Predicting Process Area Workforce for Human Resource Development in a Nuclear Power Plant

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Abstract

Following the 2021 UN Climate Change Conference, there were calls to introduce alternative energy sources to mitigate global warming. The increase of alternative energy sources such as nuclear energy in developing countries like Nigeria will not only combat climate change but also provide a sustainable supply of electricity to its teeming populace. Therefore, developing and planning human resources requirements is a key cross-cutting component of the International Atomic Energy Agency (IAEA) milestones approach identified to aid the development and sustainable operation of nuclear infrastructure in existing and nuclear newcomer countries. Hence, this study extends the agency's nuclear power human resources modeling tool to model the process area requirements for newcomer countries' nuclear power plant (NPP) operation from 2015 to 2045. The results indicate that for total operation and six process areas, support training is the dominant process area (i.e., about 36%) at the end of the modeling period (2045). This bolsters the build–own–operate–transfer contract critical clause of transferring knowledge to the domestic nation. On the other hand, configuration management (approximately 6.37%) is the least considered process area because of the people required to maintain computer systems, servers, and software. Alternatively, when the process area is delineated according to the professional workforce and technical workforce contribution, professionals should contribute 2.67 times the number of technicians in the operations process area in 2045. Such results are expected to provide a holistic perspective of workforce needs during policy and decision-making processes.

Keywords: system dynamics modeling; nuclear power plants; workforce planning; operation

1. Introduction

Setting good energy priorities and the requisite policy that allows the combination of one or more energy sources in countries with energy resource challenges can help meet the challenges of growing economic demands. However, these priorities must include adequate workforce and staffing plans that help to identify a mix of experiences and competencies to implement and sustain such policies. Additionally, the plans and policies must begin with an analysis of national capability and identification of roles as well as set achievable timelines to attract, recruit, and retain a high-quality workforce. To meet these growing energy demands, Nigeria and many similar countries are now considering acquiring or expanding peaceful nuclear power applications. Unfortunately, the growing demand for professional and technical workers is expected to double by 2040 [1]. At the same time, mitigating the effects of an existential challenge of climate crisis [2] must be accomplished. Notwithstanding the surge in the deployment of renewables to resolve these energy and climate challenges, global carbon dioxide (CO_2) emissions increased by about 0.9% in 2022, which translates to an addition of 321 Mt CO_{2eq} and raises global emissions to an all-time high record of 36.8 Gt CO_{2eq} [3]. To mitigate both challenges and follow Article 4 of the Paris Agreement [4], activating an ambitious energy transition [5] from fossil-generated energy, which is one of the major sources of carbon emissions, is inevitable. Intrinsically, nuclear energy generation not only provides key attributes to meeting these challenges, but it also promotes emission reduction targets while playing a pivotal role in meeting some of the essential elements of the sustainable development goals as well as economic development in nuclear newcomer countries. For emerging countries considering nuclear energy generation, it is necessary to understand the country's energy needs [6] and the available labor force to support the implementation of a new form of energy generation vis-à-vis the projections for demand and supply. Nuclear newcomer countries often do not to have the expertise or required workforce to support the initial phase of construction and the operation of the plant because of the specialized set of skills needed. Conversely, developing countries are partnering with vendors, reactor-origin countries, and the IAEA to develop a critical mass workforce [7].

The IAEA has provided general recommendations on the recruitment and selection of appropriate personnel as well as the processes to establish criteria and the type of training to develop the competencies needed [8] to help countries embarking on or expanding their nuclear program prepare and to maintain qualified personnel for commissioning and safe operation of nuclear plants. In addition, the IAEA has developed an internationally accepted comprehensive phased process known as the "milestone approach" to assist countries developing nuclear power from planning to operation [6]. In the milestone approach, the agency identified the establishment of a sustainable human resource program as one of the 19 infrastructure requirements to support the program from cradle to grave of the life cycle, which must be considered in the first phase of the first milestone [6]. Nonetheless, for newcomers, the availability of the required skill set to initiate a nuclear program is a challenge; consequently, they will have to depend on the country where the technology was developed [9], or as specified by the contractual agreement between the vendor and the purchasing country [10]. Therefore, this paper enumerates the result from nuclear power human resource (NPHR) modeling for staffing requirements of a new nuclear build in seven process areas (including equipment reliability, operations, material services, support services and training, work management, configuration management, and loss prevention) for the deployment of a nuclear plant to predict the ratio of technical and nontechnical workforce contribution.

However, several methodologies and approaches have been put forward to identify current and future workforce needs to implement a new nuclear program. Although some researchers have used a statistical data approach, others have relied on expert judgement. Note, even though the IAEA has provided human resource planning guidance for countries embarking on or expanding peaceful nuclear power use, workforce planning may not be identical. Banks et al. [11] used expert judgement to evaluate human resource development in three countries in the Middle East including the United Arab Emirates, Jordan, and Turkey. The study concluded that workforce planning should be considered on an individual basis determined by the variable nature of the economic, political, and social background of each country. The overall challenges in the three countries evaluated ranged from lack of operational experience of new reactor technology being deployed, decreasing financial and political support that is impacting the existing technical community's buy-in on project, contractual model (finance, build, own, and operate), and general lack of experience to position newcomer as an "intelligent customer" [11].

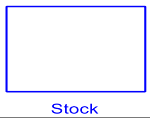
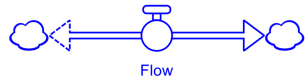
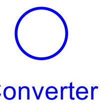
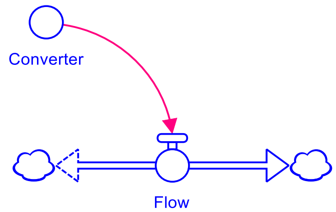
A recent study by Egieya et al. [2] analyzed the anticipated workforce requirements for the life cycle of an NPP following the IAEA milestone approach using the IAEA's NPHR to model workforce requirement as well as personnel size in three process areas: owner/operator, regulators, and construction workers for 30 years. The authors projected that during the early phase of NPP human resource planning, 73% of the total workforce will be construction workers, most of whom are sourced locally at the beginning of construction. Firoz et al. [7] urged that workforce planning for newcomer countries should begin by conducting long-term feasibility studies and benchmarking [7] the available skills set from relevant stakeholders [12] within the country. Hence, the importance of overcoming constraints of inexperience, lack of adequate data, and workforce challenges [2]. O'Brien et al. [13] advocated the use of labor market analysis and stakeholder inclusion in workforce planning due to migration and stated the challenges some developing countries faced with ever-increasing migration that may have been caused by economic challenges and lower worker compensation, producing professionals only for exports. O'Brien and colleagues proposed using mobility data could help workforce planning and modeling for new infrastructure [13]. Alternatively, owing to economic challenges and migration common within developing countries, Egieya et al. [14], analyzed the workforce needs to deploy small modular reactors and considered the technology as a solution to the contending high cost of regular NPP. The authors simulated and reported the workforce requirements for a 300 MWe integral pressurized water reactor analyzed with the upgraded IAEA NPHR from 2018 to 2055. The average annual salary payment or net present cost for the operating workers considering a discount rate of 10% and standard deviation of 8% will amount to about $431 million USD [14].

Hence, past studies have failed to highlight the domestic operating workforce requirement based on education level (professional, technicians, and craft). This study highlights the education level workforce requirement delineated by professional, technician, and craft workers over a modeling period of 30 years (2015–2045). However, subsequent sections include the methodology, case study results and discussion, and conclusion with possible future research for workforce development of a new nuclear build is also enumerated.

2. Methodology

The methodology builds on the works of Egieya et al. [2] [14], who employed the IAEA NPHR tool built on a system dynamic modeling approach using Stella Architect to assess the workforce requirements for a newcomer nation's nuclear power program. A detailed description of the NPHR modeling tool is presented in the methodology section of Egieya et al. [2]. However, the NPHR modeling tool uses the IAEA milestone approach to extrapolate critical workforce requirements at each stage of the NPP life cycle (see Figure 1). It also allows for the assessment of staffing models for important NPP contributors such as Nuclear Energy Program Implementing Organization (NEPIO), regulatory bodies, owner/operators, and construction contractors. The NPHR model is uniquely designed to evaluate a country's education and training strategies while considering related industries that may compete or supply the necessary workforce. The owner/operator workforce is the focus of this study, which is based on seven process skill areas (see Section 1). The operation workforce modeled in the life cycle represented in Figure 1 encompasses workers needed from when the nuclear reactors are completed (Site 1 Completed reactors) until the shutdown of reactors (Site 1 Shut Down Reactors). Furthermore, the systems dynamics modeling approach in which the NPHR tool is built consists of stock and flow diagrams (see Table 1) that show the accumulation and transition of the workforce over a specified period.

Table 1: Key elements of stock and flow diagrams (Egieya et al. [14])

Component	Description	Component	Description
	Stocks represent accumulation in a system.		Flow(s) facilitate the movement of materials both into and out of stocks.
	Converter(s) represent parameters, equations, and constants that can significantly influence the rates of material flow within a system.		Connector(s) are the red line(s) used to signify the relationship between components in stock and flow diagrams.

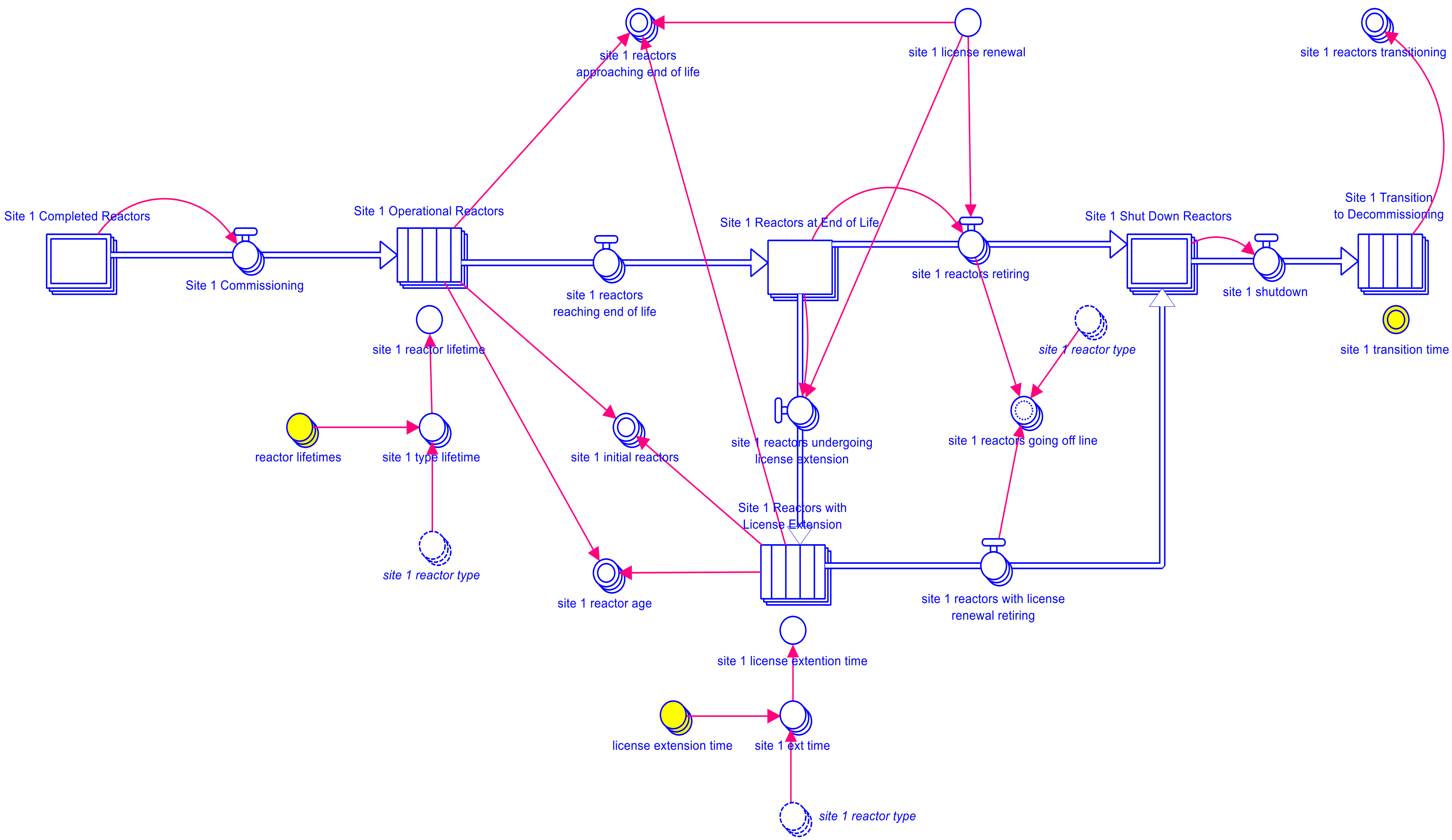


Figure 1: Life cycle of NPPs [14].

3. Case study Results and Discussion

Within the past decade, Nigeria has been working to introduce NPPs into its energy mix over a 10 year time frame from 2027 to 2037 using the conventional 1,000 MWe pressurized water reactor technology (see Table 2). However, as stated in Section 1, a key constraint to the sustainable implementation of this program is the workforce planning to operate these nuclear plants even with a contractual agreement. This section highlights the workforce requirements planned for the domestic country (i.e., Nigeria) concerning the NPP seven process skill areas. Furthermore, the operation process area is split into its four functional areas to assess the level of effort required. The section ends with a brief discussion about the level of education needed to effectively fill the process skill areas according to professionals, technicians, and craft.

Table 2: Model key assumptions (Egieya et al. [2])

Item	Description/Quantity
Industrial objective	Electricity generation
Reactor technology	Light water reactors (pressurized water reactors)
Unit size	1,000 Mwe
Unit construction period	6.5 years
Construction licensing period	3.5 years
Start-up years for NPPs	2027, 2030, 2033, 2037
Potential ownership model	Vendor/owner operator
Potential contractual model	Build–own–operate–transfer (5 years delay and 10 years transition time)

Figure 2 illustrates the trend of workforce requirements for the domestic workforce from 2015 to 2045. This figure shows a steady increase in personnel needed to cater to the NPPs being introduced to a total of about 2,271 personnel with a 10% standard deviation. Furthermore, Figure 2 shows a slight dip in the rise of workforce requirements that may be attributed to the total of 15 years of transition time assumed (incorporated into the model) for the complete transfer of the NPP operation from the vendor to the domestic workers. On one hand, a more in-depth look at Figure 2 shows that at the end of the modeling period, the support services and training process area is the dominant process area accounting for just more than 30% (i.e., about 700 personnel) of the workforce because of the consistent need to train and retrain staff working in the nuclear industry. Alternatively, the operations process area suggests a contribution of about 12% of the workforce representing on-shift staff responsible for primary, secondary and liquid radioactive waste systems [9]. However, a further assessment of Figure 2 shows that the material services process area is the smallest contributor (i.e., 2.6%) to the total workforce requirements at the end of the modeling period. The low number of personnel in the material services process area may be attributed to the composition of workers involved in the process area including inventory control managers, procurement personnel, and warehouse managers. Only a few of these personnel are required for the sustained continuous operation of the power plants.

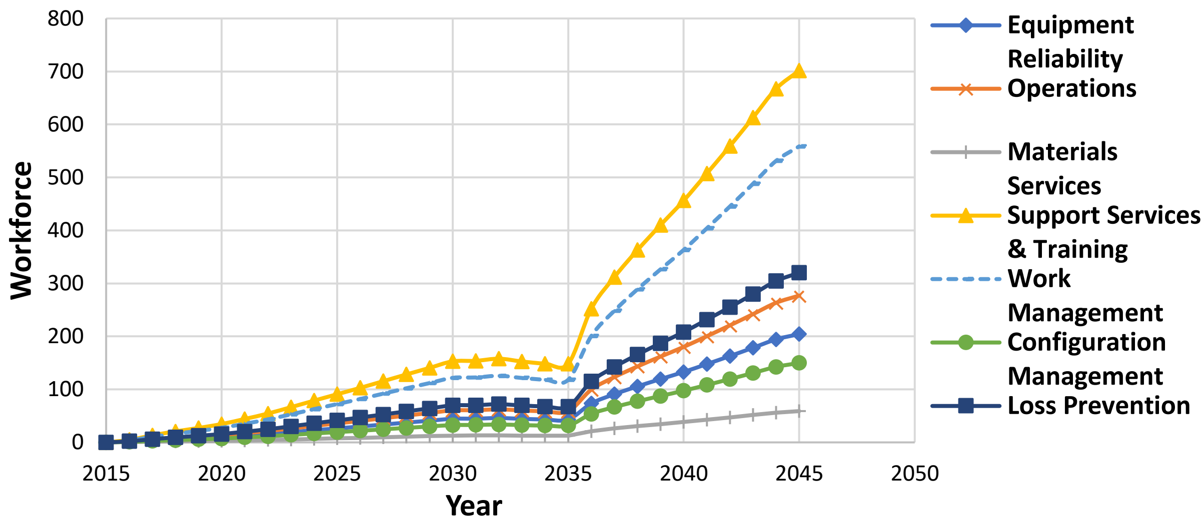


Figure 2: Workforce process skill areas over the modeling period.

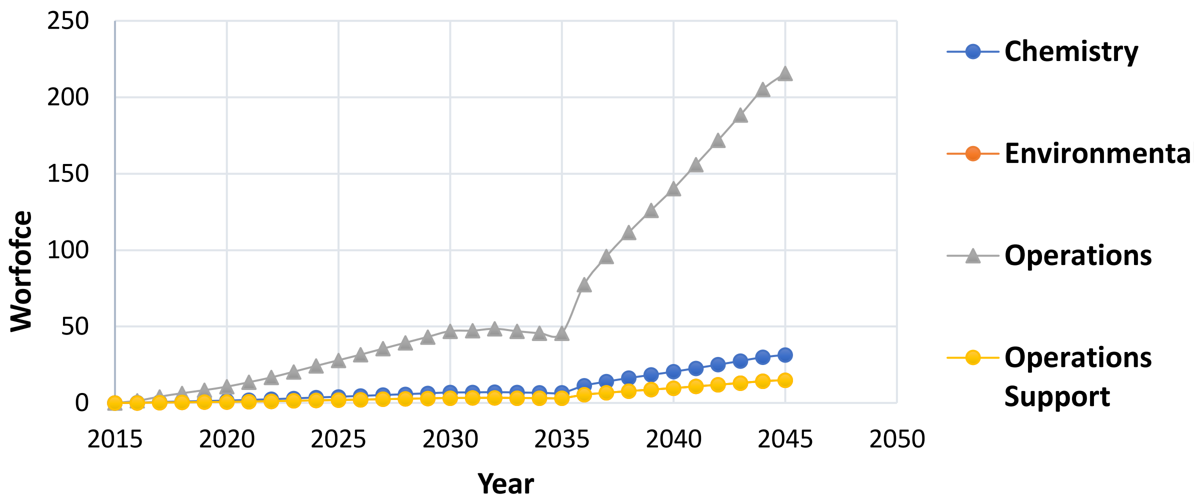


Figure 3: Operation workforce skill areas over the modeling period.

On the other hand, Figure 3 illustrates the situation whereby the "operate the plant" skill area is split into four functional areas including chemistry, environmental, operations, and operations support. The results portray the dominance of the operations functional area with a contribution of just over three-quarters of personnel (slightly more than 200 personnel) at the end of the modeling period. The dominance of the operations functional area may be due to the need for personnel to continuously operate, monitor, and supervise the primary, secondary, and liquid radioactive waste systems. The other functional areas include chemistry, operations support, and environmental contribute about 11.34%, 5.39%, and 5.39%, respectively, to the total number of personnel in the plant operations functional area at the end of the modeling period.

Finally, Figure 4 displays the trend for recruitment of domestic workers over time for the sustained operation of nuclear plants. It is evident that professional degree holders with more than 4 years of education are dominant at the end of the modeling period and should be recruited about at a level of three times more than the technician diploma/degree holders. Alternatively, the need for professionals at the end of the modeling period should account for at least 45% of the total operation workforce, whereas craft and technician roles should each contribute about 40% and 15%, respectively, to the total domestic workforce recruitment drive.

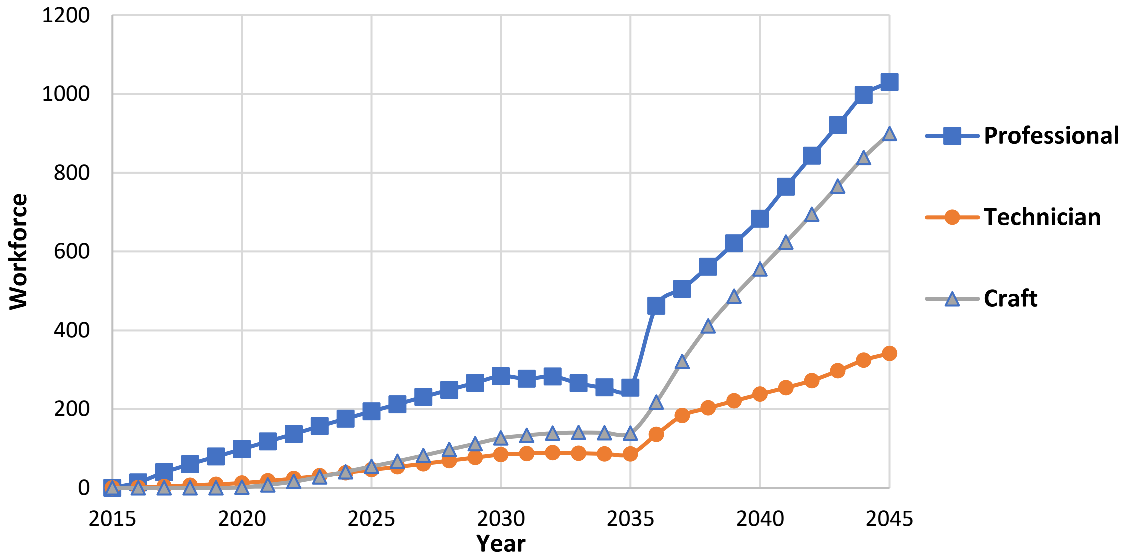


Figure 4: Domestic workforce delineation by education level attained.

4. Conclusion

This paper outlines a practical method for determining the workforce requirements in seven process skill areas for a planned NPP. To estimate the domestic workforce trends for Nigeria, a typical newcomer country that is developing and planning its human resources for a peaceful nuclear program, the authors utilized the IAEA milestone approach and the NPHR modeling tool. The NPHR model was used to project the process area requirements for workforce planning over a 25 year span (2015–2040) for a conventional 1,000 MWe pressurized water reactor technology and the build–own–operate–transfer contractual model. Based on the results obtained, the NPHR tool predicted that about 2,271 personnel would be required for introducing the NPP, with a standard deviation of 10%. Additionally, the support training personnel requirement was the most critical process area, accounting for 36% (i.e., approximately 700 personnel) because of the need for knowledge transfer and personnel training and retraining. On the other hand, the material services process area contributed the least at 2.6% from its limited role in NPP operations. The model also predicted the recruitment trend for domestic workers over time to sustain the nuclear plant operation, stratified by educational level. The results indicated that professionals with a 4 year degree would account for 45%, and craft and technician workers would represent 40% and 15% of the total operational workforce, respectively. The NPHR tool provided a comprehensive perspective on workforce needs during policy and decision-making processes for a typical newcomer country, simulating both the process area and educational level requirements.

Acknowledgements

Our gratitude goes to Kris Kern, formerly with the IAEA and now at Los Alamos National Laboratory, for providing us with the training platform and guidance on using the NPHR modeling tool. We would like to express our special thanks to Prof. Neill Goosen for his valuable input in conceptualizing the preliminary data used in the model. Furthermore, we extend our appreciation to the Stellenbosch University Strategic Fund (cost point B915A) and Water Research Commission project (CP-11892). This work was supported by the US Department of Energy under contract DE-AC05-00OR22725 with UT-Battelle LLC.

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