What makes a competent nuclear engineer?

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Ms. Tina Baradaran is a physicist, higher education educator and a PhD candidate in Nuclear Engineering Education at the University of New South Wales (UNSW), Australia. Collaborating with the Australian Nuclear Science and Technology Organization (ANSTO), Tina explores the core competencies, essential knowledge, and skills and attributes needed in nuclear engineering and the role of on-the-job training in developing these competencies. As one of the pioneering PhD scholars in engineering education at UNSW Engineering, this research aims to create and implement a competency framework for nuclear engineering to guide university programs, leading to the development of a highly skilled and competent nuclear engineering workforce. Ms. Tina Baradaran also demonstrates strong commitment to teaching and encouraging young women to pursue STEM careers. She is dedicated to advancing the field of Nuclear Engineering through her research in education, while also communicating the immense benefits of nuclear science and technology to various audiences.

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ABSTRACT

Nuclear engineering in Australia is entering a period of growth, prompting several universities to consider new educational programs. There is a pressing need for guidance on the necessary training to upskill the existing workforce to meet the demands of this emerging sector. This research collects data from Position Descriptions (PDs) at the Australian Nuclear Science and Technology Organisation (ANSTO), to identify core competencies in terms of Knowledge, Skills and Attributes (KSAs). Analysis of the PDs identifies critical knowledge and skill learning outcomes necessary for training competent nuclear engineers. This paper summarizes the core competencies required in various roles at ANSTO. The results show nuclear and non-nuclear knowledge is needed, however the skills needed are non-nuclear specific, apart from nuclear based coding skills, and attributes carry through to all tasks across various roles. This is important in design of a learning program that encompasses both nuclear and non-nuclear knowledge and skills. These insights enhance the effectiveness of training initiatives and ensure their alignment with job requirements. The findings contribute to workforce training plans by providing an understanding of the core competencies and KSAs associated with nuclear engineering roles at ANSTO.

Keywords – nuclear engineering education, competency, knowledge, skills and attributes, position description.

INTRODUCTION

The discipline of nuclear engineering was first defined by Murray (1957) in the book 'Introduction to Nuclear Engineering' at a time when no distinct field bore the prefix of *nuclear*. The term *nuclear engineering* was applied to the design, construction, testing, and operation of equipment related to nuclear processes and materials, particularly fissionable elements and their by-products (Murray, 1957). The second edition of 'Introduction to Nuclear Engineering' expanded on the definition describing it as an application of the science of nuclear physics, to the design of equipment, structures, or machinery involving nuclear processes, considering the properties of the atoms of a material must be considered as well (Murray, 1964). Similarly, Freidberg (1998) defined the core of nuclear engineering as "applied nuclear science," including nuclear physics and the interaction of ionizing radiation with matter (Freidberg, 1998). Elsevier's Dictionary of Nuclear Science and Technology defined nuclear engineering as research and development associated with the construction and practical use of nuclear reactors and their products (Clason, 1970). Furthermore, the American Nuclear Society (ANS) specifies nuclear engineering as the branch of engineering directly concerned with the release, control, and utilization of all types of energy from nuclear sources, including the design and development of systems such as fission and fusion reactors, for the controlled release of nuclear energy and the applications of radiation (Johnston, 2009).

Nuclear engineers research and develop new techniques, methods and materials for the release, control, and use of energy from nuclear reactions applicable to nuclear power production, nuclear propulsion, nuclear forensics investigation, nuclear medicine production and nuclear waste management (O*Net, 2024; US Bureau of Labor Statistics, 2022; Townsend et al., 2022). Johnston (2009) affirms that nuclear engineers require knowledge and expertise in reactor analysis and design, radiation effects analysis, shielding design, radiation utilisation, radioactive materials control and processing, and nuclear energy systems design for constructing nuclear reactors.

Australia's nuclear landscape consists of abundant uranium reserves, a well-established mining industry and a diverse nuclear workforce. Australia plays a crucial role in the global nuclear fuel supply chain, exporting up to 12% of uranium production, for use in nuclear power generation worldwide (World Nuclear Association, 2023). Australia has a skills shortage in nuclear engineering (Commonwealth of Australia, 2006) and until the recent growth of university programs, nuclear engineers have been primarily trained at the Australian Nuclear Science and Technology Organisation (ANSTO). ANSTO engages in nuclear research and development, nuclear medicine production, neutron transmutation doping of silicon and the management of nuclear waste resulting from its activities. Following the nuclear pledge made by more than 22 countries, including the US, Canada, the UK, and France, at the UN Climate Change Conference (COP28), to triple nuclear power capacity by 2050, the global demand for expertise in the nuclear industry is expected to grow exponentially over the next couple of decades (Donovan, 2023). Australia with its substantial uranium reserves, participation in the global nuclear supply chain and existing expertise in nuclear medicine and research, presents both opportunities and challenges in meeting the future workforce needs.

Learning nuclear engineering in Australia occurs either at university or through on-the-job (OTJ) training, with a significant portion of the learning taking place in the workplace (Baradaran et. al, 2023). The University of New South Wales (UNSW) offers formal qualifications in nuclear engineering, at both the postgraduate and undergraduate levels. At the postgraduate level, the Master of Engineering Science in Nuclear Engineering, established in 2013, provides graduates from engineering disciplines a pathway to pursue a career in industries including nuclear science, nuclear medicine, mining and resources, energy, manufacturing, aerospace, space exploration and defence. At the undergraduate level, a minor in Nuclear Engineering, was introduced in 2024, to allow students to integrate nuclear studies into their primary engineering discipline. The Graduate Certificate in Engineering Science with a specialization in Nuclear Engineering provides graduate engineers the opportunity to deepen their expertise in nuclear engineering at UNSW. This certificate serves as a pathway to the Graduate Diploma of Engineering Science.

Nuclear engineers need to be trained appropriately with the requisite nuclear knowledge and skills at the university level to meet future workforce demands (Baradaran et. al., 2024). While formal education at UNSW provides foundational knowledge, ANSTO is where indispensable practical experience is gained. The workplace plays a fundamental role in providing experience for engineering graduates (Baradaran et. al, 2024). Therefore, there is a need to understand what learning takes place in the workplace and the specific tasks and activities that nuclear engineers undertake within their roles at ANSTO, to uncover the core competencies and create educational programs that align with workforce needs.

Competency, in terms of Knowledge, Skill and Ability refers to the integrated application of these attributes by professionals in specific contexts to achieve high performance and meet quality standards required by their roles (Warier, 2014). Competencies are the building blocks of work performance (Warier, 2014). Hoge et al. (2005) state that the performance of most tasks requires the simultaneous or sequenced demonstration of multiple competencies (Hoge, Tondora, & Marrelli, 2005). An individual remains ‘competent’ as long as they can demonstrate their accountabilities within the workplace environment utilising the Knowledge, Skills and Abilities (KSAs) that constitute competence. Although an individual may possess the KSAs for a particular role they may still be classified as ‘not competent’ if the job description changes (Warier, 2014).

The IEEE Recommended Practice for Defining Competencies recommends a structured text methodology to create statements that are consistent and understandable (IEEE Recommended Practice for Defining Competencies, 2022). There are various models for writing structured text competency statements. The CAR model (Oliver, 2021), the STAR model (Civil Service Resourcing, 2016) and the AIR model. All three models arrange the context, action and result of the statement differently. The CAR model defines the Context first which is the circumstance, role or topic, followed by the Action (verb defining the activity) and the Result of the task. The STAR model highlights the Situation first, similar to the context, followed by the Task, Action (verb defining the activity) and the Result of the task. The AIR model defines the Action (verb defining the activity), instead of the context, followed by the Instruction (the object forming the focus of the action) and then the Result expected (outcome or utility of that activity) (IEEE Recommended Practice for Defining Competencies, 2022). Although, all three models incorporate the same basic elements, context, action and result, they differ in emphasis of the elements, which affects how a competency is assessed. The STAR model is utilised more widely, as it gives a complete story of the competency from start to finish, which makes it effective in behavioural interviews where competency assessment is based on specific and detailed examples (Doyle, 2023).

Within the literature, job analysis is considered an empirical technique for understanding the competencies required for a role (Waters et al., 2017). The analysis of job descriptions enables the identification of key knowledge, skills and competencies sought after in various roles, allowing for a comprehensive evaluation of skill mismatches or emerging trends in job expectations. The analysis of positions highlights the patterns that inform the effectiveness of training initiatives and their alignment with job requisites, thereby contributing to the enhancement of organizational performance and the formulation of tailored training strategies. This will enable a deeper understanding of jobs and positions related to nuclear engineering in the workplace, paving the way for strategic decision-making in workforce planning and talent development.

This study uncovers the key competencies, in terms of Knowledge, Skills and Attributes (KSAs) required in the workplace by analysing position descriptions (PDs) of nuclear engineers at ANSTO. The competency statements inform the development of learning objectives for training nuclear engineers. Ultimately, the goal is to bridge the gap between formal education and the practical training requirements in the workplace, ensuring that the next generation of nuclear engineers are prepared for the challenges and opportunities of a growing nuclear industry in Australia. The findings inform engineering educators, what needs to be incorporated in the nuclear engineering curriculum so that students can be trained with the core competencies to prepare them for entering the workforce.

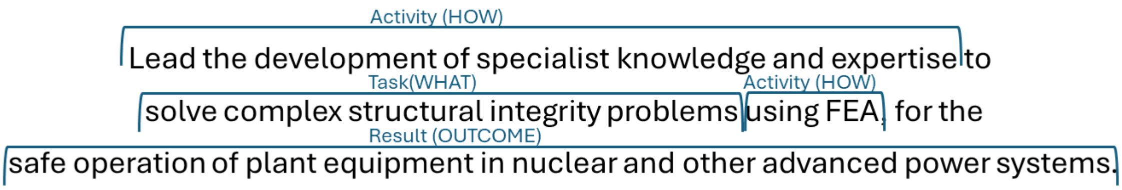
METHODS

The Position Descriptions (PDs) of nuclear engineers in the Nuclear Fuel Cycle (NFC) Group at ANSTO were analyzed utilizing the qualitative software analysis package NVivo. The 10 PDs were selected with the inclusion of a tertiary qualification requirement to establish a strict criterion for the PD selection analysis.

Through a deductive deconstruction approach the job accountabilities of the PDs were coded into Situation, Task, Activity and Result (S.T.A.R) nodes. The S.T.A.R nodes were then collated to form a competency statement. The key Knowledge, Skills and Attributes of each PD were coded separately.

The most common approach to writing competency statements in the civil service is the S.T.A.R model (Civil Service Resourcing, 2016). This model provides all the relevant information about the specific capability that the role requires. The Situation provides the title and gives the context of the role. The Task starts with an action verb and provides the information on what is being done. The Activity explains the actions that lead to the result, i.e. detailing how the task is being accomplished. The Result showcases the outcomes of the actions. The situation and the task are kept brief while the actions and the result are detailed. Figure 1. shows an example of the S.T.A.R method utilized for analyzing PD accountability.

PD Accountability:



STAR Statement:

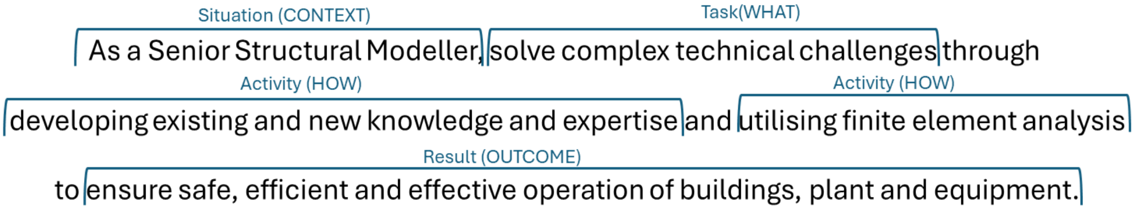


Figure 1. Position Description accountability analysis and formulation of S.T.A.R statement.

The competency statements were exported from NVivo and compared for similarity using the Levenshtein ratio, which measured the similarity between the statements based on the minimum number of single-character edits (insertions, deletions or substitutions) required to transform one statement into the other (Levenshtein, 1966). The result is a similarity coefficient between 0 (completely different) and 1 (identical). This similarity coefficient was then converted into a distance matrix (distance = 1 – similarity), which was used for the hierarchical clustering.

Hierarchical clustering analysis was performed utilising Ward's method (Ward, 1963). This method minimised the variance within clusters as the hierarchical tree (dendrogram) is built. The dendrogram visually represents the hierarchical clustering process, showing how the statements are grouped (Nielsen, 2016). The branches indicate the groups of statements that are more similar to each other based on their Levenshtein ratio (Levenshtein, 1966). The number of clusters formed is determined by setting a distance threshold i.e. drawing vertical a line through the distance axis to group the branches of the dendrogram that are most similar together. A lower threshold creates smaller, more specific clusters while a higher threshold creates more inclusive clusters. The clustering behaviour in hierarchical clustering depends on the linkage method used during the clustering process (Nielsen, 2016). The linkage method determines how the distance between clusters is calculated and how the hierarchy is constructed (Nielsen, 2016).

RESULTS

From the analysis of 10 PDs in the Nuclear Fuel Cycle (NFC) group, a total of 267 competencies were formulated. Using a dendrogram to visualise the competency similarity and by setting the distance axis threshold cutoff to 1.5, a total of 10 competency cluster areas were formed. These clusters represent the key competency areas of this group of nuclear engineers.

Table 1. shows the 10 competency clusters, the context of each cluster, the composition from the total competency statements and the number of PDs in each cluster obtained from a distance axis threshold cutoff of 1.5.

Table 1. Competency clusters and cluster context.

Cluster	Cluster Name	Cluster Context	Cluster Comp. (%) *	PDs (out of 10) **
1	Providing technical input	This cluster involves providing technical input by evaluating the accuracy and validity of results, to support informed decision making. This includes determining the accuracy and validity of results to inform reporting in the workplace.	2	3
2	Solving technical challenges	This cluster involves solving technical challenges and developing new concepts and methods by applying specialist knowledge of engineering design, plant systems and construction.	7	6
3	Managing human resources	This cluster includes coaching, mentoring, and providing professional development opportunities to enhance the knowledge, skills, and capabilities of team members. Encouraging continuous learning and personal training, whether through workplace programs or staying abreast of industry advancements, ensures the team remains competitive and innovative. Additionally, promoting staff	5	5

		professional development through training programs and expert advice helps set high standards for worker training. These efforts not only contribute to the successful delivery of research project outcomes but also ensure that valuable knowledge and expertise are captured and effectively transferred within the organization.		
4	Professional networking	This cluster focuses on establishing professional networks through fostering collaboration, building strategic national and international relationships to support research, liaising with clients, participating in professional forums, and contributing to high quality research outputs. These competencies collectively ensure effective professional networking ultimately enhancing the organisation’s reputation and impact within the nuclear and scientific communities.	8	8
5	Presenting research	This cluster centres on presenting research at conferences, through publishing in high quality refereed journals and participating in professional forums and committees, to boost organizational reputation as the premier source of expertise in the nuclear field. These competencies emphasise communication, leveraging insights from conferences and showcasing the organisation’s expertise within the nuclear and scientific communities.	4	4
6	Scientific output	This cluster focuses on leveraging publication to drive scientific output through conducting applied scientific research, initiating innovative research projects and utilising networks. These competencies highlight the importance of generating scientific output, enhancing organisation’s knowledge base, and creating intellectual property. Additionally, these competencies contribute to maximizing ANSTO’s reach within the nuclear and scientific communities, supporting innovative research initiatives, and reinforcing the organization’s status as a leader in its field.	5	9
7	Materials research and modelling	This cluster focuses on evaluating and assessing the properties and performance of materials to support decisions on remaining life assessments, in compliance with Australian and international standards. The work involves using diverse methods such as analysing material structures and components, interpreting engineering drawings and design	15	7

		information, and leveraging advanced tools like finite element analysis and modelling techniques. Together, these competencies ensure robust decision-making processes, aligning material assessments with engineering and regulatory standards to enhance reliability and safety.		
8	Evaluation of materials	This cluster contains all the tasks and activities relevant to the evaluation of nuclear materials.	5	4
9	Experimental testing	This cluster involves experimental testing to understand the structure and property relationships of structural materials. These competencies collectively support a deep understanding of material behaviour under various conditions, fostering advancements in structural materials and aligning with industry and scientific goals.	9	7
10***	Miscellaneous	This cluster contains a mixture of competencies and is the largest cluster in the dendrogram.	40	10

*Competency Composition refers to the number of competencies associated with this cluster i.e. 6/267 = 2%
**PD (out of 10) refers to the number of PDs associated with the cluster.
***10. This cluster couldn't be identified and has been labelled as miscellaneous.

Figure 2. shows competency statement tasks with conduct applied scientific research found in 25 out of 267 (9%) competency statements. Build and maintain relationships found in 21 out of 267 (8%) competency statements and produce and present high-quality research, found in 20 out of 267 (7%) competency statements.

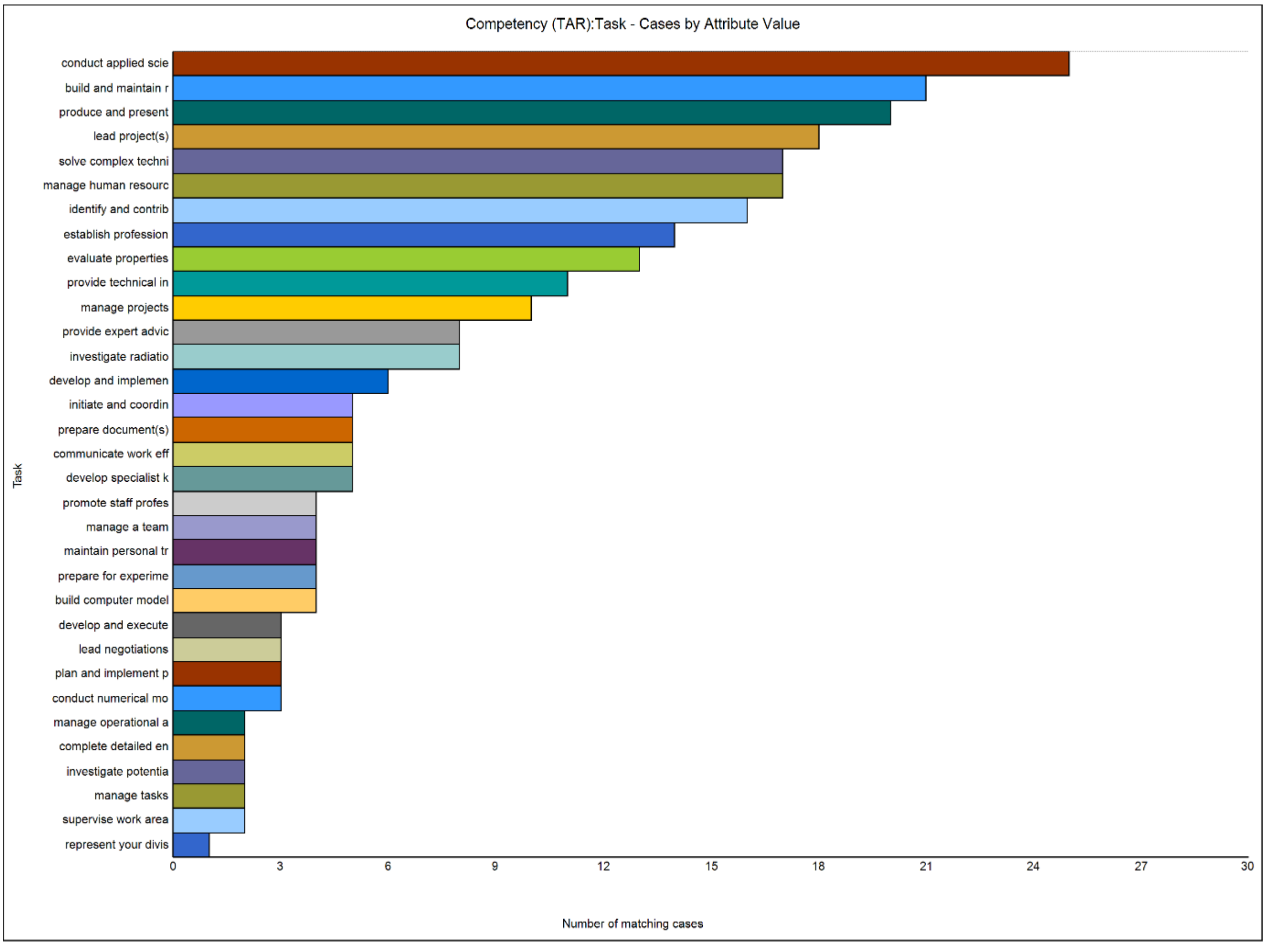


Figure 2. Tasks and the number of matching cases (competency statements).

Table 2. shows the KSAs extracted from the 10 PDs at ANSTO. The knowledge and skill areas have been separated into nuclear and non-nuclear, while the attributes are not nuclear specific.

Table 2. Key Competencies (KSAs) extracted from PDs at ANSTO.

Knowledge (nuclear/non-nuclear)	Skill (nuclear/non-nuclear)	Attribute
Nuclear:	**Nuclear:**	1. Add value to the team
1. Nuclear Industry & Governance	1. Nuclear based codes	2. Client focused
2. Nuclear Materials & Structural Performance	**Non-nuclear:**	3. Commitment to Continuous Improvement
3. Nuclear Reactor Physics & Engineering	1. Academic publishing	4. Commitment to Quality
4. Nuclear Standards & Regulations	2. Coaching and mentoring	5. Deadline driven
Non-nuclear:	3. Communication	6. Influential
1. Computational Modelling & Simulation	4. Computing	7. Motivational
2. Experimental & Analytical Techniques	5. Conflict resolution	8. Positive attitude
3. Materials Processing & Testing	6. Data analysis	9. Reliable
4. Materials Science & Characterization	7. Flexibility	10. Responsible
5. Metallurgy	8. Judgement	11. Share knowledge
6. Structural & Thermal Performance	9. Leadership	12. Take “best for ANSTO view”
	10. Listening	13. Work independently
	11. Negotiation	
	12. Organisation and prioritisation	
	13. People management	
	14. Project management	
	15. Relationship	
	16. Strategical thinking	
	17. Teamwork	

DISCUSSION

The analysis of the 10 PDs from the NFC group provided valuable insights into what makes a competent nuclear engineer in this specialised field. By applying the S.T.A.R. method to formulate competencies and performing cluster analysis, 267 individual competency statements were identified. The use of hierarchical clustering and a dendrogram to visualise the similarity between competencies, with a distance axis threshold cutoff at 1.5, enabled the formation of meaningful and manageable clusters that encapsulate the critical competency areas necessary for training competent nuclear engineers within the NFC group.

The structured clustering revealed 9 key nuclear competency clusters which include providing technical input, solving technical challenges, managing human resources, professional networking, presenting research, scientific output, material research and modelling, evaluation of materials and experimental testing. Among these, materials research and modelling emerged as the most significant competency, forming a large portion of the dendrogram (15%). These competencies closely align closely with the Engineers Australia Stage 1 Competencies (Engineers Australia, 2019), which specify knowledge and skill base, engineering application abilities, and professional skills, values and attitudes that must be demonstrated at the point of entry into professional practice. For example, Engineers Australia Competency 2: Engineering Application Ability aligns with the clusters related to providing technical input, solving technical challenges and evaluation of materials, demonstrating a clear linkage between industry practice and professional Engineers Australia competency framework.

As in most fields, nuclear engineering is multidisciplinary requiring nuclear and non-nuclear knowledge, skills and experience. Given the highly regulated nature of the nuclear industry, the results in Table 2. show that graduates must demonstrate knowledge in nuclear industry & governance, and nuclear standards & regulations. Knowledge of nuclear materials & structural performance, nuclear reactor physics & engineering, are expected from nuclear engineers in these positions, aligning well with the initial definition of nuclear engineering Murray, 1957, 1964) and the expertise expected from nuclear engineers (Johnston, 2009). Table 2. shows the skills required for nuclear engineers are non-nuclear specific, apart from nuclear based coding skills and attributes carry through to all tasks across various roles. This is important in design of a learning program that encompasses both nuclear and non-nuclear knowledge and skills.

The identified competency clusters in Table 1. and tasks in Figure 2. provide a structured foundation for designing targeted training programs and curriculum development. Each competency cluster could represent a distinct area of focus, and task alignment with a knowledge or skill would enable a tailored curriculum design that addresses specific knowledge and skills gaps. The coverage of clusters across all the PDs could guide the prioritization of training resources toward areas with the highest concentration of competencies or those that span multiple PDs. Additionally, the analysis provides a foundation for competency-based evaluations, aiding in workforce development and performance management to align individual capabilities with organizational needs.

The results from analysis of the PDs in the NFC group represent only a small portion of the organisation and further analysis of a greater number of PDs is needed to provide a complete understanding of competency requirements of nuclear engineers at ANSTO. It is also important to note that the while the PDs may provide a baseline understanding of expected qualifications, competencies and KSAs, they may not fully capture the evolving nature of engineering tasks and projects. The nature of the work conducted evolves as time and projects progress, meaning the actual tasks and activities of a practicing nuclear engineer may be different from those that were written in the position description. Additionally, the miscellaneous cluster contained a large portion of the competencies which were not able to be clustered suggesting that further analysis is needed to cluster these tasks. The size of the clusters is also unlikely to represent the proportion of time spent in each competency area, as some tasks may be more frequent but less emphasised in the PDs.

CONCLUSION

This paper summaries the 9 key competency clusters which include providing technical input, solving technical challenges, managing human resources, professional networking, presenting research, scientific output, material research and modelling, evaluation of materials and experimental testing, required for training nuclear engineers in the NFC group. The PDs show the knowledge needed can be nuclear or non-nuclear, however the skills are non-nuclear specific, apart from nuclear based coding skills and attributes carry through to all tasks across various roles. This is important in design of a learning program that encompasses both nuclear and non-nuclear knowledge and skills. Through linking the competencies to professional frameworks such as the Engineers Australia Stage 1 Competencies, the study provides a roadmap for curriculum development and workforce training initiatives. While PDs are an essential tool for identifying baseline competencies, KSA requirements and training needs, ongoing research is needed to understand the evolving nature of nuclear engineering practice. Overall, the findings contribute to strategic workforce planning and talent development by offering a comprehensive understanding of the roles and responsibilities associated with nuclear engineering in Australia.

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