BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
10-03B (2022) 01-12

Decommissioning cost estimation considering the activities facilitation due remote-controlled equipment

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ABSTRACT

The decommissioning is a complex, costly and hazard process which should be performed in the end of the operational life of a nuclear power plant aiming to reduce the risks offered due to its operation to the environment and public at large. Several kinds of activities are required, with the decontamination and dismantling comprising some of the most important. Several tasks of these activities should be performed in places submitted to high radiation activity, increasing the exposure risks to the labors and costs since more labors and additional time are required aiming to reduce the risks. Despite of it, several of the equipment often used during the plant's operation have some automation degree, which allow to control it remotely. This technology could be used during the decommissioning, as it is done nowadays in several projects around the world. In the present work, the influence of the adoption of this technology to perform decontamination and dismantling activities would be evaluated regarding the cost reduction. A hypothetical plant would be considered as case of study, to which some idealized assumptions was made. The results demonstrates that to this limit case the cost of the project could be reduced by more than 50%, indicating the potential which the adoption of this technology could have in the project.

Keywords: **Remote-controlled, decommissioning, cost reduction, facilitation, risks.**

ISSN: 2319-0612
DOI: https://doi.org/10.15392/2319-0612.2022.1836
Submitted: 2022-01-28
Accepted: 2022-09-21

1. INTRODUCTION

The Nuclear Power Plants (NPPs) had been seen as one of most important ways to produce energy to attend the increase demand without produce large amounts of energy without the Green House Gases (GHGs) emissions [[1],[2]]. Despite of the good perception of public regarding this energy source, there is still some problems and issues to be solved. One of them is related with the end of useful life of the NPPs, when they should be decommissioned to make possible to give another new use to its site by the society and the reduce the inherent risks offered by the facility that remains even after its retirement/permanent shutdown [[3]-[7]].

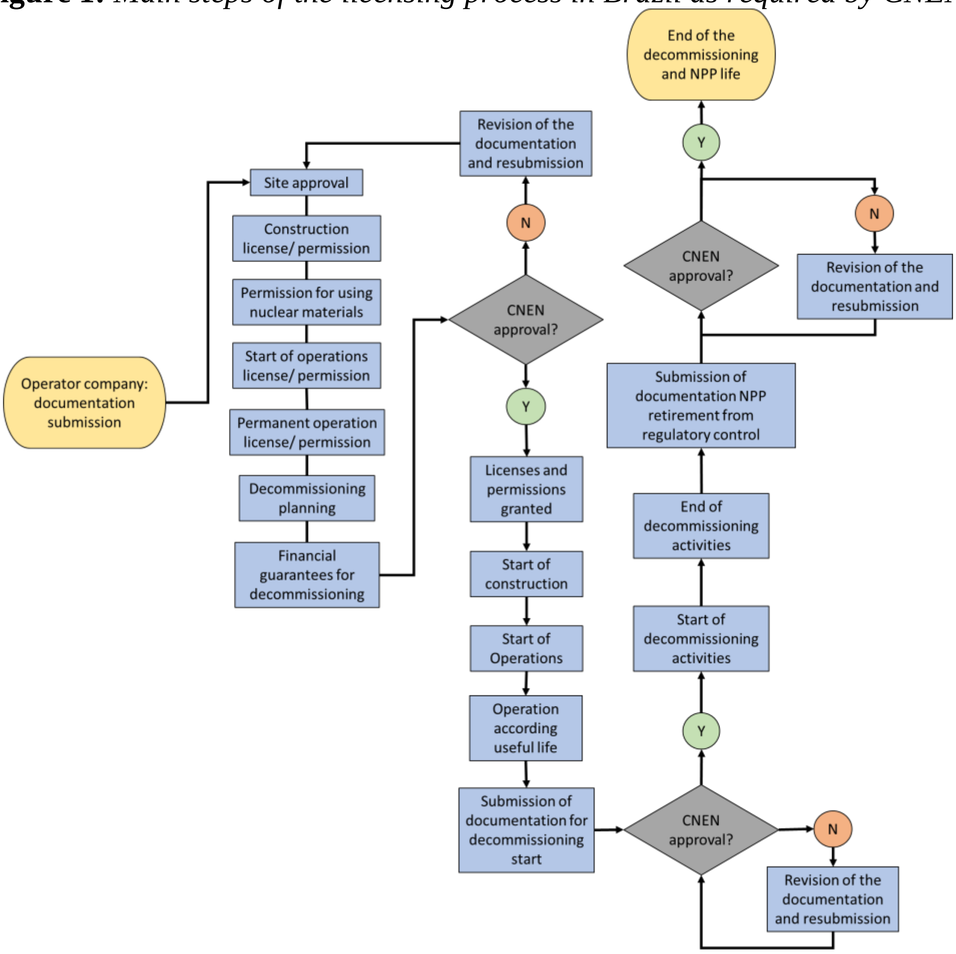
According to the resolution #133 of the CNEN, the Brazilian regulatory body, the NPPs should be decommissioned once its operational life finishes. The decommissioning is part of the licensing process to each new plant [8]. At the time when the operator company submits the documentation for approval by CNEN, the decommissioning planning, financial guarantees and other specific documentation and should be provided for evaluation together with other regular documents required in the licensing process [8]-[9]]. The decommissioning obligation was stated by the resolution #133 since 2012. For the NPPs already existent, the decommissioning documentation should be submitted to CNEN for evaluation and approval, otherwise the operation license of the plant could be terminated [8]-[9]].

The licensing process of a NPP in Brazil is ruled by the Standard CNEN NE 1.04, which is complemented by the Standard CNEN NN 9.01 [8]-[9]]. The main steps of the licensing process in Brazil, as required by CNEN, are following detailed and summarized in Figure 1 [8]-[9]]:

- The operator company requests CNEN the approval of the NPP's site, the construction license, the permissions to manage nuclear material, to start interim operation and for permanent operation. These requests include the submission of reports and documentation. The decommissioning planning, its schedule, costs and financial guarantees is part of the documentation that is submitted for evaluation;
- The CNEN would evaluate the documentation and maybe suggest amendments, that should be fully attended by the operator company for the licenses being conceded;

- Just before the NPP reach the end of its operational life, the operator company should provide to CNEN an updated version of the decommissioning planning and other related documentation for evaluation. Once the documentation is approved, the decommissioning could be started. At that time, the NPP's license would be changed from a nuclear facility to a contaminated/activated industrial facility, removing it from the regulatory control and safeguards. This new license terminates only after the decommissioning being finished, after a new round of documentation evaluation.

Figure 1: *Main steps of the licensing process in Brazil as required by CNEN.*



The decommissioning of a NPP is a long-term and costly process, requiring a very stringent planning and execution chronogram, not only to reduce the duration of process and the costs involved as well as the risks offered during the activities performing [[5]-[7]]. To overcome these issues, the use of automatic/autonomous and remote-controlled equipment is interesting. As has been done in several projects, robots and remote-controlled arms/vehicles could be used to perform some tasks in a hazard environment during maintenance and survey activities as well as to perform decontamination and dismantling tasks during the decommissioning or after accidents. The employment of such kind of equipment contributes to reduce the risks, project duration and its costs [7].

Despite of the inherent advantages, some challenges faced since the beginning of the nuclear industry still lacks a solution. Examples includes limitations of operating the equipment for long periods in locals with high radiation fields, improvements in reliability and safety, additional degrees of freedom, etc. These limitations were exposed during the course of the Fukushima accident, when a prompt response was expected but there was no suitable technology available [[10][18]].

The limitations exposed by the Fukushima accident are now gradually being overcoming with new developments to make the equipment more resistant to high radiation fields as well as to make possible to control them remotely, safely and with reliability [[10]-[12], [14], [16]-[18]]. The new generation of equipment is being designed to perform survey, monitoring, decontamination and dismantling activities in NPPs, embedding cybersecurity features. As consequence, they are more resistant to a cyber-attack that could lead to an unauthorized operation (equipment hacking) or a failure during its use [[16]-[18]]. In the past the projects were adapted to make possible to control them remotely, an adaptation new technologies without the required care regarding cybersecurity features, giving rise to problems related to technologies incompatibility, lack of security, etc [[16]-[18]].

Despite the challenges mentioned, most part of the technology (equipment/hardware, cybersecurity technology, etc) and processes are readily available, contributing to reducing time and costs for its development, being similar to that in current use for maintenance or NPP's operation, reducing the need of training the workforce to operate them [[5]-[7], [10]-[15]].

Regarding licensing, the major challenges are related to the evaluation/approval process to allow the use of new techniques/process and equipment to perform the decommissioning activities [8]-[9]]. The long time needed gives rise to a disconnection between the documentation submitted and the state of art technology available, affecting the way in which the activities would be conducted as well as its costs [8]-[9]]. Briefly, the documentation and approved technique/process and equipment could be obsolete when the permission to start the project is conceded, and the cost estimation could become under or overestimated, affecting directly the financial guarantees and the decommissioning strategy [8]-[9]].

The decommissioning cost estimation could be performed by using several methods, some of them presented and discussed by [[5]-[7]]. However, due to the uncertainties in the beginning of the project, a more appropriate approach is to use a top-down tool or method. A top-down tool and method was developed by [[5]-[7]]. According to the approach proposed by the authors, the project is divided in few levels, which is enough to obtain a cost value with the precision required for budget or bid depending on the quality of the data used and the detail level required [[5]-[7]].

The tool developed by these authors allows to estimate the decommissioning cost according to the top-down approach and permits to include the difficulties associated to each activity and task, as need, together with the men-hour required to perform each one, their costs, workforce idleness, etc, as well as contingencies. The tool was validated by the authors considering a case of study plant, similar to the Brazilian NPP of Angra 2 in terms of size/power, type of reactor and systems arrangement [[5]].

The authors performed an evaluation of several scenarios, varying parameters such men-hour cost, difficulties, site release condition, disposal of exemption wastes in the site, etc. However, they do not address the possibility to use remote controlled equipment and the possible cost and time reduction that could be achieved during decommissioning activities execution [[5]]. To fulfill this lack, the present work aims to estimate the decommissioning cost for this same hypothetical NPP considering the use of such kind of equipment. The results would be compared with the cost estimated by [[5]], considered as a reference cost, allowing to evaluate if the use of remote-controlled equipment is interesting also from costs or only for technical and safety reasons.

2. MATERIALS AND METHODS

The use of Ger-Descom tool and Av-Descom model to perform a cost estimation requires some data such as men-hour costs and duration of each task, quantity of labors that would be necessary to perform a task and its idleness, the difficulty factors that represents the difficulties associated to the task execution and contingencies [[5]]. The values of difficulty factors and contingencies should be provided according to the method developed by the authors, which consists in a scale based on the FMEA (Failure Mode and Effect Analysis) method, largely employed for engineering purposes (design, process and services). Since the cost estimation would be performed a the hypothetical NPP, as considered by [[5]], some assumptions are required to address the objectives in the present work. These assumptions are detailed in section 2.2.

2.1. Ger-Descom tool and Av-Descom model

In this section the management tool (Ger-Descom) and its mathematical model (Av-Descom) is briefly presented. Their details could be accessed in deep in the works of [[5]-[7]].

The Ger-Descom tool is a management tool with 2 modules: one module dedicated to evaluating an existent decommissioning strategy or aid a manager to propose a new one and a second module to perform the cost estimation. This second module includes the mathematical model Av-Descom. Since in the present work the strategy is already defined (the same considered by [5]), only the second module would be addressed.

The Av-Descom model estimates the decommissioning cost by summing the cost to decommissioning each plant at the site. In case of a standalone plant, the total and the NPP's cost are equal. On the other hand, the decommissioning cost of each plant is obtained by summing the cost of the decommissioning activities. The Av-Descom model considers 6 activity's classes, namely: planning, preparations to permanent shutdown, SAFSTOR period, decontamination and dismantling (D&D), remediation and waste management. These activities are divided in additional two levels, which one having with tasks and subtasks. The activities costs are related to: the difficulties to perform them, the workforce required, workforce cost and duration. The contingencies are added to these costs as a percentage, according to the method proposed by [5]. The equation (1) presents briefly the relationship among these costs. The details of each cost and how they are calculated based on the features mentioned could be accessed in deep in the works of [[5]-[7]], that presents the Av-Descom model.

$$CD_i = C_{Plan} + C_{Shut} + C_{SAF} + C_{D\&D} + C_{Rem} + C_{WasteMan} \quad (1)$$

in which C_{Plan} is the cost of the planning activities, C_{Shut} is the cost related to the preparation for the permanent shutdown, C_{SAF} is the cost of the SAFSTOR Period (when it exists), $C_{D\&D}$ is the cost of the decontamination and dismantling activities, C_{Rem} is the cost of the remediation and $C_{WasteMan}$ is the cost of the waste management (all types).

2.2. Assumptions

In this section the main assumptions considered to estimate the decommissioning cost using the Ger-Descom tool and Av-Descom model are presented. They are based on [[5]-[7]] works.

- All the labors that perform the decontamination and dismantling activities (D&D) would be substituted by remote-controlled equipment. In the present work, it was not considered that the equipment is autonomous, that is, those that does not require an external control to perform a task. Instead, it was considered the employ of equipment that still requires a human to control it. In this manner, giving the improved capacity of the equipment to perform heavy tasks or that in a high radiation field, it was considered that only half of the workers is required to perform a task. As consequence of this change, the radiation exposure risks to labors are reduced, allowing each labor to work safely for an extended period;
- The time required to perform was considered to be unchanged since each labor required to control each equipment works as usual during a working-shift. That is, even considering the improved capacity of the equipment and that the tasks could be performed quickly, there is only a half of the workers/equipment available, resulting in the same task duration [7];
- The quantity of shifts remains unchanged regarding the assumptions made by [[5],[7]] for each activity;

- The remote-controlled equipment is readily available, being similar to that used to perform maintenance and other routine tasks during the NPP's operational life. In this manner, it was considered that there would no additional costs to development of this equipment and that they are properly shielded, avoiding failures and maintenances due to the radiation fields exposure [7]. For the exceptional cases in which some development, adaptation or change in the equipment is necessary, it was considered that it could be performed by key partners, such as Universities, as part of research projects;
- Since the labors that would operate does not require any or only a basic training because the equipment is familiar, and considering that no other especial skill is required, it was considered that the men-hour cost be unchanged [7];
- The decommissioning would be performed according to the immediate dismantling approach which, according to [[5]-[7]], is the approach that presents the highest costs since the radiation field is elevated. As consequence, a higher quantity of labors is required to perform the decommissioning activities aiming to comply with the radiological safety standards and rules as well as offers a higher difficulty to perform each task (especially D&D tasks). Even considering the employ of remote-controlled equipment, the quantity of labors is still higher than that required for the deferred dismantling approach [[5]-[7]];
- The site would be released for unrestricted use after the decommissioning finishes [[5],[7]];
- There is only a NPP at the site to be decommissioned [[5],[7]].

3. RESULTS AND DISCUSSION

Considering the assumptions detailed in section 2 and the values required as inputs by the Av-Descom model, (the same as proposed by [[5],[7]]), the decommissioning cost of a standalone NPP using remote-controlled equipment was estimated. The result is presented graphically in Figure 2 as a unit cost factor. A value below unit represents a cost reduction. The reference cost (total decommissioning cost) was estimated to be US$513.4 million (or about R$2,567 million, using an exchange rate equal to US$1=R$5.00). The costs of each decommissioning activity and their contribution to the total cost is presented in Figures 3 (a) and (b) and detailed in Table 1.

Figure 2: *Unit cost factor related to decommissioning cost with remote-controlled equipment.*

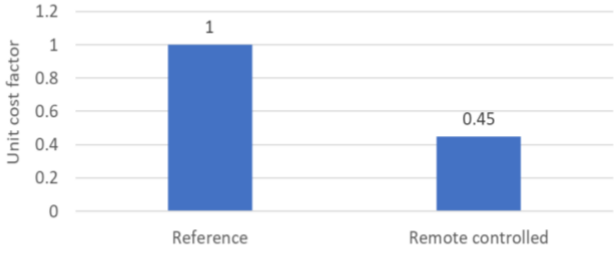
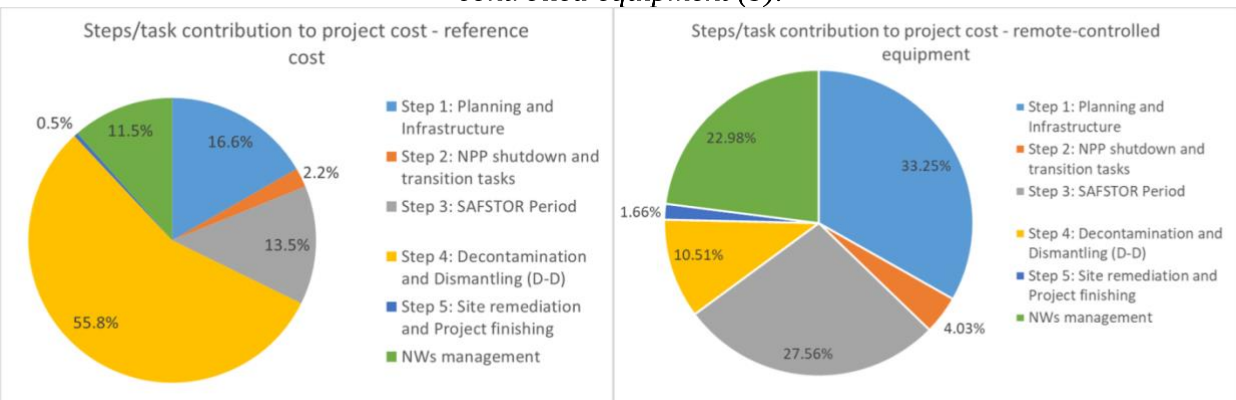


Figure 3: *Activities contribution to the decommissioning cost – reference (a) and with remote-controlled equipment (b).*



Source: of figure (a) [5],[7]

Table 1: Costs of decommissioning activities.

	Costs (millions of US$)	
Decommissioning activities	**Reference**	**Present work**
Step 1	85.4	76.7
Step 2	11.2	9.3
Step 3	69.2	63.6
Step 4	286.4	24.2
Step 5	2.3	3.8
Nuclear Waste management	58.8	53.0
Total cost	513.4	230.6

As could be observed in Figure 2 and Table 1, the decommissioning cost could be reduced to less than a half with respect to the reference cost due to the employment of remote-controlled equipment. This reduction is mainly driven by the reduction in Step 4 cost (D&D activities), despite the other activities have their costs reduced too. The exception is the Step 5, which have the costs increased due to the additional effort for preparing reports and submission to CNEN, aiming to ensure that the remote-controlled technology is reliable and safe and could perform the tasks as required.

As could be observed, the use of remote-controlled equipment makes possible to reduce the decommissioning cost to about 55% if the assumptions made are verified. This result should be understood as a best case, setting a minimum value that the cost could be reduced considering the very stringent conditions. In this manner, this result it should be understood as the potential cost reduction provided by the employment of this technology to decommissioning NPPs.

An important remark addressing this potential refers to future decommissioning projects. As pointed by [7], in future it is expected that more automated equipment would be used to perform hazards activities, having positive impacts over the health of workers, once the difficulties and challenges are overcome. Notwithstading, as the results presented, substantial cost reductions are expected once the activities could be better and quickly performed requiring a fraction of the original workforce.

Despite of the possible reduction in the workforce requirements, the use of remote-controlled technology should be viewed as an opportunity to development of new and better equipment and technologies as well as to offer a better qualification to workers to design, construct, operate and make maintenance in these machines. The employment of such technology should not be a concern related to loss of jobs.

In the view of the potential demonstrated by the results presented in this work, it is important to highlight that new research lines should be initiated aiming to develop better the technology to overcome the challenges pointed as well as to reduce its costs and let them more accessible. This could be made by the plant's operator company, nuclear industry, regulatory body and academy.

4. CONCLUSION

In the present work the cost to decommissioning a hypothetical NPP considering the use of remote-controlled equipment was estimated. The results demonstrate a good potential of the employment of this technology, since in the best case it was estimated that the cost was reduced in about 55%. The cost was estimated using the Av-Descom mathematical model, which has been used to estimate the cost of a plant similar to the Brazilian NPP Angra 2. In this manner, this work could support future projects and research aiming to introduce this technology for a future decommissioning project in Brazil.

ACKNOWLEDGMENT

The authors are thankful to Eletrobras-Eletronuclear and Universidade Federal do ABC (UFABC) for the opportunity to develop this research and participate of meetings during the Descom project as well as the people and companies that directly or indirectly contributed with insights and knownledge.

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