Decommissioning Costs of Nuclear Power Plants – an International Overview

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Introduction

The number of nuclear power plants (NPP) to be decommissioned and dismantled will grow within the next years. **Figure 1** shows the age of the reactors worldwide in power production[1]. It indicates a coming final shut down of several units assuming operation periods between 40 and 60 years. Particularly NPP in Europe and in the United States are affected.

Owners/licensees are generally responsible for developing decommissioning cost estimates. A good understanding of decommissioning costs is fundamental for the development of cost estimates based on realistic decommissioning plans. Transparent cost estimates also provide a basis for reserving the necessary funds and further assessing the decommissioning process with the aim of ensuring that necessary funds are available when needed to cover the actual cost of decommissioning activities. [2]

An important business area of NIS is the estimation of decommissioning costs for NPP and other nuclear facilities as well as the preparation of the related decommissioning plans. The following sections provide an overview of the:

- NIS references
- Methodology for calculating the decommissioning costs
- Main figures and results for the decommissioning of selected NIS references
- Conclusion.

NIS references

Siempelkamp NIS Ingenieurgesellschaft mbH (NIS), located in Alzenau, Germany, has worked in the field of decommissioning of nuclear facilities for more than 40 years now. NIS analyses these projects from a technical as well as from an economical point of view. All gained experience is steadily included in the NIS decommissioning cost calculations to assure being up-to-date with regard to modern techniques.

Today, NIS prepares annual decommissioning cost calculations for the German NPP quite recently

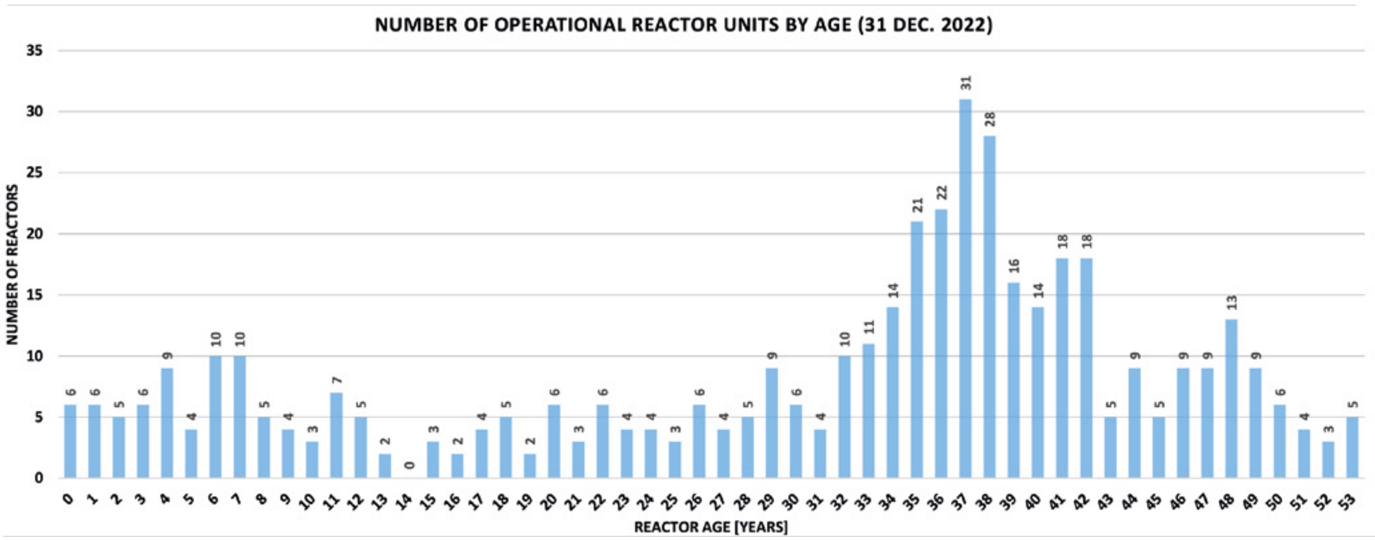

Fig. 1.
Reactor age worldwide

shut down as well as those in decommissioning. These annual expert assessments are mainly prepared for liability purposes relevant for the operators' annual financial accounting. Additionally, they are often considered for the planning and project management work.

Since the 1990s, these experiences led to several contracts in foreign European countries. For the Belgian NPP, NIS prepares decommissioning cost calculations and preliminary decommissioning plans (PDP) every 3 years. Also decommissioning studies and cost calculations for NPP in Switzerland and in the Netherlands are updated regularly every 5 years. Further decommissioning cost calculations are performed for NPP in Slovenia, Slovakia, Lithuania and France.

Additionally, NIS prepares decommissioning cost calculation and planning for several German nuclear research facilities.

Figure 2 summarizes the reference countries for NIS decommissioning cost calculations. For the current projects (dark-blue), the methodology subsequently presented is applied and they are the basis for the overview in the main figures and results for NPP.

Methodology

In general, the performance of the NIS decommissioning cost estimation relies on four steps:

1. Analysis of the masses to be considered (mass analysis)
2. Creation of a work breakdown structure (WBS)
3. Scheduling of the decommissioning project
4. Performance of the cost calculation.

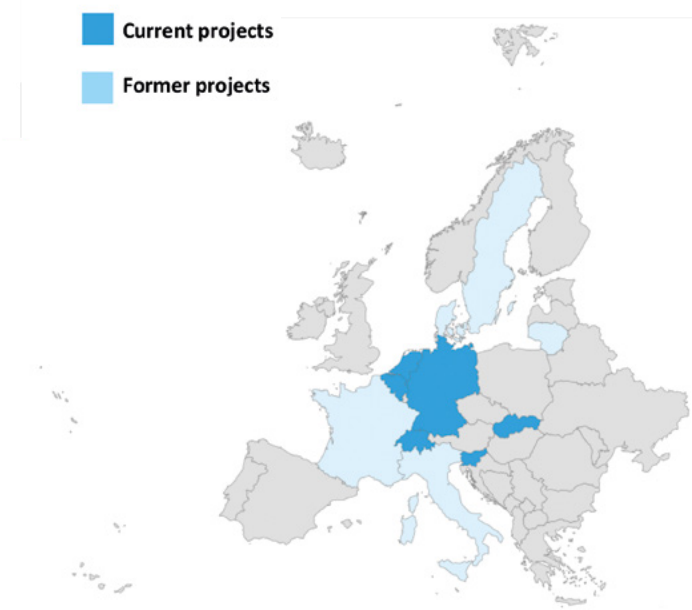

Fig. 2.
Reference countries NIS decommissioning cost calculations

At first, the inventory of the NPP is registered in the NIS database application. For each component, an adequate treatment (e.g. dismantling, cutting, decontamination, etc.) and waste disposal route (e.g. super-compaction, direct packaging, clearance measurement, etc.) is defined referring to the developed applicable waste management concept. Also, appropriate containers are chosen. At the end of the mass analysis, resulting waste amounts and disposal volumes are available. For the following planning and scheduling activities, the components are assigned to possible dismantling steps relying on systems or rooms for example.

Next, all measures and steps necessary for the decommissioning and dismantling of the NPP are identified and listed. This includes planning, licensing, preparation, nuclear dismantling, decontamination, clearance, conventional dismantling, waste processing, disposal and operation tasks. These tasks are arranged in a hierarchical WBS and customized e.g. according to the International Structure for Decommissioning Costing (ISDC) [3].

For scheduling the decommissioning project, appropriate techniques and processes are selected. By means of linking measures and steps the sequence for the whole project is set. The duration of steps is determined according to personnel requirements and capacities as well as by the chosen techniques.

Finally, the WBS as well as the time schedule are implemented in the NIS database application to perform the cost calculation. Cost factors (e.g. wages per required qualification, costs of dismantling equipment, costs for consumables, container costs, etc.) are assigned to the individual steps to calculate the costs in a bottom-up principle. The total costs, costs for each level of the WBS as well as yearly costs according to the project schedule are now available.

As NIS is involved in several current decommission projects, experience accrues and is consequently considered in each of the four steps.

The total decommissioning costs for the selected references presented in the following section are broken down in the same way to allow a meaningful comparison. They are split up in administration/operation, dismantling and waste management.

Administration/operation involves all types of activities concerned with the management of decommissioning activities, engineering, technical, safety and other relevant support, during all phases of the decommissioning project. Furthermore, the remaining site infrastructure and the

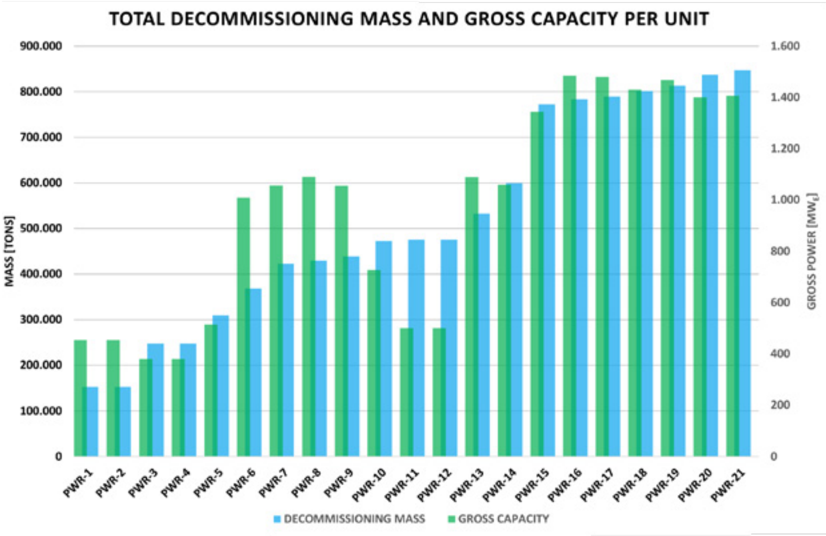

Fig. 3.
Total decommissioning masses/inventory and gross capacities

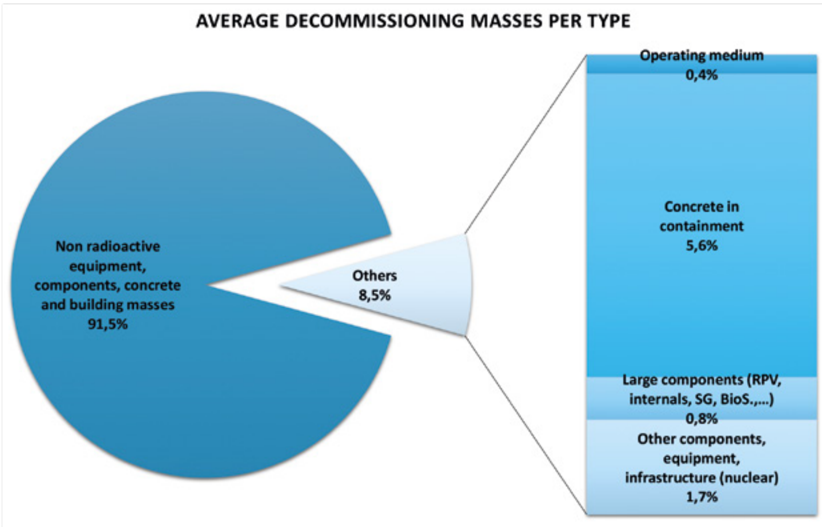

Fig. 4.
Average distribution of decommissioning masses per type

operation needs to be managed. So, the necessary measures for the retention of a safe operation of the plant and the containment of the remaining radioactivity during the decommissioning work are considered. Also includes are operation and maintenance efforts, radiological protection and health physics, security and other operational expenditures.

First of all, dismantling involves nuclear removal of the systems and structures within the controlled area, particularly procurement of equipment for decontamination and dismantling, preparation and support for dismantling, pre-dismantling decontamination, removal of materials requiring specific procedures, dismantling of main process systems, structures and components, dismantling of other systems and components, removal of contamination from building structures and the final radioactivity survey for release of buildings. Secondly, conventional dismantling of systems in premises outside of the controlled area and demolition of structures, both for buildings originally located within the controlled area and for buildings outside the controlled area is covered. The site clean-up and landscaping as well as the final survey of the site to realize "green field" status is included.

Waste management deals with all aspects of treating radioactive, hazardous and conventional waste generated during the removal activities. Beside the treatment itself, it considers conditioning for disposal, including container costs. Sometimes storage efforts are covered if regulated by law.

Main figures and results

As described previously, NIS has prepared various decommissioning cost calculations for different reactor types and nuclear facilities for decades. For a reasonable comparison, the following overview of main figures and results is evaluated from projects of PWR regarding the immediate dismantling decommissioning strategy. In total, figures and results of 21 PWR units located in 6 European countries are selected. Due to confidentiality, the plants and countries are anonymized.

Figure 3 shows the masses to be removed during decommissioning of the referenced PWR units and their gross capacities. Dependent on the size, between 150.000 and 850.000 tons are registered in the NIS database application. The greatest part is non-radioactive equipment, components, concrete and building masses.

Figure 4 provides particularly the distribution of the remaining (non-conventional) part. Especially for these components and masses, nuclear dismantling techniques are applied. Furthermore, site specific waste management concepts are developed considering the radiological evaluations, packaging and disposal policies.

Figure 5 presents the required final disposal volumes for the remaining radioactive waste of the referenced PWR units. Between 3.200 and 9.100 m^3 are estimated. Obviously, there is no clear correlation between the amount of the decommissioning mass and the resulting final disposal volume as the country-specific packaging and disposal policies

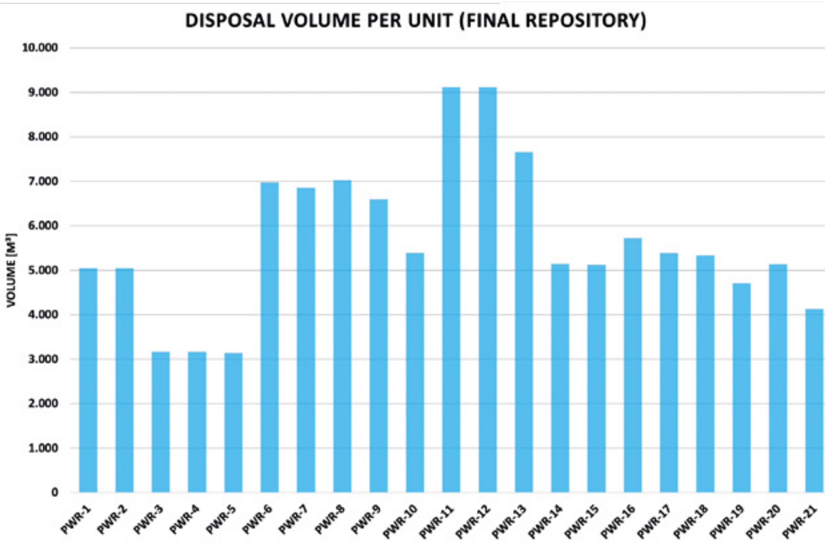

Fig. 5.
Final disposal volumes for radioactive waste

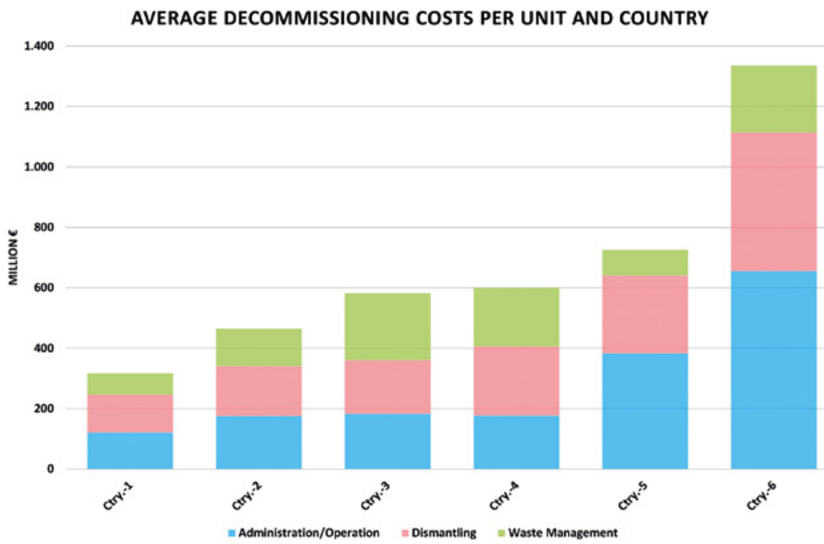

Fig. 6.
Overview decommissioning costs

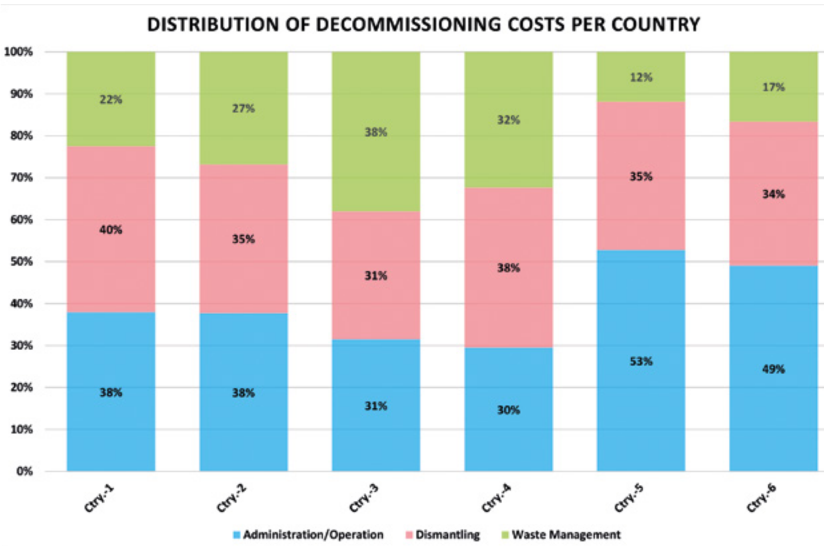

Fig. 7.
Distribution of decommissioning costs per country

are of importance in the NIS decommissioning cost calculations.

Figure 6 shows the average of the total costs per PWR unit estimated by NIS for each reference country. The total costs are split into costs for administration/operation, dismantling and waste management. There is a range of 320 to 1.340 Million € for the average in total costs. 120 – 650 Million € are determined for administration/operation, 130 – 460 Million € for dismantling and 70 – 220 Million € for waste management. **Figure** 7 provides the distribution of the total decommissioning costs by percentage for each of the 6 referenced countries. There is a range of 30 % to 53 % for administration/operation, 31 % – 40 % for dismantling and 12 % – 38 % for waste management costs.

Conclusion

The total costs for the decommissioning of the selected 21 PWR units range between 320 and 1.500 Million € per unit. Due to the strong correlation between the registered decommissioning masses and the corresponding decommissioning effort, larger PWR units consequently cause higher decommissioning costs. **Figure 6** shows the highest average costs for the country with the largest PWR units.

Some countries show significantly lower price and wage levels, accordingly leading to lower decommissioning costs. This mainly affects administration/operation, waste management and simple dismantling tasks. In particular the dismantling of the main components (e.g. reactor pressure vessel, internals) is not affected, as this work is usually carried out by specialized world-wide service suppliers. This is one reason for different ratios between dismantling and administration/operation costs as shown in **Figure** 7.

Second, there is a sensitivity of decommissioning costs regarding the project duration. Cost reductions due to optimized scheduling of the decommissioning project are mainly driven by savings in administration/operation costs, particularly during the first years after final shut down.

Obviously, it is important to avoid delays in the achievement of milestones permitting the reduction of operation support. This particularly applies to the removal of spent fuel as well as the granting of licenses to start dismantling as early as possible.

A look at countries with multi-unit sites shows lower average decommissioning costs for each single unit. The NIS decommissioning cost calculations point out cost advantages due to economies of scale. The degression of fixed costs, learning curve effects as well as capacity optimizations are considered here.

The regulation in some countries involves the intermediate storage and (partly) the final storage of the remaining radioactive waste in the decommissioning costs. This leads to a larger share of waste management costs in these countries, as shown in **Figure 7**.

Figure 8 provides an international comparison of a mass-specific decommissioning cost figure in €/ton (total costs from **Figure 6**, per decommissioning mass from **Figure 3**). It illustrates countries with significantly lower price and wage levels. Furthermore, countries where large plants as well as multi-unit site are located, show lower mass-specific decommissioning costs than countries with smaller plants and single unit sites.

Figure 9 completes the international overview with a decommissioning cost figure related to the gross capacities of the PWR in the different countries. The averages range between about 0,60 Billion €/GW_e and 1,20 Billion €/GW_e or between 0,60 €/W_e and 1,20 €/W_e alternatively noted. In conclusion, it confirms the findings on the impact of plant size, multi-unit sites as well as price and wages levels on decommissioning costs of nuclear power plants.

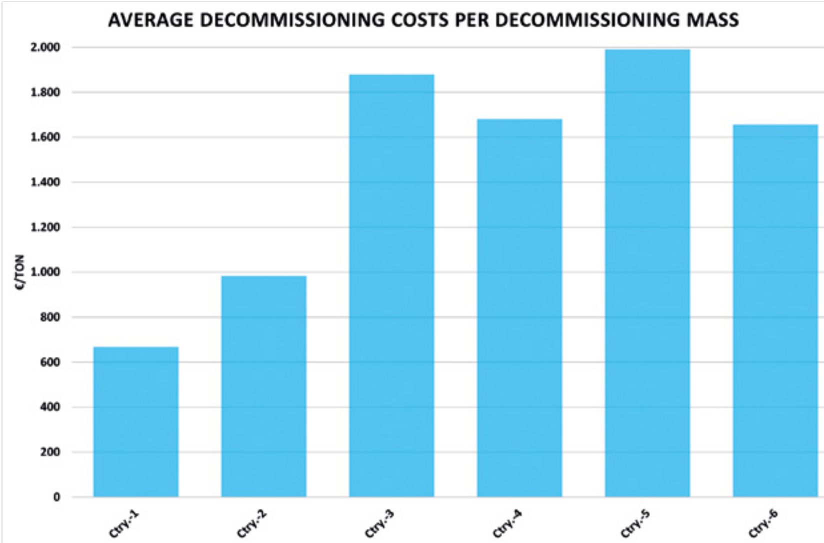

Fig. 8.
Decommissioning costs per mass

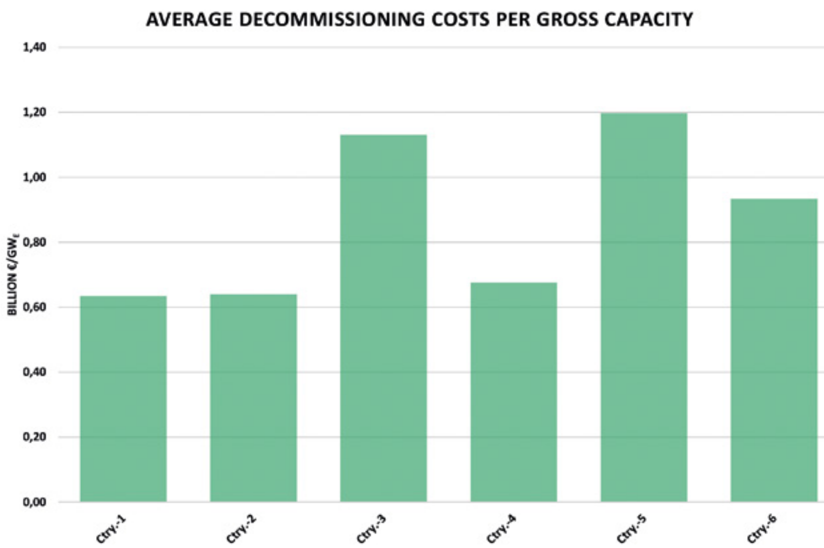

Fig. 9.
Decommissioning costs per gross capacity

References

[1] IAEA (2021): Nuclear Power Reactors in the World, IAEA reference data series No. 2, edition 2021, IAEA, Vienna.

[2] NEA (2016): Costs of Decommissioning Nuclear Power Plants, OECD, Paris.

[3] NEA (2012): International Structure for Decommissioning Costing (ISDC) of Nuclear Installations, OECD, Paris.

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Peter is an expert in nuclear decommissioning and the corresponding costs for these projects. In 2009, he started at Siempelkamp NIS located in Alzenau, Bavaria, Germany, calculating decommissioning costs for nuclear power plants and facilities in Germany. Over the years, his scope expands with the preparation of decommissioning plans and cost estimates for nuclear facilities in several European countries.