costs without VAT for the sensitivity case have an amount of **405.3 Million €**. For VAT additional 56.1 Million € are calculated.

Detailed results of the decommissioning costs estimation are given in the following tables and figures.

Table 15-6 shows the total costs per WBS project for both cases. There is only a difference between the calculated costs in "SFDS (fuel, operation, decommissioning)". The operational costs of the SFDS are assigned to this element. As the end of SFDS operation in the sensitivity case is 28 years earlier than in the base case the operational costs are lower.

**Costs per WBS project [Million €]**

| WBS | Base case | | Sensitivity case | | VAT *) |
|---|---|---|---|---|---|
| | without VAT | incl. VAT | without VAT | incl. VAT | percentage |
| 01 Pre-decommissioning actions | 3.2 | 3.7 | 3.2 | 3.7 | 0% / 22% |
| 02 Preparatory work | 31.1 | 36.8 | 31.1 | 36.8 | 0% / 22% |
| 03 Nuclear material (operational waste) | 0.0 | 0.0 | 0.0 | 0.0 | 0% / 22% |
| 04 Dismantling outside controlled area | 10.8 | 12.4 | 10.8 | 12.4 | 0% / 22% |
| 05 Dismantling controlled area | 11.2 | 12.8 | 11.2 | 12.8 | 0% / 22% |
| 06 Dismantling primary loop components | 3.4 | 4.0 | 3.4 | 4.0 | 0% / 22% |
| 07 Dismantling RPV internals | 28.6 | 34.4 | 28.6 | 34.4 | 0% / 22% |
| 08 Dismantling RPV | 17.6 | 21.3 | 17.6 | 21.3 | 0% / 22% |
| 09 Dismantling biological shield | 5.3 | 6.2 | 5.3 | 6.2 | 0% / 22% |
| 10 Dismantling remaining systems | 7.9 | 9.2 | 7.9 | 9.2 | 0% / 22% |
| 11 Clearance of building structures | 14.5 | 17.4 | 14.5 | 17.4 | 0% / 22% |
| 12 Demolition, site restoration, cleanup and landscaping | 14.6 | 17.4 | 14.6 | 17.4 | 0% / 22% |
| 13 Project management, engineering and site support | 28.9 | 30.4 | 28.9 | 30.4 | 0% / 22% |
| 14 Site security, surveillance and maintenance | 112.0 | 118.8 | 112.0 | 118.8 | 0% / 22% |
| 15 Waste processing, storage and disposal | 36.2 | 44.2 | 36.2 | 44.2 | 0% / 22% |
| 16 SFDS (fuel, operation, decommissioning) | 75.6 | 88.4 | 63.3 | 75.8 | 0% / 22% |
| 17 Local Incentives | 16.6 | 16.6 | 16.6 | 16.6 | 0% |
| **TOTAL:** | **417.6** | **474.0** | **405.3** | **461.4** | |

*) Local incentives and NEK personnel 0%; all others 22%

Table 15-6: Costs per WBS project for base and sensitivity case

The same effect can be found out in Table 15-7, where the costs per category are listed. Personnel costs and consumables for the SFDS operation differ between the both cases.

**Costs per category [Million €]**

| Cost category | Base case | | Sensitivity case | | VAT |
|---|---|---|---|---|---|
| | without VAT | incl. VAT | without VAT | incl. VAT | percentage |
| NEK personnel | 144.6 | 144.6 | 133.7 | 133.7 | 0% |
| External personnel | 70.9 | 86.5 | 70.9 | 86.5 | 22% |
| Investments | 12.8 | 15.6 | 12.8 | 15.6 | 22% |
| Consumables | 85.8 | 104.7 | 84.4 | 103.0 | 22% |
| Others (containers, ext. treatment, ...) | 86.9 | 106.0 | 86.9 | 106.0 | 22% |
| Local incentives | 16.6 | 16.6 | 16.6 | 16.6 | 0% |
| **TOTAL:** | **417.6** | **474.0** | **405.3** | **461.4** | |

Table 15-7: Cost per category for base and sensitivity case

Table 15-8 and Table 15-9 show the yearly costs per WBS project without VAT for the base case and the sensitivity case respectively. The costs for the sensitivity case are lower due to the shorter SFDS operation period assigned to the WBS project “SFDS (fuel, operation, decommissioning)”.

Table 15-10 and Table 15-11 show the yearly costs per WBS project including VAT for the base case and the sensitivity case respectively. The costs for the sensitivity case are lower due to the shorter SFDS operation period assigned to the WBS project “SFDS (fuel, operation, decommissioning)”.

Figure 15-1 show the total yearly costs for base and sensitivity case without VAT. The costs for both cases are the same except the operational costs for the SFDS due to the different storage periods. Figure 15-2 show the total yearly costs for base and sensitivity case but including VAT.

**Yearly Costs per WBS project for base case without VAT [Million €]**

| WBS | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2100 | 2101 | 2102 | 2103 | 2104 | 2105 | 2106 | 2107 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 Pre-decommissioning actions | **3.2** | 0.5 | 1.1 | 1.1 | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 02 Preparatory work | **31.1** | | | | 0.3 | 10.3 | 7.6 | 8.5 | 1.8 | 2.2 | 0.3 | | | | | | | | | | | | | | | | | | | |
| 04 Dismantling outside controlled area | **10.8** | | | | 0.4 | 2.3 | 1.9 | 0.6 | | | | | | | | 0.1 | 0.2 | 0.6 | 1.1 | | | | | 0.1 | 0.8 | 2.1 | 0.6 | | | |
| 05 Dismantling controlled area | **11.2** | | | | | | | | | | | 0.3 | 2.7 | 3.2 | 2.6 | 2.0 | 0.4 | | | | | | | | | | | | | |
| 06 Dismantling primary loop components | **3.4** | | | | | 0.1 | 0.5 | 2.1 | 0.7 | | | | | | | | | | | | | | | | | | | | | |
| 07 Dismantling RPV internals | **28.6** | | | | | | 0.6 | 3.6 | 12.0 | 8.4 | 4.0 | | | | | | | | | | | | | | | | | | | |
| 08 Dismantling RPV | **17.6** | | | | | | | | 0.0 | 0.3 | 6.5 | 9.7 | 1.1 | | | | | | | | | | | | | | | | | |
| 09 Dismantling biological shield | **5.3** | | | | | | | | | | 0.1 | 0.3 | 1.9 | 3.0 | | | | | | | | | | | | | | | | |
| 10 Dismantling remaining systems | **7.9** | | | | | | | | | | | | 0.0 | 0.5 | 1.2 | 1.9 | 1.6 | 1.1 | 0.4 | | | | | | 0.2 | 1.0 | 0.0 | | | |
| 11 Clearance of building structures | **14.5** | | | | | | | | | | | | | | | 0.2 | 4.0 | 5.8 | 4.0 | 0.5 | | | | | | | | | | |
| 12 Demolition, site restoration, cleanup and landscaping | **14.6** | | | | | | | | | | | | | | | | | | | | | | | | | | 0.4 | 6.2 | 5.5 | 2.5 |
| 13 Project management, engineering and site support | **28.9** | | | | | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 1.6 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 0.2 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 14 Site security, surveillance and maintenance | **112.0** | | | | | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 6.0 | 5.3 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 0.6 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| 15 Waste processing, storage and disposal | **36.2** | | | | | 0.0 | 2.2 | 2.4 | 1.9 | 3.9 | 3.7 | 0.2 | 1.8 | 2.8 | 2.7 | 3.5 | 3.0 | 3.2 | 2.1 | 0.5 | | | | | | 0.0 | 0.0 | 1.2 | 0.8 | 0.0 |
| 16 SFDS (fuel, operation, decommissioning) | **75.6** | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 23.5 | 23.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | ... | 0.4 | 0.4 | 0.5 | 6.4 | 1.1 | 0.8 | | |
| 17 Local Incentives | **16.6** | | | | | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.1 | | | | | | | | | | |
| **TOTAL:** | **417.6** | **0.5** | **1.1** | **1.1** | **1.2** | **27.5** | **27.6** | **31.9** | **31.2** | **29.6** | **52.8** | **48.7** | **15.9** | **17.1** | **14.0** | **15.2** | **16.6** | **18.2** | **15.0** | **2.3** | **0.4** | **...** | **0.4** | **0.6** | **1.5** | **9.7** | **2.3** | **8.4** | **6.5** | **2.7** |

Table 15-8: Yearly costs per WBS project for base case without VAT

**Yearly Costs per WBS project for sensitivity case without VAT [Million €]**

| WBS | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 Pre-decommissioning actions | **3.2** | 0.5 | 1.1 | 1.1 | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 02 Preparatory work | **31.1** | | | | 0.3 | 10.3 | 7.6 | 8.5 | 1.8 | 2.2 | 0.3 | | | | | | | | | | | | | | | | | | | |
| 04 Dismantling outside controlled area | **10.8** | | | | 0.4 | 2.3 | 1.9 | 0.6 | | | | | | | | 0.1 | 0.2 | 0.6 | 1.1 | | | | | 0.1 | 0.8 | 2.1 | 0.6 | | | |
| 05 Dismantling controlled area | **11.2** | | | | | | | | | | | 0.3 | 2.7 | 3.2 | 2.6 | 2.0 | 0.4 | | | | | | | | | | | | | |
| 06 Dismantling primary loop components | **3.4** | | | | | 0.1 | 0.5 | 2.1 | 0.7 | | | | | | | | | | | | | | | | | | | | | |
| 07 Dismantling RPV internals | **28.6** | | | | | | 0.6 | 3.6 | 12.0 | 8.4 | 4.0 | | | | | | | | | | | | | | | | | | | |
| 08 Dismantling RPV | **17.6** | | | | | | | | 0.0 | 0.3 | 6.5 | 9.7 | 1.1 | | | | | | | | | | | | | | | | | |
| 09 Dismantling biological shield | **5.3** | | | | | | | | | | 0.1 | 0.3 | 1.9 | 3.0 | | | | | | | | | | | | | | | | |
| 10 Dismantling remaining systems | **7.9** | | | | | | | | | | | | 0.0 | 0.5 | 1.2 | 1.9 | 1.6 | 1.1 | 0.4 | | | | | | 0.2 | 1.0 | 0.0 | | | |
| 11 Clearance of building structures | **14.5** | | | | | | | | | | | | | | | 0.2 | 4.0 | 5.8 | 4.0 | 0.5 | | | | | | | | | | |
| 12 Demolition, site restoration, cleanup and landscaping | **14.6** | | | | | | | | | | | | | | | | | | | | | | | | | | 0.4 | 6.2 | 5.5 | 2.5 |
| 13 Project management, engineering and site support | **28.9** | | | | | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 1.6 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 0.2 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 14 Site security, surveillance and maintenance | **112.0** | | | | | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 6.0 | 5.3 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 0.6 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| 15 Waste processing, storage and disposal | **36.2** | | | | | 0.0 | 2.2 | 2.4 | 1.9 | 3.9 | 3.7 | 0.2 | 1.8 | 2.8 | 2.7 | 3.5 | 3.0 | 3.2 | 2.1 | 0.5 | | | | | | 0.0 | 0.0 | 1.2 | 0.8 | 0.0 |
| 16 SFDS (fuel, operation, decommissioning) | **63.3** | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 23.5 | 23.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | ... | 0.4 | 0.4 | 0.5 | 6.4 | 1.1 | 0.8 | | |
| 17 Local Incentives | **16.6** | | | | | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.1 | | | | | | | | | | |
| **TOTAL:** | **405.3** | **0.5** | **1.1** | **1.1** | **1.2** | **27.5** | **27.6** | **31.9** | **31.2** | **29.6** | **52.8** | **48.7** | **15.9** | **17.1** | **14.0** | **15.2** | **16.6** | **18.2** | **15.0** | **2.3** | **0.4** | **...** | **0.4** | **0.6** | **1.5** | **9.7** | **2.3** | **8.4** | **6.5** | **2.7** |

Table 15-9: Yearly costs per WBS project for sensitivity case without VAT

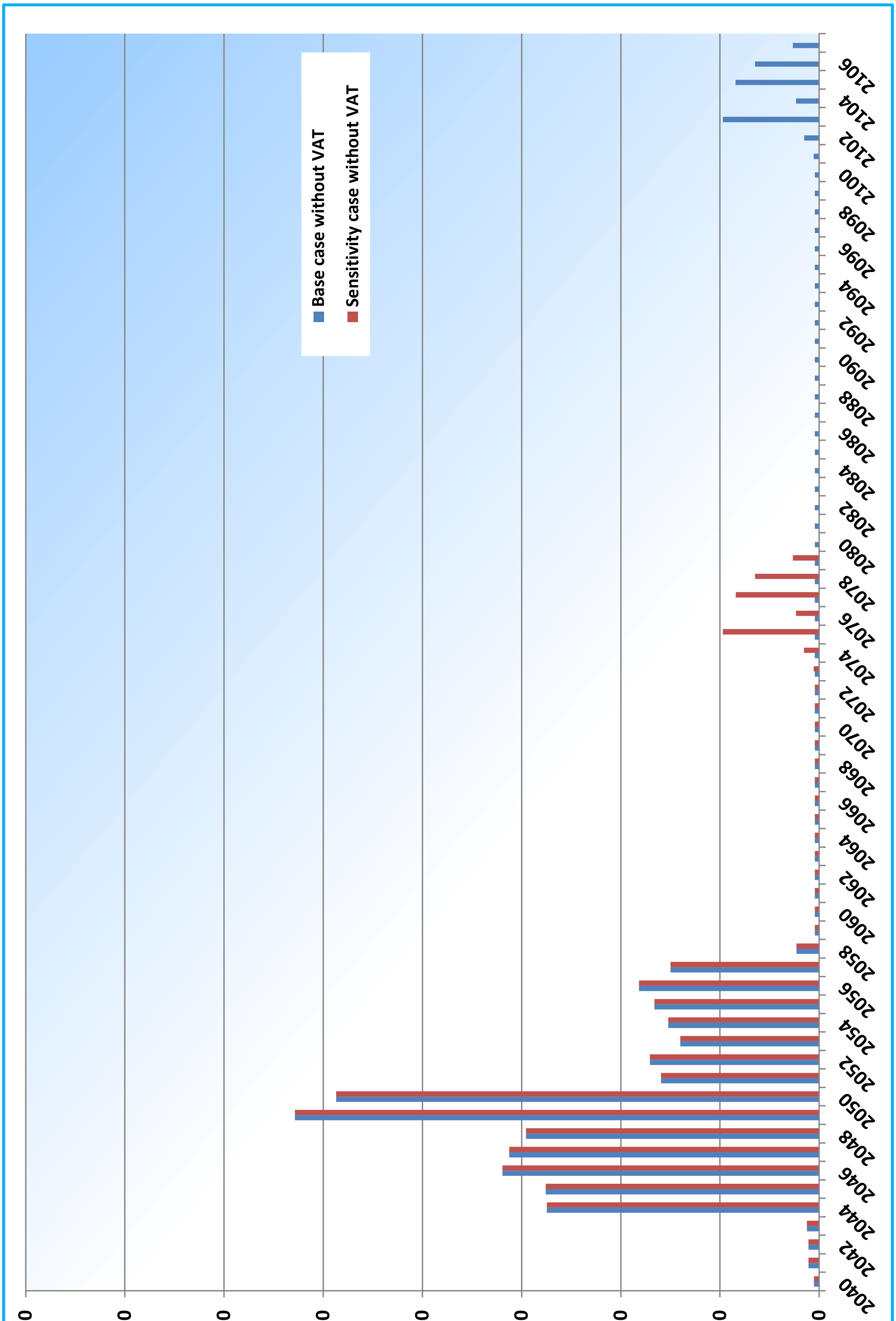



Figure 15-1: Total costs per year for base and sensitivity case without VAT

**Yearly Costs per WBS project for base case including VAT [Million €]**

| WBS | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2100 | 2101 | 2102 | 2103 | 2104 | 2105 | 2106 | 2107 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 Pre-decommissioning actions | **3.7** | 0.6 | 1.2 | 1.2 | 0.6 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 02 Preparatory work | **36.8** | | | | 0.3 | 12.2 | 9.0 | 10.2 | 2.1 | 2.6 | 0.3 | | | | | | | | | | | | | | | | | | | |
| 04 Dismantling outside controlled area | **12.4** | | | | 0.4 | 2.7 | 2.2 | 0.7 | | | | | | | | 0.1 | 0.2 | 0.6 | 1.3 | | | | | 0.1 | 0.8 | 2.5 | 0.7 | | | |
| 05 Dismantling controlled area | **12.8** | | | | | | | | | | | 0.3 | 2.9 | 3.7 | 3.1 | 2.4 | 0.4 | | | | | | | | | | | | | |
| 06 Dismantling primary loop components | **4.0** | | | | | 0.1 | 0.6 | 2.5 | 0.9 | | | | | | | | | | | | | | | | | | | | | |
| 07 Dismantling RPV internals | **34.4** | | | | | | 0.7 | 4.2 | 14.5 | 10.1 | 4.8 | | | | | | | | | | | | | | | | | | | |
| 08 Dismantling RPV | **21.3** | | | | | | | | 0.0 | 0.3 | 7.9 | 11.8 | 1.3 | | | | | | | | | | | | | | | | | |
| 09 Dismantling biological shield | **6.2** | | | | | | | | | | 0.1 | 0.3 | 2.2 | 3.6 | | | | | | | | | | | | | | | | |
| 10 Dismantling remaining systems | **9.2** | | | | | | | | | | | | 0.0 | 0.6 | 1.4 | 2.2 | 1.9 | 1.3 | 0.4 | | | | | | 0.2 | 1.2 | 0.0 | | | |
| 11 Clearance of building structures | **17.4** | | | | | | | | | | | | | | | 0.2 | 4.7 | 7.0 | 4.8 | 0.6 | | | | | | | | | | |
| 12 Demolition, site restoration, cleanup and landscaping | **17.4** | | | | | | | | | | | | | | | | | | | | | | | | | | 0.4 | 7.4 | 6.5 | 3.0 |
| 13 Project management, engineering and site support | **30.4** | | | | | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 1.6 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 0.2 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 14 Site security, surveillance and maintenance | **118.8** | | | | | 11.1 | 11.1 | 11.1 | 11.1 | 11.2 | 11.1 | 11.1 | 6.4 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 0.7 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| 15 Waste processing, storage and disposal | **44.2** | | | | | 0.1 | 2.7 | 2.9 | 2.3 | 4.8 | 4.6 | 0.2 | 2.2 | 3.4 | 3.3 | 4.3 | 3.7 | 4.0 | 2.6 | 0.6 | | | | | | 0.0 | 0.0 | 1.5 | 1.0 | 0.0 |
| 16 SFDS (fuel, operation, decommissioning) | **88.4** | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 28.7 | 28.7 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | ... | 0.4 | 0.4 | 0.5 | 7.7 | 1.3 | 1.0 | | |
| 17 Local Incentives | **16.6** | | | | | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.1 | | | | | | | | | | |
| **TOTAL:** | **474.0** | **0.6** | **1.2** | **1.2** | **1.3** | **30.6** | **30.7** | **36.1** | **35.4** | **33.4** | **61.8** | **56.8** | **17.6** | **19.2** | **15.7** | **17.1** | **18.8** | **20.7** | **16.9** | **2.6** | **0.4** | **...** | **0.4** | **0.6** | **1.5** | **11.6** | **2.7** | **10.1** | **7.7** | **3.1** |

Table 15-10: Yearly costs per WBS project for base case including VAT

**Yearly Costs per WBS project for sensitivity case including VAT [Million €]**

| WBS | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 Pre-decommissioning actions | **3.7** | 0.6 | 1.2 | 1.2 | 0.6 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 02 Preparatory work | **36.8** | | | | 0.3 | 12.2 | 9.0 | 10.2 | 2.1 | 2.6 | 0.3 | | | | | | | | | | | | | | | | | | | |
| 04 Dismantling outside controlled area | **12.4** | | | | 0.4 | 2.7 | 2.2 | 0.7 | | | | | | | | 0.1 | 0.2 | 0.6 | 1.3 | | | | | 0.1 | 0.8 | 2.5 | 0.7 | | | |
| 05 Dismantling controlled area | **12.8** | | | | | | | | | | | 0.3 | 2.9 | 3.7 | 3.1 | 2.4 | 0.4 | | | | | | | | | | | | | |
| 06 Dismantling primary loop components | **4.0** | | | | | 0.1 | 0.6 | 2.5 | 0.9 | | | | | | | | | | | | | | | | | | | | | |
| 07 Dismantling RPV internals | **34.4** | | | | | | 0.7 | 4.2 | 14.5 | 10.1 | 4.8 | | | | | | | | | | | | | | | | | | | |
| 08 Dismantling RPV | **21.3** | | | | | | | | 0.0 | 0.3 | 7.9 | 11.8 | 1.3 | | | | | | | | | | | | | | | | | |
| 09 Dismantling biological shield | **6.2** | | | | | | | | | | 0.1 | 0.3 | 2.2 | 3.6 | | | | | | | | | | | | | | | | |
| 10 Dismantling remaining systems | **9.2** | | | | | | | | | | | | 0.0 | 0.6 | 1.4 | 2.2 | 1.9 | 1.3 | 0.4 | | | | | | 0.2 | 1.2 | 0.0 | | | |
| 11 Clearance of building structures | **17.4** | | | | | | | | | | | | | | | 0.2 | 4.7 | 7.0 | 4.8 | 0.6 | | | | | | | | | | |
| 12 Demolition, site restoration, cleanup and landscaping | **17.4** | | | | | | | | | | | | | | | | | | | | | | | | | | 0.4 | 7.4 | 6.5 | 3.0 |
| 13 Project management, engineering and site support | **30.4** | | | | | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 1.6 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 0.2 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 14 Site security, surveillance and maintenance | **118.8** | | | | | 11.1 | 11.1 | 11.1 | 11.1 | 11.2 | 11.1 | 11.1 | 6.4 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 0.7 | | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| 15 Waste processing, storage and disposal | **44.2** | | | | | 0.1 | 2.7 | 2.9 | 2.3 | 4.8 | 4.6 | 0.2 | 2.2 | 3.4 | 3.3 | 4.3 | 3.7 | 4.0 | 2.6 | 0.6 | | | | | | 0.0 | 0.0 | 1.5 | 1.0 | 0.0 |
| 16 SFDS (fuel, operation, decommissioning) | **75.8** | | | | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 28.7 | 28.7 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | ... | 0.4 | 0.4 | 0.5 | 7.7 | 1.3 | 1.0 | | |
| 17 Local Incentives | **16.6** | | | | | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.1 | | | | | | | | | | |
| **TOTAL:** | **461.4** | **0.6** | **1.2** | **1.2** | **1.3** | **30.6** | **30.7** | **36.1** | **35.4** | **33.4** | **61.8** | **56.8** | **17.6** | **19.2** | **15.7** | **17.1** | **18.8** | **20.7** | **16.9** | **2.6** | **0.4** | **...** | **0.4** | **0.6** | **1.5** | **11.6** | **2.7** | **10.1** | **7.7** | **3.2** |

Table 15-11: Yearly costs per WBS project for sensitivity case including VAT

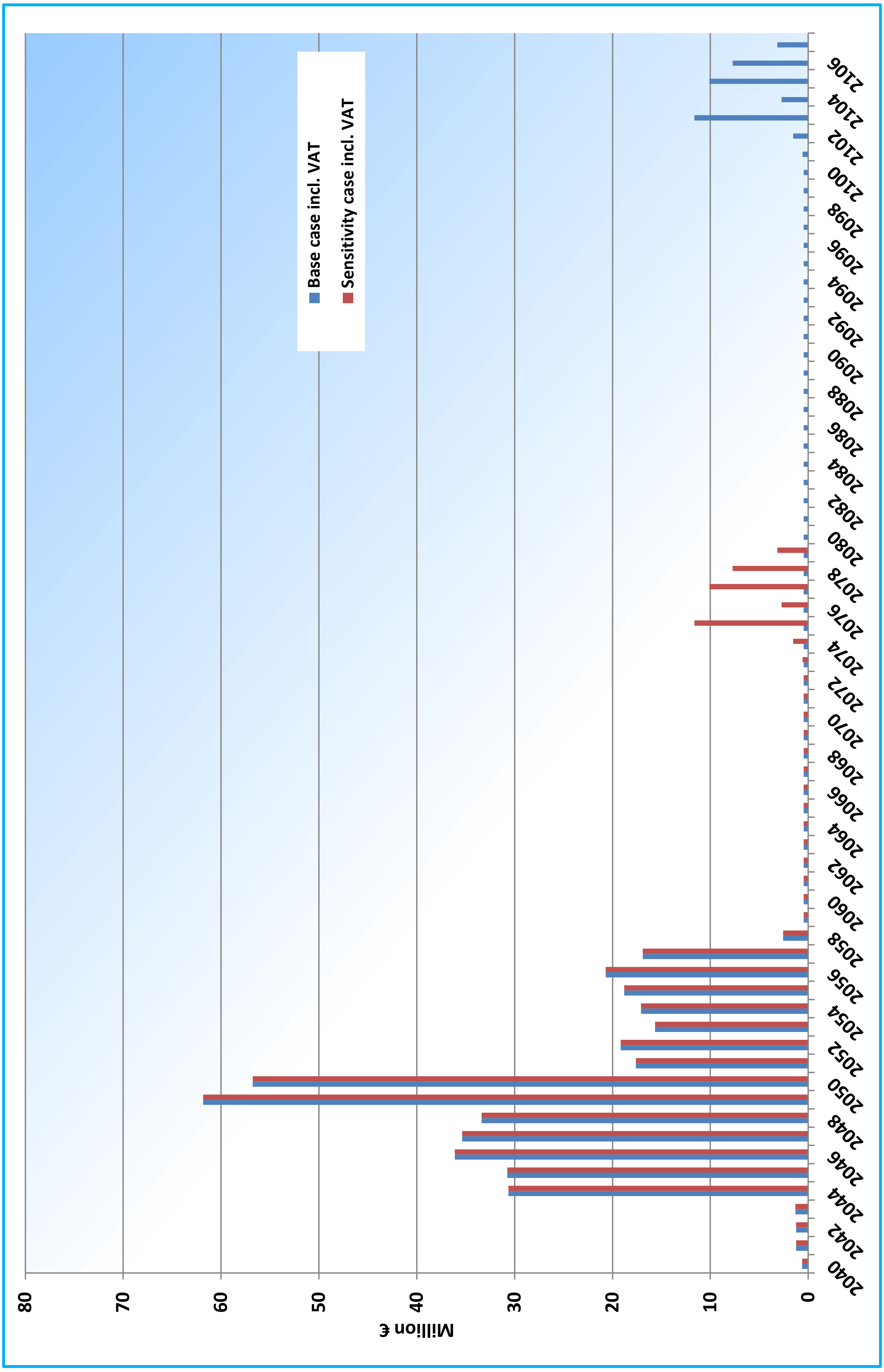



Figure 15-2: Total costs per year for base and sensitivity case including VAT

All the calculated costs relate on the price level in €$_{2018}$. The figures above show that the payments will be much later. Referring to the assumptions and settings in [22] and [23] following today's net present values are calculated:

- Base case (2103): 143.5 Million € (162.8 Million € incl. VAT)
- Sensitivity case (2075): 144.9 Million € (164.8 Million € incl. VAT)

Although the total costs in €$_{2018}$ for the base case are 12.3 Million € higher than for the sensitivity case, the net present value is 1.4 Million € lower. So, the interest earning effect due to later spending for the green field phase exceeds the savings for the shorter operation of the SFDS.

### 15.6.2. Manpower requirement and personnel capacity

One of the most important aspects in a decommissioning project is the required manpower. Table 15-7 show that about 45 % of the total costs are personnel costs.

The calculated total manpower for the D&D project is 5,811 man-years for the base case and 5,446 man-years for the sensitivity case.

The distribution of the man-years and the associated personnel costs are presented in Table 15-12 for both cases (without and including VAT).

**Man-years and personnel costs [Million €] per WBS project**

| WBS | Base case | | | | Sensitivity case | | | |
|---|---|---|---|---|---|---|---|---|
| | without VAT | | incl. VAT | | without VAT | | incl. VAT | |
| | Man-years | personnel costs [Million €] | Man-years | personnel costs [Million €] | Man-years | personnel costs [Million €] | Man-years | personnel costs [Million €] |
| 01 Pre-decommissioning actions | 36.1 | 3.2 | 36.1 | 3.7 | 36.1 | 3.2 | 36.1 | 3.7 |
| 02 Preparatory work | 292.3 | 12.3 | 292.3 | 13.9 | 292.3 | 12.3 | 292.3 | 13.9 |
| 04 Dismantling outside controlled area | 214.4 | 8.7 | 214.4 | 9.9 | 214.4 | 8.7 | 214.4 | 9.9 |
| 05 Dismantling controlled area | 253.9 | 9.7 | 253.9 | 10.9 | 253.9 | 9.7 | 253.9 | 10.9 |
| 06 Dismantling primary loop components | 49.3 | 1.9 | 49.3 | 2.1 | 49.3 | 1.9 | 49.3 | 2.1 |
| 07 Dismantling RPV internals | 156.9 | 17.3 | 156.9 | 20.6 | 156.9 | 17.3 | 156.9 | 20.6 |
| 08 Dismantling RPV | 70.4 | 8.4 | 70.4 | 10.0 | 70.4 | 8.4 | 70.4 | 10.0 |
| 09 Dismantling biological shield | 87.8 | 3.5 | 87.8 | 3.9 | 87.8 | 3.5 | 87.8 | 3.9 |
| 10 Dismantling remaining systems | 133.5 | 5.3 | 133.5 | 6.0 | 133.5 | 5.3 | 133.5 | 6.0 |
| 11 Clearance of building structures | 229.1 | 8.7 | 229.1 | 10.2 | 229.1 | 8.7 | 229.1 | 10.2 |
| 12 Demolition, site restoration, cleanup and landscaping | 277.2 | 9.7 | 277.2 | 11.4 | 277.2 | 9.7 | 277.2 | 11.4 |
| 13 Project management, engineering and site support | 589.8 | 22.2 | 589.8 | 22.2 | 589.8 | 22.2 | 589.8 | 22.2 |
| 14 Site security, surveillance and maintenance | 2,679.6 | 81.0 | 2,679.6 | 81.0 | 2,679.6 | 81.0 | 2,679.6 | 81.0 |
| 15 Waste processing, storage and disposal | 115.9 | 4.9 | 115.9 | 6.0 | 115.9 | 4.9 | 115.9 | 6.0 |
| 16 SFDS (fuel, operation, decommissioning) | 625.0 | 18.8 | 625.0 | 19.1 | 259.8 | 7.9 | 259.8 | 8.2 |
| 17 Local Incentives | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **TOTAL:** | **5,811.3** | **215.4** | **5,811.3** | **231.0** | **5,446.1** | **204.5** | **5,446.1** | **220.1** |

Table 15-12: Man-years and personnel costs per WBS project for base and sensitivity case

Most of the man-years are in the WBS projects 13 and 14 which are reflecting the required manpower for the project management and the operation of the plant during decommission. The content of these WBS projects is described in chapter 4.3.3.13 and chapter 4.3.3.14.

The personnel cost breakdown by the used personnel qualifications is given in Table 15-13.

**Personnel costs per qualification [Million €] and percentage of total personnel costs**

| Qualification *) | Base case, without VAT: personnel costs [Million €] | Base case, without VAT: percentage | Base case, incl. VAT: personnel costs [Million €] | Base case, incl. VAT: percentage | Sensitivity case, without VAT: personnel costs [Million €] | Sensitivity case, without VAT: percentage | Sensitivity case, incl. VAT: personnel costs [Million €] | Sensitivity case, incl. VAT: percentage |
|---|---|---|---|---|---|---|---|---|
| N_Accountant | 5.6 | 2.6% | 5.6 | 2.4% | 5.6 | 2.7% | 5.6 | 2.5% |
| N_Craftsman | 12.7 | 5.9% | 12.7 | 5.5% | 12.7 | 6.2% | 12.7 | 5.8% |
| N_Foreman | 5.5 | 2.6% | 5.5 | 2.4% | 5.5 | 2.7% | 5.5 | 2.5% |
| N_Guard | 25.2 | 11.7% | 25.2 | 10.9% | 17.9 | 8.7% | 17.9 | 8.1% |
| N_Health Physicist | 5.4 | 2.5% | 5.4 | 2.3% | 5.4 | 2.6% | 5.4 | 2.4% |
| N_HP_Engineer | 2.1 | 1.0% | 2.1 | 0.9% | 2.1 | 1.0% | 2.1 | 0.9% |
| N_Labourer | 17.1 | 8.0% | 17.1 | 7.4% | 17.1 | 8.4% | 17.1 | 7.8% |
| N_OnSite Manager | 8.0 | 3.7% | 8.0 | 3.5% | 6.3 | 3.1% | 6.3 | 2.9% |
| N_Project Engineer | 39.2 | 18.2% | 39.2 | 17.0% | 39.2 | 19.1% | 39.2 | 17.8% |
| N_Projectleader | 7.7 | 3.6% | 7.7 | 3.3% | 7.7 | 3.8% | 7.7 | 3.5% |
| N_Technical Designer | 0.6 | 0.3% | 0.6 | 0.2% | 0.6 | 0.3% | 0.6 | 0.3% |
| N_Technician | 12.6 | 5.8% | 12.6 | 5.5% | 10.7 | 5.3% | 10.7 | 4.9% |
| N_Technician_HP | 3.0 | 1.4% | 3.0 | 1.3% | 3.0 | 1.5% | 3.0 | 1.4% |
| S_Craftsman | 9.5 | 4.4% | 11.6 | 5.0% | 9.5 | 4.6% | 11.6 | 5.3% |
| S_Foreman | 15.5 | 7.2% | 18.9 | 8.2% | 15.5 | 7.6% | 18.9 | 8.6% |
| S_HP Engineer | 0.3 | 0.1% | 0.3 | 0.1% | 0.3 | 0.1% | 0.3 | 0.1% |
| S_HP Technician | 1.0 | 0.5% | 1.2 | 0.5% | 1.0 | 0.5% | 1.2 | 0.5% |
| S_Project Engineer | 7.1 | 3.3% | 8.7 | 3.8% | 7.1 | 3.5% | 8.7 | 4.0% |
| S_Projectleader | 0.7 | 0.3% | 0.8 | 0.4% | 0.7 | 0.3% | 0.8 | 0.4% |
| S_Technician | 10.4 | 4.8% | 12.6 | 5.5% | 10.4 | 5.1% | 12.6 | 5.7% |
| W_Labourer | 3.0 | 1.4% | 3.7 | 1.6% | 3.0 | 1.5% | 3.7 | 1.7% |
| W_Project Engineer | 9.7 | 4.5% | 11.9 | 5.1% | 9.7 | 4.8% | 11.9 | 5.4% |
| W_Technician | 13.7 | 6.4% | 16.7 | 7.2% | 13.7 | 6.7% | 16.7 | 7.6% |
| **TOTAL:** | **215.4** | **100.0%** | **231.0** | **100.0%** | **204.5** | **100.0%** | **220.1** | **100.0%** |

*) N = NEK personnel; S = Slovenian foreign personnel; W = Western standard personnel

Table 15-13: Personnel costs per qualification for base and sensitivity case

The yearly personnel capacity is given in Table 15-14 for the base case and in Table 15-15 for the sensitivity case. The personnel capacities are split in:

- NEK (operation / admin.)
- NEK (decommissioning)
- Slovenian companies
- Western companies

Figure 15-3 and Figure 15-4 show the yearly personnel capacity for the base and the sensitivity case of the Krško D&D project in diagrams.

**Yearly man-years for base case**

| Personnel | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2100 | 2101 | 2102 | 2103 | 2104 | 2105 | 2106 | 2107 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base case NEK (Operation/Admin.) | **3,854.8** | 0.0 | 0.0 | 0.0 | 0.0 | 305.2 | 304.0 | 305.2 | 305.2 | 306.3 | 305.2 | 304.0 | 174.4 | 153.2 | 152.6 | 152.6 | 152.6 | 152.0 | 152.6 | 30.0 | 13.1 | ... | 13.1 | 13.0 | 13.0 | 5.7 | 5.7 | 5.7 | 5.7 | 3.1 |
| Base case NEK (Decommissioning) | **676.8** | 5.0 | 10.0 | 10.0 | 23.6 | 52.5 | 56.1 | 50.4 | 39.0 | 30.7 | 23.9 | 28.4 | 57.7 | 55.7 | 23.7 | 29.0 | 30.6 | 31.2 | 19.3 | 1.0 | 0.0 | | 0.0 | 3.2 | 28.6 | 19.4 | 9.4 | 15.1 | 15.1 | 8.2 |
| Base case Slovenian companies | **1,172.8** | 0.0 | 0.0 | 0.0 | 0.0 | 58.7 | 79.9 | 71.9 | 58.4 | 26.1 | 10.7 | 2.4 | 49.8 | 81.2 | 59.3 | 67.2 | 94.7 | 102.1 | 85.1 | 6.3 | 0.0 | | 0.0 | 0.0 | 0.0 | 44.9 | 28.6 | 159.0 | 80.6 | 6.0 |
| Base case western companies | **107.0** | 1.0 | 2.0 | 2.0 | 1.0 | 0.0 | 10.3 | 5.0 | 15.6 | 21.6 | 19.9 | 20.1 | 2.5 | 0.8 | 0.7 | 1.0 | 1.1 | 1.1 | 1.0 | 0.4 | 0.0 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **TOTAL:** | **5,811.3** | **6.0** | **12.0** | **12.0** | **24.6** | **416.4** | **450.2** | **432.4** | **418.1** | **384.8** | **359.7** | **354.9** | **284.4** | **290.8** | **236.4** | **249.8** | **279.0** | **286.3** | **258.0** | **37.6** | **13.1** | **...** | **13.1** | **16.2** | **41.6** | **70.0** | **43.7** | **179.8** | **101.3** | **17.3** |

Table 15-14: Yearly man-years for base case

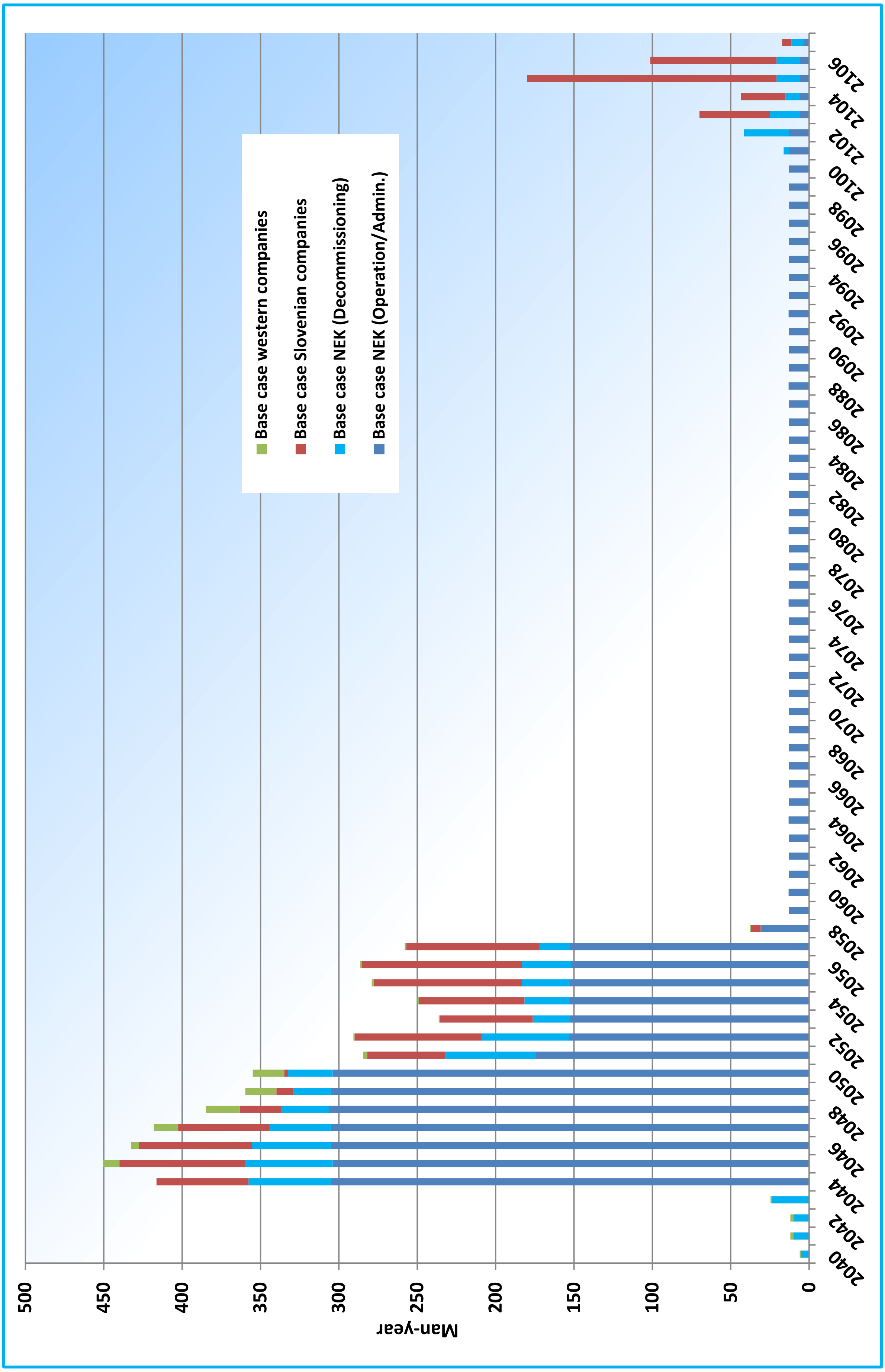



Figure 15-3: Yearly personnel capacity for the base case

**Yearly man-years for sensitivity**

| Personnel | Sum | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | ... | 2072 | 2073 | 2074 | 2075 | 2076 | 2077 | 2078 | 2079 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sens. case NEK (Operation/Admin.) | **3,489.6** | 0.0 | 0.0 | 0.0 | 0.0 | 305.2 | 304.0 | 305.2 | 305.2 | 306.3 | 305.2 | 304.0 | 174.4 | 153.2 | 152.6 | 152.6 | 152.6 | 152.0 | 152.6 | 30.0 | 13.1 | ... | 13.1 | 13.0 | 13.1 | 5.7 | 5.7 | 5.7 | 5.7 | 3.1 |
| Sens. case NEK (Decommissioning) | **676.8** | 5.0 | 10.0 | 10.0 | 23.6 | 52.5 | 56.1 | 50.4 | 39.0 | 30.7 | 23.9 | 28.4 | 57.7 | 55.7 | 23.7 | 29.0 | 30.6 | 31.2 | 19.3 | 1.0 | 0.0 | | 0.0 | 3.2 | 28.6 | 19.4 | 9.4 | 15.1 | 15.0 | 8.2 |
| Sens. case Slovenian companies | **1,172.8** | 0.0 | 0.0 | 0.0 | 0.0 | 58.7 | 79.9 | 71.9 | 58.4 | 26.1 | 10.7 | 2.4 | 49.8 | 81.2 | 59.3 | 67.2 | 94.7 | 102.1 | 85.1 | 6.3 | 0.0 | | 0.0 | 0.0 | 0.0 | 44.9 | 28.6 | 159.0 | 80.5 | 6.0 |
| Sens. case western companies | **107.0** | 1.0 | 2.0 | 2.0 | 1.0 | 0.0 | 10.3 | 5.0 | 15.6 | 21.6 | 19.9 | 20.1 | 2.5 | 0.8 | 0.7 | 1.0 | 1.1 | 1.1 | 1.0 | 0.4 | 0.0 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **TOTAL:** | **5,446.1** | **6.0** | **12.0** | **12.0** | **24.6** | **416.4** | **450.2** | **432.4** | **418.1** | **384.8** | **359.7** | **354.9** | **284.4** | **290.8** | **236.4** | **249.8** | **279.0** | **286.3** | **258.0** | **37.6** | **13.1** | **...** | **13.1** | **16.2** | **41.6** | **70.0** | **43.7** | **179.8** | **101.2** | **17.4** |

Table 15-15: Yearly man-years for sensitivity case

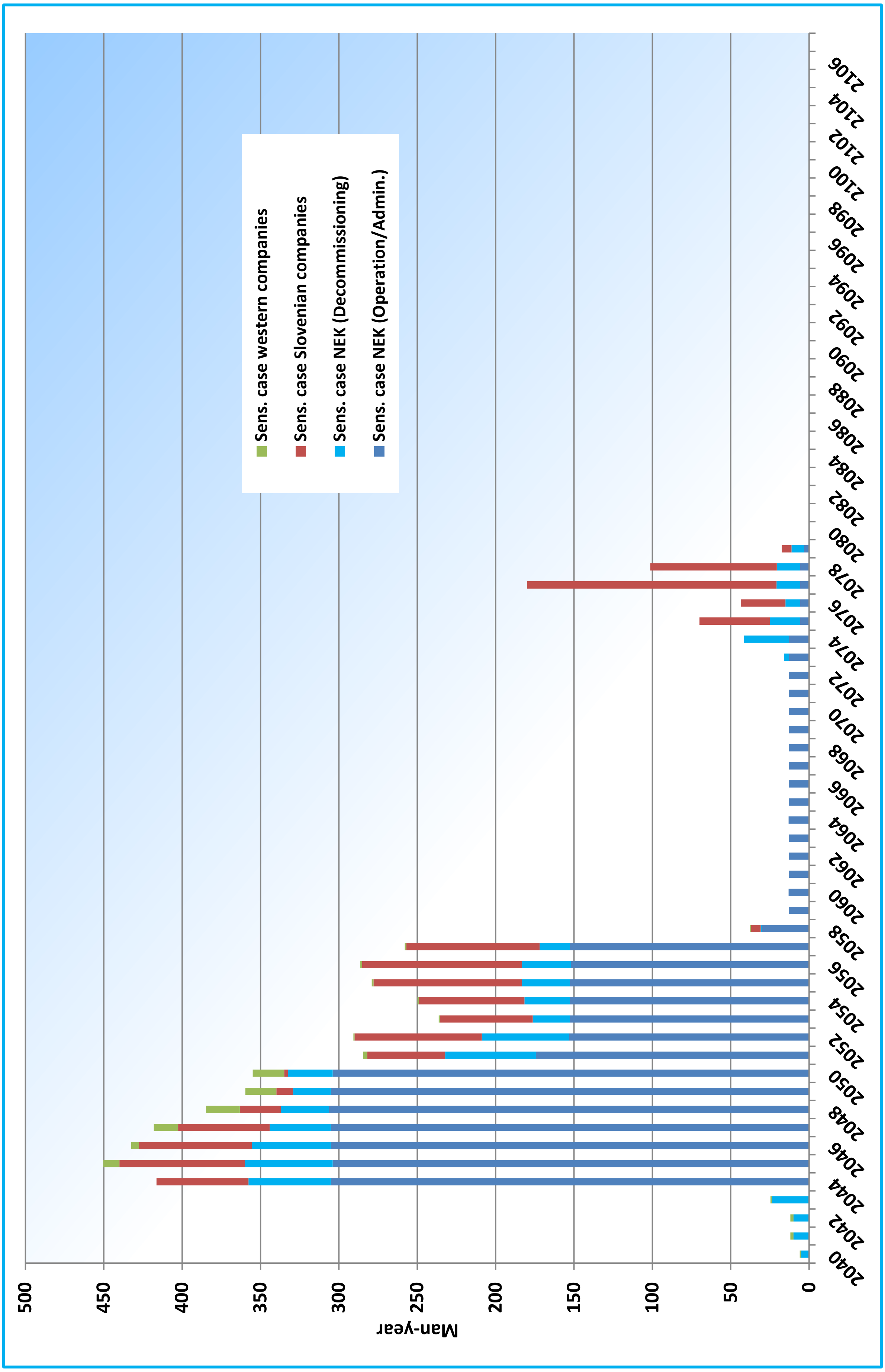



Figure 15-4: Yearly personnel capacity for the sensitivity case

## 15.7. Comparison PDP results 2009 variant 2043 / 2018 base case

In 2009 total costs without VAT with an amount of 622 Million € (price level 2009) were estimated for the NPP Krško decommissioning applying to variant 2043. From 2009 till 2017 an average inflation rate of 1.2% per year was identified for Slovenia referring to [22]. So escalating the 2009's total costs to the price level 2018 taken this rate into account leads to an amount of 693 Million €. In Table 15-16 the updated costs relying on DP rev.3 are compared with the 2009's nominal as well as the escalated costs.

**Costs per WBS project [Million €]**

| WBS | 2009 variant 2043 price level 2009 | 2009 variant 2043 escalated 2018* | 2018 base case price level 2018 |
|---|---|---|---|
| 01 Pre-decommissioning actions | 2.6 | 2.9 | 3.2 |
| 02 Preparatory work | 41.4 | 46.1 | 31.1 |
| 03 Nuclear material (operational waste) | 278.9 | 310.5 | 0.0 |
| 04 Dismantling outside controlled area | 12.8 | 14.3 | 10.8 |
| 05 Dismantling controlled area | 5.7 | 6.3 | 11.2 |
| 06 Dismantling primary loop components | 3.2 | 3.6 | 3.4 |
| 07 Dismantling RPV internals | 26.2 | 29.2 | 28.6 |
| 08 Dismantling RPV | 13.9 | 15.5 | 17.6 |
| 09 Dismantling biological shield | 5.2 | 5.8 | 5.3 |
| 10 Dismantling remaining systems | 6.7 | 7.5 | 7.9 |
| 11 Clearance of building structures | 17.7 | 19.7 | 14.5 |
| 12 Demolition, site restoration, cleanup and landscaping | 14.0 | 15.6 | 14.6 |
| 13 Project management, engineering and site support | 40.5 | 45.1 | 28.9 |
| 14 Site security, surveillance and maintenance | 113.9 | 126.8 | 112.0 |
| 15 Waste processing, storage and disposal | 39.4 | 43.9 | 36.2 |
| 16 SFDS (fuel, operation, decommissioning) | 0.0 | 0.0 | 75.6 |
| 17 Local incentives | 0.0 | 0.0 | 16.6 |
| **TOTAL:** | **622.1** | **692.6** | **417.6** |

* 1.2% per year

Table 15-16: Comparison PDP cost results 2009 / 2018

In total the costs decreased with an amount of 204.5 Million €. Taking costs after the price escalation into account they decrease with an amount of 275.0 Million €.

In following the explanation for remarkable changes (> 1 Million €) between the actual study (base case) and the 2009`s study (escalated) are given:

*02 Preparatory work -15 Million €*

Main reason for the cost reduction in this WBS project 02 is that the disposal of the remaining "Operational waste" is not considered in this WBS project anymore. Now it is moved to WBS project 03 "Nuclear material (operational waste)".

NOTE: But due to the agreed boundary conditions [5] for the present DP rev.3 the results for the disposal of the "Operational waste" are only given in Attachment 4.

*03 Nuclear material (operational waste) -311 Million €*

In the present DP rev.3 the disposal of the remaining “Operational waste”, which is assumed with a gross mass of 6,100 Mg, is not considered in the main part of DP rev.3. Nevertheless the results for the disposal of the operational waste are given in Attachment 4 of this study. The assignment of the “Operational waste” to the WBS would be in this WBS project.

In addition all costs relating to the spent fuel, the storage in the SFDS building as well as the decommissioning of the SFDS building are summarised in WBS project 16.

Therefore, the WBS project 03 contains no costs anymore.

NOTE: Depending on the packaging strategy (50% N2d container / 50% RCC; 100% N2d container or 100% RCC) the costs for the disposal of the 6,100 Mg operational waste are varying from 14.5 Million € to 27.4 million € (see Attachment 4 for more information).

*04 Dismantling outside controlled area -4 Million €*

The adaption of working effort applying to gained experiences as well as the reduction of hourly working costs based on the review on needed qualifications and corresponding wages lead to the cost reduction.

*05 Dismantling controlled +5 Million €*

In this case the adaption of working effort applying to gained experiences leads to a cost increase.

*08 Dismantling RPV +2 Million €*

Also here the adaption of working effort applying to gained experiences leads to a cost increase. Furthermore the raise of the hourly working costs for western companies exceeds an escalation applying to the Slovenian inflation rate.

*11 Clearance of building structures -5 Million €*

The adaption of working effort applying to gained experiences as well as the reduction of hourly working costs based on the review on needed qualifications and corresponding wages lead to the cost reduction.

*13 & 14 Project management, engineering and site support & site security, surveillance and maintenance -31 Million €*

Nevertheless that the non-personnel yearly costs increased due to the site specific experiences of the past years the total cost are lower.

The reason therefore is a new assessment of the plant operator NEK about the necessary number of personnel which will be required for the tasks described in WBS projects 13 and 14 (see chapters 4.3.3.13 and 4.3.3.14 for detailed information). The estimated manpower is significantly lower than in the last PDP rev.5 [10].

*15 Waste processing, storage and disposal -8 Million €*

The N3 container is substituted by the new N2d container (50% of radioactive waste mass) and the new RCC (50% of radioactive waste mass) applying to the new packaging concept. This decreases the container costs.

*<u>16 SFDS (fuel, operation, decommissioning) +76 Million €</u>*

At first sight the WBS project 16 shows an increase in costs of about 76 Million €.

But as mentioned under WBS project 03 all costs related to spent fuel have been moved to this WBS project 16. So the estimated costs have to be compared with the former costs of WBS project 03 which shows an escalated amount of almost 311 Million € (see Table 15-16). So there is actually a cost reduction of about 235 Million € compared to the costs given in PDP rev.5.

The main reasons for that strong decrease are:

- Consideration of the new spent fuel packaging concept (e.g. no CASTOR anymore)
- Only a remaining part of spent fuel elements (1,098 SF) have to be taken into account (PDP rev.5: 2,500 SF)
- Erection costs of the SFDS are not considered anymore

On the other hand a longer operation period of the SFDS (in the base case up to 2103) and the later decommissioning of the SFDS are now considered in the DP rev.3.

Both, the decreasing effects and the increasing effects lead to the new results in the present DP rev.3.

*<u>17 Local incentives +17 Million €</u>*

The consideration of local incentives for the period until the decommissioning of the NPP is completed (2044 until 2058 – “Brown field”-status) leads to remarkable additional costs.

# 16. Uncertainty and sensitivity analyses

The cost estimation for a D&D project over some decades in future depends on certain assumptions, defined in chapter 15.4. Every assumption contains the uncertainty, whether it enters as planned or not. Therefore it will be analysed which sensitivities are contained in the cost estimation and which risks will remain for the future. The analysis of the risks contains today's knowledge and cannot lay any claim to completeness.

Following the partition in cost categories of the estimated decommissioning costs, shown in Table 15-7, the main direct cost drivers are the personnel costs and the other costs containing especially container costs, costs for external waste treatment and the local incentives.

Indirect cost drivers are the dismantling duration, the estimated mass of the inventory, the assumed radiological situation, and the necessary operational expenditures during the dismantling, respectively the decrease of the operational efforts while dismantling.

The cost estimation performed by NIS reflects the actual state of the art and the actual boundary conditions for decommissioning of nuclear facilities. The calculations of the decommissioning masses are made in a status of “best engineering judgement” and don’t include contingencies for future risks or uncertainties.

## 16.1. Uncertainties / Sensitivities in mass and radiological data

The data collection and calculations for mass and surface made in earlier studies and actualised in this study is based on several data sources provided by NEK but also on information from NIS experiences.

The mass data collected are verified by NIS. Nevertheless they contain certainly tolerances, i.e. of about +/- 10% for the most important masses (parts of the RPV and Internals) and some more %-values for other groups of components. The possible tolerances affect the calculations for waste amount, repository volume and cost in different fields. The analysed results on storage volumes and/or masses are given in Table 16-1.

**Sensitivities and risks of masses and volumes**

| Risk factor | Risk assumptions | Description | Changes in repository volume [$m^3$] |
|---|---|---|---|
| Mass calculation | RPV, internals, biol. shield +/-10% | Number of containers are directly linked to the additional mass | +/- 198.8 |
| | Contaminated components +/- 20% | | +/- 456.4 |
| | Non-radioactive material +/- 30% | Additional non-radioactive rubble for conventional deposition or land filling | +/- 0 |
| Radioactive inventory evaluation | Activation calculation results +/- 1,000% | Deviations will be balanced by one Holtec cask more or less | +/- 34 |
| | Contamination comp. results +/- 1,000% | No significant changes of the load per container | +/- 0 |
| | Contamination Build. results +/- 1,000% | No significant changes of the load per container | +/- 0 |

Table 16-1: Uncertainties / Sensitivities and risks of masses and volumes

## 16.2. Uncertainties / Sensitivities in costs

The cost estimations for the decommissioning of the Krško NPP are made in a status of “best engineering judgement” without contingencies for future risks or uncertainties.

Nevertheless it is recognised that several sensitivities or risks remain, i.e.:

- Project duration
- Manpower requirements
- Dismantling efficiency
- Price escalation, wages, external services and provisions
- Decontamination and release
- Spent fuel management
- Waste treatment and packaging cost
- LILW repository

### 16.2.1. Project duration

The performed planning and calculation considers boundary conditions which effect the total duration, resulting in the time schedule of about 14 years. This decommissioning period will be effected by some optimisation opportunities but also by several risks for a project delay

- The period for the spent fuel transport can be reduced by an optimised packaging strategy or by an earlier start
- The existing operational waste can be conditioned and packaged during the remaining operation period
- The old SG can be removed in the remaining operation period

Time reduction affects the cost in the fields of project management, administration, operation, and maintenance and others.

Delays in the decommissioning project are possible, e.g. needed licenses might be not available and unexpected technical problems may occur. Such effects include a risk in time extension in the mentioned working fields.

### 16.2.2. Manpower requirements

The DP is divided in approximately 2,200 activities for the calculation of the manpower requirements, duration and cost. Each decommissioning activity is calculated separately concerning used tools, equipment, consumables and the needed number of personnel. The existing qualification groups given by NEK were considered.

Additional personal capacity is planned for specific decommissioning work carried out by Slovenian Companies, and for some special work (RPV and internals) carried out by western companies. The calculated number of personnel can have a tolerance which concerns the project duration and the cost.

### 16.2.3. Dismantling efficiency

With respect to the cost, all participants in decommissioning projects are interested in optimising the working efficiency. This concerned dismantling and decontamination efficiency, but also the working tasks “administration” and “operation support” which should be minimised. The decommissioning cost could be reduced by an increasing efficiency.

### 16.2.4. Price escalation, wages, external services and provisions

The personnel costs as an important factor for the decommissioning cost are calculated based on the wages provided by NEK. It is recognized that these wages are cheaper than in Western European countries today. Therefore it is a risk, that the increase in wages could exceed the normal inflation. The same applies for external Slovenian companies. Furthermore an increase of the partition of western companies could also increase the costs.

### 16.2.5. Decontamination and release

The calculated efforts for the decontamination of the concrete surfaces are revised and actualised by NIS applying to their experiences in current D&D projects in Germany. Nevertheless there remains a risk for additional working expenditures, because it can't be excluded that radioactivity got deeper in the building structure as assumed.

Additionally stricter rules for the release can lead to higher decontamination efforts, or possibly to higher quantities of radioactive waste. In both cases the costs will increase as well.

### 16.2.6. Spent fuel management

In the PDP it is planned to store the spent fuel elements in the SFDS till 2103 for the base and till 2075 for the sensitivity case. The cost for the operation of this facility is considered in the DP cost estimation.

If the HLW Repository is available earlier the cost for the dry storage facility will be reduced; in other case if the HLW Repository is not available the cost will increase corresponding.

It has to be remarked, that the net present value decreases by delaying the end of the SFDS operation as shown in chapter 15.6.1.

### 16.2.7. Waste treatment and packaging cost

The cost for the planned waste containers was collected by information on waste containers provided by NEK. Adequate packaging factors are chosen by NIS considering gained experiences and established approaches.

The uncertainties and tolerance in the packaging data and in the container cost concerns:

- Container cost
- Packaging cost
- Expenditures for interim storage facilities
- Transport expenditures
- Repository cost

### 16.2.8. LILW repository

The DP assumes LILW repositories in Slovenia and Croatia available in due time. The already existing storage areas are occupied today by the operational waste and it is assumed that this waste will be removed in due time.

In case that a repository will not available the complete decommissioning strategy developed for the DP will be concerned. Alternatively an additional interim storage facility for low and intermediate level waste could be provided on site.

## 16.3. Uncertainties / Sensitivities and Risk calculation and results

The uncertainties, sensitivities and risks mentioned above are calculated and evaluated separately. The results are given in the Table 16-2 below.

### Sensitivities and risks

| Risk factor | Risk assumptions | Cost changes | Propabilitiy for total risk |
|---|---|---|---|
| Mass calculation | RPV, internals, biol. shield +/-10% | +/- 6.3 Million € | 50% |
| | Contaminated components +/- 20% | +/- 7.7 Million € | |
| | Non-radioactive material +/- 30% | +/- 6.2 Million € | |
| Radioactive inventory evaluation | Activation calculation results +/- 1,000% | +/- 1.6 Million € | 30% |
| | Contamination comp. results +/- 1,000% | +/- 0.0 Million € | |
| | Contamination build. results +/- 1,000% | + 7.2 Million €<br>- 3.6 Million € | |
| Waste treatment and packaging cost | Number of container +/- 20% | +/- 3.2 Million € | 20% |
| | Treatment expenditures +/- 30% | +/- 6.1 Million € | |
| Project duration (brown field) | 3 month delay in general | +/- 3.0 Million € | 50% |
| | 6 month delay in general | +/- 6.0 Million € | 30% |
| | 12 month delay in general | +/- 12.1 Million € | 10% |
| Manpower requirements | Manpower operation +/- 10% | +/- 8.1 Million € | 10% |
| | Manpower administration +/- 10% | +/- 2.2 Million € | |
| Dismantling efficiency | Dismantling efficiency +20% | - 22.6 Million € | 20% |
| Price escalation, wages, external services and provisions | Wages +20% | + 29.1 Milllion € | 20% |
| | External services Slovenia +20% | + 8.9 Million € | |
| | External services western companies +10% | + 2.7 Million € | |
| Decontamination and release of building structures | Surfaces and deepness to scarify +30% | + 12.2 Million € | 30% |
| Spent fuel management | Dry storage facility not available | + 22.6 Million € per year | 10% |
| | HLW repository not available | + 0.4 Million € per year | 50% |
| LILW repository | LILW repository not available | + 20.0 Million € interim storage facility | 20% |

Table 16-2: Uncertainties / Sensitivities and Risks

## 16.4. Sensitivities in discounting

The chosen real discount rate has a high impact on the resulting NPV. This effect resulting from performed sensitivity calculations is shown in Figure 16-1 for the base case and in Figure 16-2 for the sensitivity case respectively. As can be seen a decrease of the rate from 3.2% to 2.2% increases the NPV of the decommissioning costs for more than 50 Million € in both cases.

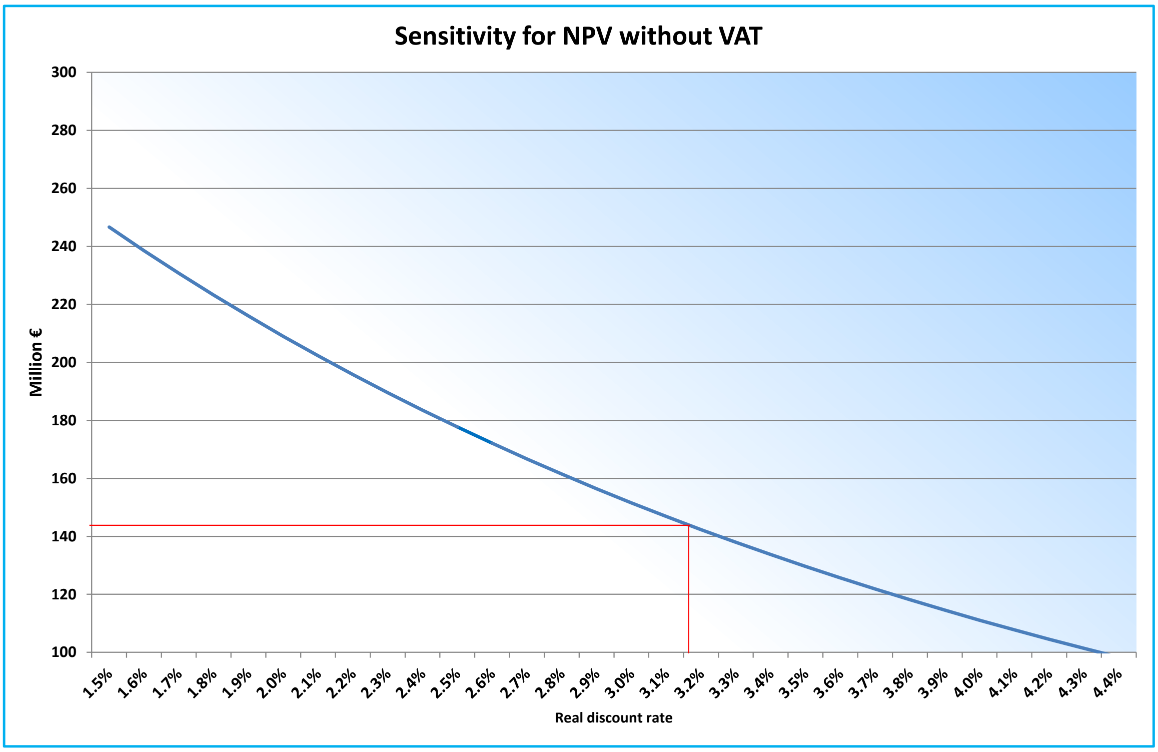



Figure 16-1: Sensitivity of the NPV for different real discount rates (base case – 2103)

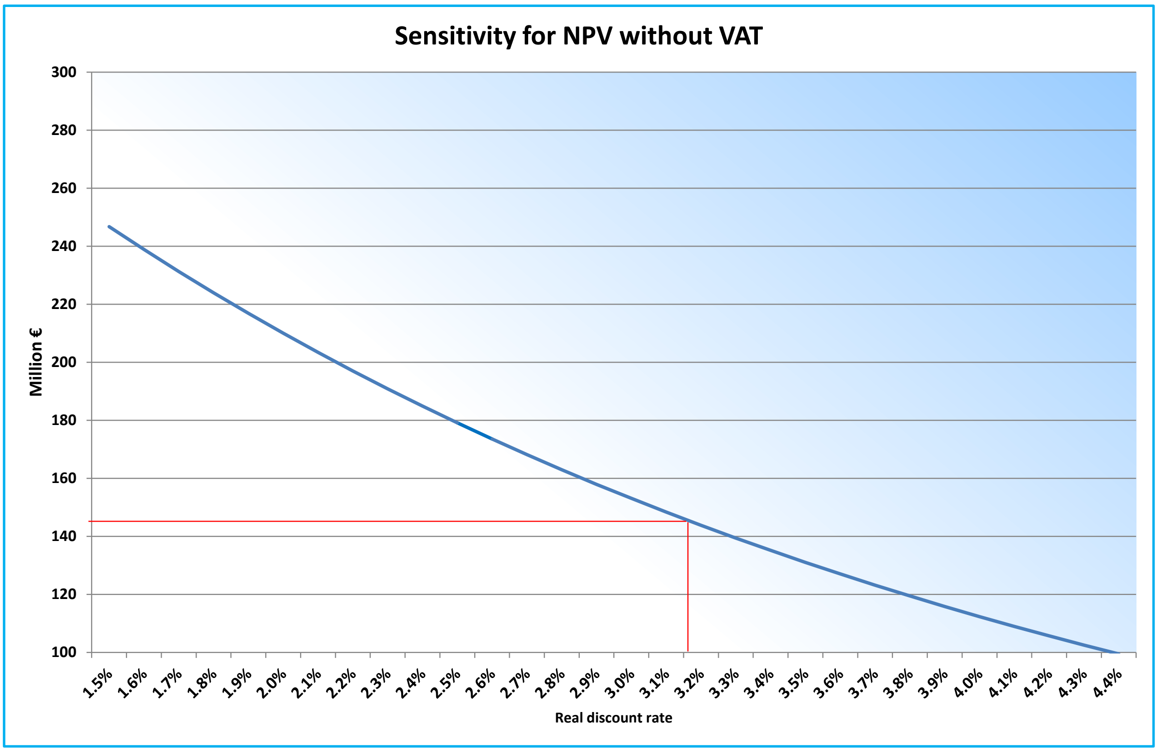



Figure 16-2: Sensitivity of NPV for different real discount rates (sensitivity case – 2075)

## 16.5. Conclusion on uncertainties / sensitivities

Taking into account the estimated cost changes and the assumed corresponding probabilities for the described uncertainties / sensitivities and risks (see Table 16-2) the total variance of the estimated decommissioning costs for the base case and the sensitivity case are shown in Table 16-3.

**Total variance in decommissioning costs**

| NPP Krško | Costs [Million €] | High confidence value [Million €] | Low confidence value [Million €] |
|---|---|---|---|
| Base case (2103) | 417.6 | 388.0 | 462.1 |
| Sensitivity case (2075) | 405.3 | 375.7 | 449.8 |

Table 16-3: Total variance of decommissioning costs due to uncertainties / sensitivities and risks

## 17. Conclusions and recommendations

During the planning work for the present DP no critical technical problems are found, and they are not expected to occur. The state of relevant technology attained by now is high enough to execute all present and future decommissioning projects. However, considering that the volume of decommissioning of installations will reach levels never handled before during next decades, the advancement of several aspects of existing techniques would be entirely desirable with regard to, for example, dose reduction, the simplification of processes, increased efficiency, the minimising of waste, and cost reduction.

Therefore, NIS recommends observing the international decommissioning projects and to compare the gathered experience and to update the DP and cost estimate from time to time accordingly.

The main important cost driver are the activities for the plant operation (WBS projects 13 and 14) representing more than 40% of the total decommissioning costs (excl. SFDS and costs for local incentives). Therefore NIS recommends further analysis of following important items:

- Personnel organization during decommissioning
- Maintenance and inspections of systems
- Safety assessment and security requirements

Furthermore the waste treatment and disposal (e.g. availability of a final repository and the corresponding repository requirements) have a huge impact on the entire decommissioning project and thus on the decommissioning costs. A decision about this aspects in due time is very important to provide a better planning reliability for the next studies.

As in any major project, a closer examination and validation of the data basis can lead to an improvement in the quality of results. For this project following key drivers have to be mentioned:

- Mass registration and documentation
- Radiological characterization (contamination as well as activation) of equipment and building surfaces
- Personnel management

Therefore, NIS recommends further efforts in these areas to achieve a more accurate input data.

NIS has more than 40 years of experience in carrying out cost estimates. NIS's expertise is based on the possibility of supporting projects over many years, updating the corresponding cost estimates and exchanging experiences with its versatile clients (see section 15.1). The experience gained within Europe is incorporated into every cost estimate of NIS and audited by several cost assessors (see section 15.2.2).

Besides the yearly estimates for all German NPPs NIS also estimates the decommissioning costs for the NPPs in:

- Belgium
- The Netherlands
- Switzerland

Therefore, NIS is certain that the present DP reflects the latest status in the field of decommissioning and dismantling of nuclear facilities and thus represents a solid basis for the subsequent decommissioning of the NPP Krško.

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## Attachment 1: Waste packaging option with using only N2d container

Due to the appliance of the General Boundary Conditions provided in the Technical Specification for the update of the NPP Krško Decommissioning Program revision 3 [5] (and in the PDP rev.6) three different options concerning the packaging of the radioactive waste have to be analysed:

(1) All decommissioning waste (100% of the mass) stored in the N2d containers
(2) All decommissioning waste (100% of the mass) stored in the RCC
(3) All decommissioning waste stored in the N2d containers and RCC, each with 50% of the mass

The main part of the present DP rev.3 covers the packaging option (3). The results for option (2) are presented in Attachment 2.

The Attachment 1 contains the results for the packaging option (1).

The necessary input data to estimate this option (1) are described in the main part of the DP rev.3, e.g.:

- Masses of components and buildings
- Radioactivity levels (activation and contamination)
- Dismantling techniques
- Decontamination techniques
- Measurement and free release techniques
- Sequence of dismantling
- Specific factors (e.g. working factors, consumable costs, wages, container costs) for the estimations with CORA & CALCOM software

Except the results of WBS project 15 “Waste processing, storage and disposal” and a very small change in the WBS project 16 “SFDS (fuel, operation, decommissioning)”, all other results including the radioactive waste masses, the costs and the sequence of work are not affected by the packaging option (1).

The WBS project contains the costs for waste treatment and the packages of the decommissioning waste. In the WBS project 16 the disposal of the activated parts of the Holtec containers is considered.

By using only the N2d container as container for the final repository the following numbers of containers and the corresponding repository volume occur.

## NPP KRŠKO number and volume of repository container (considering N2d cont.)

| Type of container: | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] |
|---|---|---|---|---|
| **Other container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| 200-l-drum | 57 | 1,137 | 0.14 | |
| Free Transport Container | 287 | 17 | | |
| TTC container | 57 | 76 | 0.15 | |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| Free Transport Container | 64 | 4 | | |
| | | | | |
| **Packaged secondary waste:** | | | | |
| 200-l-drum | 130 | 657 | 0.08 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 171 | 29 | | |
| TTC container | 23 | 18 | 0.04 | |
| | | | | |
| **Total:** | | | | |
| 200-l-drum | 187 | 1,794 | 0.22 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 523 | 49 | | |
| TTC container | 80 | 94 | 0.19 | |
| | | | | |
| **Repository container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| N2d Container | 1,999 | 242 | 2.56 | 2,970 |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| N2d Container | 744 | 75 | 0.80 | 922 |
| | | | | |
| **Packaged secondary waste:** | | | | |
| N2d Container | 507 | 93 | 0.99 | 1,142 |
| | | | | |
| **Total:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| N2d Container | 3,251 | 410 | 4.35 | 5,035 |
| | | | | |
| **Total for reposotory container:** | **3,391** | **417** | **15.25** | **5,272** |

Table A1-1: Detailed information about waste package results (N2d container)

NOTE: About 550 Mg of the packed waste mass are resulting from the SFDS decommissioning (incl. radioactive waste from the spent fuel storage containers. Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.

The packaging option (1) leads to the cost shown in the following table:

**Costs per WBS project [Million €]**

| WBS | Base case without VAT | Base case incl. VAT | Sensitivity case without VAT | Sensitivity case incl. VAT |
|---|---|---|---|---|
| 01 Pre-decommissioning actions | 3.2 | 3.7 | 3.2 | 3.7 |
| 02 Preparatory work | 31.1 | 36.8 | 31.1 | 36.8 |
| 03 Nuclear material (operational waste) | 0.0 | 0.0 | 0.0 | 0.0 |
| 04 Dismantling outside controlled area | 10.8 | 12.4 | 10.8 | 12.4 |
| 05 Dismantling controlled area | 11.2 | 12.8 | 11.2 | 12.8 |
| 06 Dismantling primary loop components | 3.4 | 4.0 | 3.4 | 4.0 |
| 07 Dismantling RPV internals | 28.6 | 34.4 | 28.6 | 34.4 |
| 08 Dismantling RPV | 17.6 | 21.3 | 17.6 | 21.3 |
| 09 Dismantling biological shield | 5.3 | 6.2 | 5.3 | 6.2 |
| 10 Dismantling remaining systems | 7.9 | 9.2 | 7.9 | 9.2 |
| 11 Clearance of building structures | 14.5 | 17.4 | 14.5 | 17.4 |
| 12 Demolition, site restoration, cleanup and landscaping | 14.6 | 17.4 | 14.6 | 17.4 |
| 13 Project management, engineering and site support | 28.9 | 30.4 | 28.9 | 30.4 |
| 14 Site security, surveillance and maintenance | 112.0 | 118.8 | 112.0 | 118.8 |
| 15 Waste processing, storage and disposal | 35.6 | 43.4 | 35.6 | 43.4 |
| 16 SFDS (fuel, operation, decommissioning) | 75.6 | 88.3 | 63.3 | 75.7 |
| 17 Local Incentives | 16.6 | 16.6 | 16.6 | 16.6 |
| **TOTAL:** | **416.8** | **473.1** | **404.6** | **460.5** |

Table A1-2: Costs per WBS project for base and sensitivity case (N2d container)

Compared to the costs given in the main part there is a decrease in the total decommissioning costs (base case without VAT) of about 0.8 Million €. The reason is the lower number of repository containers taking into account only N2d container together with their specific price.

## Attachment 2: Waste packaging option with using only RCC

Due to the appliance of the General Boundary Conditions provided in the Technical Specification for the update of the NPP Krško Decommissioning Program revision 3 [5] (and in the PDP rev.6) three different options concerning the packaging of the radioactive waste have to be analysed:

(1) All decommissioning waste (100% of the mass) stored in the N2d containers
(2) All decommissioning waste (100% of the mass) stored in the RCC
(3) All decommissioning waste stored in the N2d containers and RCC, each with 50% of the mass

The main part of the present DP rev.3 covers the packaging option (3). The results for option (1) are presented in Attachment 1.

The Attachment 2 contains the results for the packaging option (2).

The necessary input data to estimate this option (2) are described in the main part of the DP rev.3, e.g.:

- Masses of components and buildings
- Radioactivity levels (activation and contamination)
- Dismantling techniques
- Decontamination techniques
- Measurement and free release techniques
- Sequence of dismantling
- Specific factors (e.g. working factors, consumable costs, wages, container costs) for the estimations with CORA & CALCOM software

Except the results of WBS project 15 “Waste processing, storage and disposal” and a very small change in the WBS project 16 “SFDS (fuel, operation, decommissioning)”, all other results including the radioactive waste masses, the costs and the sequence of work are not affected by the packaging option (2).

The WBS project contains the costs for waste treatment and the packages of the decommissioning waste. In the WBS project 16 the disposal of the activated parts of the Holtec containers is considered.

By using only the RCC as container for the final repository the following numbers of containers and the corresponding repository volume occur.

## NPP KRŠKO number and volume of repository container (considering RCC)

| Type of container: | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] |
|---|---|---|---|---|
| **Other container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| 200-l-drum | 57 | 1,137 | 0.14 | |
| Free Transport Container | 287 | 17 | | |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| Free Transport Container | 64 | 4 | | |
| | | | | |
| **Packaged secondary waste:** | | | | |
| 200-l-drum | 130 | 657 | 0.08 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 171 | 29 | | |
| | | | | |
| **Total:** | | | | |
| 200-l-drum | 187 | 1,794 | 0.22 | |
| BigBag | 171 | 571 | | |
| Free Transport Container | 523 | 49 | | |
| | | | | |
| **Repository container:** | | | | |
| **Packaged waste from controlled area:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| RCC | 1,999 | 683 | 4.10 | 3,356 |
| | | | | |
| **Packaged waste from monitored area:** | | | | |
| RCC | 744 | 166 | 1.00 | 817 |
| | | | | |
| **Packaged secondary waste:** | | | | |
| RCC | 507 | 224 | 1.34 | 1,099 |
| | | | | |
| **Total:** | | | | |
| Packaging Holtec HI-SAFE cask | 140 | 7 | 10.90 | 237 |
| RCC | 3,251 | 1,073 | 6.44 | 5,272 |
| | | | | |
| **Total for repository container:** | **3,391** | **1,080** | **17.34** | **5,509** |

Table A2-1: Detailed information about waste package results (RCC)

NOTE: About 550 Mg of the packed waste mass are resulting from the SFDS decommissioning (incl. radioactive waste from the spent fuel storage containers). Radioactive waste from the last campaign of the SFDS decommissioning will be treated in the HLRW depository as the LILW disposal will not be reopened due to the SFDS dismantling. This means, that all decommissioning waste at the end of SFDS operation will be stored together with HLRW in the HLRW repository.

The packaging option (2) leads to the costs shown in the following table:

**Costs per WBS project [Million €]**

| WBS | Base case without VAT | Base case incl. VAT | Sensitivity case without VAT | Sensitivity case incl. VAT |
|---|---|---|---|---|
| 01 Pre-decommissioning actions | 3.2 | 3.7 | 3.2 | 3.7 |
| 02 Preparatory work | 31.1 | 36.8 | 31.1 | 36.8 |
| 03 Nuclear material (operational waste) | 0.0 | 0.0 | 0.0 | 0.0 |
| 04 Dismantling outside controlled area | 10.8 | 12.4 | 10.8 | 12.4 |
| 05 Dismantling controlled area | 11.2 | 12.8 | 11.2 | 12.8 |
| 06 Dismantling primary loop components | 3.4 | 4.0 | 3.4 | 4.0 |
| 07 Dismantling RPV internals | 28.6 | 34.4 | 28.6 | 34.4 |
| 08 Dismantling RPV | 17.6 | 21.3 | 17.6 | 21.3 |
| 09 Dismantling biological shield | 5.3 | 6.2 | 5.3 | 6.2 |
| 10 Dismantling remaining systems | 7.9 | 9.2 | 7.9 | 9.2 |
| 11 Clearance of building structures | 14.5 | 17.4 | 14.5 | 17.4 |
| 12 Demolition, site restoration, cleanup and landscaping | 14.6 | 17.4 | 14.6 | 17.4 |
| 13 Project management, engineering and site support | 28.9 | 30.4 | 28.9 | 30.4 |
| 14 Site security, surveillance and maintenance | 112.0 | 118.8 | 112.0 | 118.8 |
| 15 Waste processing, storage and disposal | 37.1 | 45.3 | 37.1 | 45.3 |
| 16 SFDS (fuel, operation, decommissioning) | 75.7 | 88.5 | 63.4 | 75.9 |
| 17 Local Incentives | 16.6 | 16.6 | 16.6 | 16.6 |
| **TOTAL:** | **418.5** | **475.1** | **406.2** | **462.6** |

Table A2-2: Costs per WBS project for base and sensitivity case (RCC)

Compared to the costs given in the main part there is an increase in the total decommissioning costs (base case without VAT) of 0.9 Million €. The reason is the higher number of repository containers taking into account only RCC together with their specific price.

# Attachment 3: Options for cementation (packaging)

The immobilization of the radioactive waste for final disposal will be done by cementation. Actually it is not finally decided, if this work will be carried out at the NPP Krško site or at the final disposal facilities in Slovenia and Croatia.

In following the costs for cementation are estimated and applied to the packaging concept presented in the NPP Krško DP rev. 3. The assumption is to package 50 % of the radioactive waste mass into N2d container and the other 50 % into RCC (Chapter 7.4.2). An optional packaging in 100 % N2d container is presented in Attachment 1 and packaging in 100 % RCC in Attachment 2. For each packaging concept the cementation (packaging) costs are estimated in case of a performance at the NPP Krško site as well as at the final disposal sites. The option with the lower costs for the 50 % N2d container and 50 % for the RCC will be selected for the waste management strategy. The decommissioning costs and the DP do not include the costs provided in this attachment as they are part of the waste disposal program [4].

*Cementation building and equipment:*

The cementation of the main part of the operational waste will be carried out from 2023 – 2025 applying to Table A4-1. At this time the Krško NPP is still in operation and consequently there is no place and capacity for a cementation facility within the existing buildings. So, an additional building has to be erected. Also at the final disposal site in Slovenia as well as in Croatia an erection of a new building has to be considered.

This new building needs a controlled area with a separate ventilation system due to the handling of open radioactive materials. Furthermore adequate manipulation space and appropriate lifting devices have to be considered. The cementation equipment itself to be installed consists of equipment well-known from non-nuclear construction technology. The main parts of the cementation facility are:

- Silo for mortar
- Mixing pump
- Hose system for backfilling

One single cementation facility per site is sufficient regarding the amount of packages to be cemented during the Krško NPP decommissioning project.

Based on the returned experiences of comparable projects 3.75 Million € costs are expected for the new cementation building and the required equipment including planning and licensing.

*Personnel:*

For the cementation of a container following work has to be done:

- Supply and removal of the container
- Handling of the mixing pump
- Backfilling
- Supervision and radiation protection

In total a team consisting of 5 persons (1 x foreman, 4 x craftsman) is considered to perform this work. Based on experiences taking into account the different dimensions of the containers following amount of work is expected:

- N2d: 6.5 Man-hour per container
- RCC: 4.5 Man-hour per container

Taking into account the qualifications and wages of staff from external Slovenian companies (see Table 15-2) the container specific personnel cost are as following:

- N2d: 95.10 € per container
- RCC: 65.84 € per container

These specific cost factors apply to the cementation on the Krško NPP site as well as on the final disposal site in Slovenia or Croatia.

*Consumables:*

The costs for consumables are determined by the costs for the required mortar. Due to the special requirements for final storage an adequate cost rate for mortar is considered with an amount of 100 € per Mg mortar.

Dependant on the chosen container and the corresponding packaging concept following cost rates are considered respecting the needed amount of mortar:

- N2d:
  - Direct packaged with radioactive waste: 1,100 € per container
    (Density of mortar = 2,200 kg/m³; filling rate waste = 20% → 80% mortar)
  - Packaged with TTC: 620 € per container
    (4 TTC per N2d container → remaining volume mortar)
  - Packaged with drums: 700 € per container
    (12 drums per N2d container→ remaining volume mortar)
- RCC:
  - Direct packaged with radioactive waste: 510 € per container
    (Density of mortar = 2,200 kg/m³; filling rate = 20% → 80% mortar)
  - Packaged with drums: 290 € per container
    (6 drums per RCC → remaining volume mortar)

These specific cost factors apply for the cementation on the Krško NPP site as well as on the final disposal site in Slovenia or Croatia.

*<u>Cost calculation for packaging 50 % of the waste mass in N2d containers and 50 % in RCC</u>*

Referring to Table 7-9 following amount of containers is taken into account:

- N2d containers packaged direct: 177
- N2d containers packaged with TTC: 12
- N2d containers packaged with drums: 16
- RCC packaged direct: 387
- RCC packaged with drums: 150

The consideration of the above defined cost factors leads to following results in case of a performance on the Krško NPP site:

- Personnel costs: 55 k€
- Consumable costs: 454 k€
- Investment for a building and equipment on the Krško NPP site: 3,750 k€

- **Total: 4,259 k€**

In case of a performance of the cementation on the Slovenian final disposal site for N2d containers and on the Croatian final disposal site for RCC the results are as follows:

- Personnel costs: 55 k€
- Consumable costs: 454 k€
- Investment for a building and equipment on the Slovenian final disposal site: 3,750 k€
- Investment for a building and equipment on the Croatian final disposal site: 3,750 k€

- **Total: 8,009 k€**

The option regarding a cementation on the Krško NPP site will be selected for the waste management strategy as it shows lower costs than the other option.

*<u>Cost calculation for packaging 100 % of the waste mass in N2d containers</u>*

Referring to Table A1-1 following amount of containers is taken into account:

- N2d containers packaged direct: 355
- N2d containers packaged with TTC: 24
- N2d containers packaged with drums: 32

The consideration of the above defined cost factors leads to following results in case of a performance on the Krško NPP site:

- Personnel costs: 39 k€
- Consumable costs: 427 k€
- Investment for a building and equipment on the Krško NPP site: 3,750 k€

- **Total: 4,216 k€**

The costs are the same in case of a cementation on the Slovenian final disposal site.

*Cost calculation for packaging 100 % of the waste mass in RCC*

Referring to Table A2-1 following amount of containers is taken into account:

- RCC packaged direct: 774
- RCC packaged with drums: 299

The consideration of the above defined cost factors leads to following results in case of a performance on the Krško NPP site:

- Personal costs: 71 k€
- Consumable costs: 481 k€
- Investment for a building and equipment on the Krško NPP site: 3,750 k€

- **Total: 4,302 k€**

The costs are the same in case of a cementation on the Croatian final disposal site.

NOTE: The complete costs of packaging without the costs for empty packages provided in Attachment 3 added with the repackaging costs provided in Attachment 4 are shown in Table A3-1. The decommissioning costs and the DP do not include these costs as they are part of the waste disposal program [4].

**Complete costs of packaging without costs for empty packages**

| **Costs [k€]** | **50% N2d container - 50% RCC** | **100% N2d container** | **100% RCC** |
|---|---|---|---|
| Investment for cementation building and equipment | 3,750 | 3,750 | 3,750 |
| Personnel costs cementation of decommissioning waste | 55 | 39 | 71 |
| Consumable costs cementation of decommissioning waste | 454 | 427 | 481 |
| Packaging costs operational waste without costs for empty packages (personnel and consumable costs) | 7,708 | 2,087 | 13,327 |
| **Total** | **11,967** | **6,303** | **17,629** |

Table A3-1: Complete costs of packaging

## Attachment 4: Disposal of "Operational waste"

The operational waste is not considered in the main part of the present DP rev.3. This is in compliance with [6] and [5]. Only to assure complete information, the disposal (incl. costs) of the operational waste is presented in this Attachment 4 of the DP rev.3.

NEK's Radioactive Waste Inventory Database shows that at the end of the year 2017 2,284 m³ of operational waste was stored in Solid Radwaste Storage Facility. Based on the waste generation prediction (NEK Radioactive Waste Management Program, TD-0C, rev. 7 and Technical Report NEK ESD-TR-03/97, rev.9, Radioactive Waste Management in NEK) 30 m³ of waste is generated per year. Taking into account normal generation of waste for the end of year 2023 2,464 m3 of operational waste is expected and for year 2043 3,064 m³ is expected.

The average packaging density of NEK's radioactive waste is 1.16 Mg/m³, and therefore the net mass of the waste in 2023 will be 2,858 Mg and 3,554 Mg at the end of 2043. The 2,858 Mg will be disposed of in the years 2023 until 2025 (80% of total mass) and the remaining 20% (696 Mg) will be disposed of in the years 2043 until 2047 (20% of total mass).

For accurate gross mass estimation, the additional weight of waste containers shall be taken into the account. Based on above data, the expected gross mass will be 6,100 Mg of operational waste in 2043.

In the WBS of the CALCOM estimate the operational waste is handled in Project 3 completely (see chapter 4.3.3.3 of the main part). All other WBS project results of the main part of DP rev.3 remain unchanged.

Three different options concerning the packaging of the operational waste have been analysed:

(1) All operational waste (100% of the mass) stored in the N2d containers
(2) All operational waste (100% of the mass) stored in the RCC
(3) All operational waste stored in the N2d containers and RCC, each with 50% of the mass

The packaging of the 6,100 Mg of operational waste lead to the following numbers of repository containers for the three options (separated into the two disposal campaigns) as shown in the following table.

**NPP KRŠKO number and volume of repository containers for "Operational waste"**

| Type of container | Total | | | | 2023 - 2025 | | | | 2043 - 2047 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] | Packed mass [Mg] | Number of packages | Cost of packages [Million €] | Repository volume [m³] |
| **Option (1): 100% N2d container** | | | | | | | | | | | | |
| N2d Container | 6,100 | 1,171 | 12.41 | 14,378 | 4,880 | 937 | 9.93 | 11,502 | 1,220 | 234 | 2.48 | 2,876 |
| **Option (2): 100% RCC** | | | | | | | | | | | | |
| RCC | 6,100 | 2,342 | 14.05 | 11,505 | 4,880 | 1,873 | 11.24 | 9,204 | 1,220 | 468 | 2.81 | 2,301 |
| **Option (3): 50% N2d container - 50% RCC** | | | | | | | | | | | | |
| N2d Container | 3,050 | 585 | 6.20 | 7,189 | 2,440 | 468 | 4.96 | 5,751 | 610 | 117 | 1.24 | 1,438 |
| RCC | 3,050 | 1,171 | 7.03 | 5,752 | 2,440 | 937 | 5.62 | 4,602 | 610 | 234 | 1.41 | 1,150 |
| **Total** | **6,100** | **1,756** | **13.23** | **12,941** | **4,880** | **1,405** | **10.58** | **10,353** | **1,220** | **351** | **2.65** | **2,588** |

Table A4-1: Detailed information about waste package results for “Operational waste”

NOTE: The costs for packages are only costs for purchasing N2d container or RCC.

It is assumed to remove the operational waste within the first 4 years after the final shutdown of the plant end of 2043. Planning activities are starting in 2043.

Therefore the disposal of the operational waste has no influence on the base case or sensitivity case.

Depending on the packaging option (see above) the cost are different. The results are given as total and yearly costs for each of the three options in the next two tables (one without VAT and one including VAT).

**Total and yearly costs for WBS project 3:**
**Nuclear material (operational waste) without VAT [Million €]**

| WBS | Sum | 2023 | 2024 | 2025 | ... | 2043 | 2044 | 2045 | 2046 | 2047 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Option (1): 100% N2d container** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **14.5** | 3.9 | 3.9 | 3.9 | ... | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| **Option (2): 100% RCC** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **27.4** | 7.3 | 7.3 | 7.3 | ... | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| **Option (3): 50% N2d container - 50% RCC** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **20.9** | 5.6 | 5.6 | 5.6 | ... | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |

Table A4-2: Yearly costs for removing “Operational waste” (without VAT)

In the costs where RCC are used, additional costs for repackaging are considered:

- Option (2): 11.2 Million €
- Option (3): 5.6 Million €

**Total and yearly costs for WBS project 3:**
**Nuclear material (operational waste) including VAT [Million €]**

| WBS | Sum | 2023 | 2024 | 2025 | ... | 2043 | 2044 | 2045 | 2046 | 2047 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Option (1): 100% N2d container** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **17.5** | 4.7 | 4.7 | 4.7 | ... | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| **Option (2): 100% RCC** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **33.2** | 8.8 | 8.8 | 8.8 | ... | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| **Option (3): 50% N2d container - 50% RCC** | | | | | | | | | | |
| 03 Nuclear material (operational waste) | **25.3** | 6.8 | 6.8 | 6.8 | ... | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table A4-3: Yearly costs for removing “Operational waste” (including VAT)

In the costs where RCC are used, additional costs for repackaging are considered:

- Option (2): 13.7 Million €
- Option (3): 6.8 Million €