Competence, education and training for nuclear merchant marine propulsion - an integrative literature review.

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Abstract

To combat global warming and climate change, requirements of emission reduction for the maritime sector have become more stringent. To achieve these emission targets for deep-sea fleets there has been a growing interest in small modular nuclear reactors (SMRs) for ship propulsion. Consequently, the maritime sector now faces fresh challenges in terms of regulations, education and training for a possible future fleet of merchant nuclear vessels. This study examines the requisite qualifications, education and training for engineering officers on nuclear-powered merchant ships. Literature on this subject is scarce since there are currently no merchant ships using SMRs as nuclear propulsion. Hence, an integrative literature review approach has been adopted as the methodology. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) does not cover manning and training for nuclear-powered merchant ships. Accordingly, this study examines the education and training of engineering officers for the early merchant experimental nuclear-powered ships as well as current US and UK Naval Nuclear Propulsion Programs. This study assesses the qualification requirements and recommendations proposed by the International Atomic Energy Agency (IAEA) for safe operation of nuclear power plants and the International Maritime Organisation (IMO) for commercial ships with nuclear propulsion. A conceptual framework is presented for an educational path combining IMO requirements with the European Nuclear Education Network certification of the European Master of Science in Nuclear Engineering. This framework aims to establish the basis for further projects concerning engineering officer competence, training and education for merchant ships employing SMRs as nuclear propulsion.

Key words:

Education and training programs, Learning outcomes, Nuclear-powered merchant ships, Engineering officers.

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List of abbreviations

Abbreviations	Full description
ABS	American Bureau of Shipping
ASN	Nuclear Safety Authority
DSA	Norwegian Radiation and Nuclear Safety Authority
ECTS	European Credit Transfer System
EMSNE	European Master of Science in nuclear Engineering
ENEN	European Nuclear Education Network
EOOW	Engineer Officer of the Watch
EU	European Union
ECTS	European Credit Transfer and Accumulation System
HTGR	High temperature helium gas cooled reactor
IAEA	International Atomic Energy Agency
IACS	International Association of Classification Societies
ILO	Intended Learning Outcome
IMO	International Maritime Organization
ISM	International Safety Management
ISQ	Initial Sea Qualification
JAERI	Japan Atomic Energy Research Institute
JNSDA	Japan Nuclear Ship Development Agency
MCA	Maritime and Coastguard Agency
MNAG	Maritime Nuclear Application Group
MSMNO	Master of Science of Maritime Nuclear operations
MSR	Molten Salt Reactor
NIRS	National Institute of Radiobiological Sciences

NISA	National Nuclear Security Administration
NNPP	Naval Nuclear Propulsion Program
NNPTC	Naval Nuclear Power Training Command
NPP	Nuclear propulsion plant
NPTU	Nuclear Power Training Unit
NRA	Nuclear Regulatory Authority
NRC	Nuclear Reactor Course
NRIC	National Reactor Innovation Centre
NS	Nuclear Ship
NSSS	Nuclear steam supply system
NUPOC	Nuclear Propulsion Officer Candidate Program
OJT	On-Job Training
ONOC	Officer Nuclear Operations Course
ONR	Office for Nuclear Regulation
U.S NRC	U.S. Nuclear Regulatory Commission
PWR	Pressurised Water Reactor
RQ	Research question
SAT	Systematic approach to training
SEMC	Systems Engineering Management Course
SMR	Small modular nuclear reactor
SOLAS	Safety of Life at Sea
SOLO	Structure of Observed Learning Outcomes
STCW	Standards of Training, Certification and Watchkeeping for Seafarers

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1 Introduction

Initiatives taken to combat climate change and stricter requirements imposed for emission reduction in the maritime sector have resulted in a growing interest in nuclear power as a means of propulsion in the merchant fleet (Emblemsvåg, 2021; Schøyen & Steger-Jensen, 2017). The UK-based maritime and technology company Core Power (Core power, 2023) promotes itself as a developer of nuclear power for the maritime segment. Core Power is collaborating with Lloyd's Register (Lloyd's Register, 2022) on a quality assurance framework for molten salt reactors for maritime applications. Further, there are several ongoing research projects concerning the use of nuclear power for the merchant fleet, inter alia, The American project, The Maritime Nuclear Application Group (MNAG) (The National Reactor Innovation Center, 2022) and the Norwegian project, Nuclear Propulsion of Merchant Ships (NuProShip) (The Research Council of Norway, 2023).

The research project, Nuclear Propulsion of Merchant Ships (NuProShip) (The Research Council of Norway, 2023), has received funding from the Research Council through the Maritim21 strategy, namely, the Norwegian government's strategic plan for research, development and innovation in the maritime industry. Part of this strategy is to facilitate relevant research projects on emission reduction in the maritime sector that fulfil agreed international emission requirements for shipping (The Research Council of Norway, 2023). NuProShip is a feasibility study for identifying Generation IV small modular nuclear reactors (SMRs) for ship propulsion that can contribute to achieving emission reduction targets in the deep-sea fleet. The current reactors assessed in the project comprise a modified version of the BREST reactor, a Molten Salt Reactor (MSR), a lead-cooled reactor and a high temperature helium gas-cooled reactor (HTGR). In addition to investigating reactor technologies, the project will examine relevant regulations, safety aspects, ship design, maintenance, operational safety, staffing and waste management (The Research Council of Norway, 2023)

According to the American Bureau of Shipping (ABS, 2018) and the Maritime Nuclear Application Group (The National Reactor Innovation Center, 2022), the regulatory framework is intricate and complex. Developers of nuclear power for merchant shipping must interpret and comply with a vast amount of different rules and regulations, both international and national. The primary international organisations concerned in this matter are The International Atomic Energy Agency (IAEA, 2023a) and International Maritime Organisation (IMO, 2023).

The IAEA’s safety guides and standards regarding qualification and training of personnel for nuclear power plants and nuclear safety present best practices and have been partly developed in collaboration with The European Union (EU) and other international and national organisations (IAEA, 2023a). National regulatory examples are the United States - U.S. Nuclear Regulatory Commission (U.S. NRC), France - Nuclear Safety Authority (ASN), Japan - Nuclear Regulatory Authority (NRA), United Kingdom - Office for Nuclear Regulation (ONR), Norway – Norwegian Radiation and Nuclear Safety Authority (DSA), of which all are members of the IAEA (IAEA, 2023a) .

Since there are significant differences between traditional diesel-powered merchant ships and nuclear-powered vessels, this implies that the existing education of seafarers is not sufficient for nuclear ships (ABS, 2018). The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) does not cover manning and training for merchant nuclear-powered ships, thus supplementary education and training for the crew of nuclear-powered vessels is absolutely necessary (ABS, 2018; Nuclear Ships, 2022; The Nuclear Code, 1981). Moreover, it must be stressed that different reactor types require different education and training (ABS, 2018; Haas, 2014). The existing rules and regulations set by IMO are mainly based on pressurised water reactor (PWR) technology (Maritime Nuclear Application Group, 2022) and most reactors in current maritime use are PWRs (ABS, 2018).

The IMO adopted Resolution A.491 (XII), Code of Safety for Nuclear Merchant Ships in 1981, but this was not implemented by any of the member states at the time (Schøyen & Steger-Jensen, 2017). However, the British government recently passed the resolution effective from 8 December 2022 (Nuclear Ships, 2022). The UK Maritime and Coastguard Agency developed the Marine Guidance Note for Nuclear Ships, MGN 679 (M), which provides guidance on the application of the Merchant Shipping (Nuclear Ships) Regulation 2022 (MGN 679 (M) Nuclear Ships 2022). Both the Code of Safety for Nuclear Merchant ships and the MGN 679 Nuclear ships provide recommendations, rules and regulations for the manning and training of crew members for nuclear-powered merchant vessels.

The International Atomic Energy Agency (IAEA, 2023a) has several publications covering the education, training and manning of traditional nuclear power plants and SMRs. Furthermore, there are international organisations working on developing higher education and training in nuclear science, technology and engineering, such as the European Nuclear

Education Network (ENEN, 2023). These policies and guidelines compiled by the UK Maritime and Coastguard Agency, IMO, IAEA and ENEN will be examined in this review.

The first naval reactor, a pressurised water reactor (PWR), was installed in the 1955 submarine USS Nautilus and is the most commonly used reactor concept in marine applications. The US shared their nuclear power technology with the United Kingdom (UK) (Lakeey;, 1988) and the Royal Navy launched their first nuclear submarine in 1962 (Carlton et al., 2011). The US Naval Nuclear Propulsion Program operates 98 reactors and has more than 7100 reactor years of experience (National Nuclear Security Administration, 2022). It is proposed that the maritime industry could learn something from the US and UK`s navies' nuclear propulsion programs with over 70 years of accident-free and safe operation of naval nuclear power, regarding operational safety as well as education and training (Maritime Nuclear Application Group, 2022).

Several nations have nuclear power as propulsion in their naval fleets, both in submarines and surface ships, viz. the US navy has 73 submarines and 11 aircraft carriers, the Russian navy has 21 submarines and 1 battle cruiser, China has 14 submarines, the British navy has 10 submarines, France has 9 submarines and 1 aircraft carrier and the Indian navy has one submarine. Further, Russia has six icebreakers in use (ABS, 2018).

There have been a few experimental merchant ships with nuclear propulsion, namely, the NS Savannah, 1962 – 1972, The German NS Otto Hahn, 1968, and the Japanese Mutsu, also a pilot project, in 1974. All three ships were pioneers in the area of non-military nuclear-powered ships and were powered by pressurized water reactors (Schøyen & Steger-Jensen, 2017).

This thesis examines the qualification requirements, education, training and competence of engineering officers for merchant ships with nuclear propulsion and the U.S. and U.K. naval nuclear propulsion programs. Since there are currently no merchant ships with nuclear propulsion, apart from some Russian icebreakers (Schøyen & Steger-Jensen, 2017), literature is scarce on the subject, hence an integrative literature review approach has been chosen as methodology (Green et al., 2006; Snyder, 2019).

By combining insights from various sources, this review can reveal whether there is sufficient knowledge to be gained by exploring the education and training of the crews of these experimental civilian ships and the contents of the US and UK Naval Nuclear

Propulsion Program. Provided the findings are beneficial, and when combined with IMO, IAEA and ENEN recommendations and regulations, this will form a solid basis for further research to be conducted on the education and training of engineering officers on merchant nuclear-powered ships.

1.1 Goal of the thesis

The goal of the study is twofold: firstly, to explore what level of competence should be acquired by engineering officers[1] on a modern merchant nuclear-powered ship, secondly, to determine how an appropriate program could be structured and executed in the future.

The objective is to create a basis for research projects concerning competence, training and education for engineering officers on nuclear-powered merchant ships. The research questions developed to achieve this goal are as follows:

1.2 Research questions (RQs):

RQ 1	What can be gained from studying current US and UK Naval Nuclear Propulsion Programs concerning education and training of engineering officers?
RQ 1.1	What rules and regulations apply to the education and training program of engineering officers on merchant nuclear-powered vessels?
RQ 1.2	What themes and elements were contained in the education and training program for engineering officers on earlier merchant nuclear-powered ships and how was the programs carried out in the past?
RQ 1.3	What should future education and training programs for engineering officers on merchant nuclear-powered ships contain and how should they be structured and executed?

[1]In this study, the terms engineering officer, marine engineering officer and engineer officer refer to the same position, namely an engineer officer qualified under the provisions of regulation III/1, III/2 or III/3 of the STCW Convention.

1.3 Limitations of the study

This study of crew competence, education and training for merchant nuclear ships applies solely to the position of engineering officers on vessels with over 3000 KW propulsion power as described in STCW (IMO, 2011). Such engineering officers must hold a higher education or university qualification, such as a BSc. degree in marine engineering. The scope of information reviewed for this study was limited to the education and training programs arranged in the UK, USA and Japan. Although Russia has extensive experience with nuclear-powered vessels (Khlopkin & Zotov, 1997; Zverev et al., 2020) it has been excluded from this study due to the language barrier and restricted publicly available information about the education and training of its seafarers. Since this is an academic review of training and education, this study does not consider the political and economic ramifications of the program.

1.4 Structure of the study

The structure of this study, apart from the introduction, consists of 6 parts. Part 2 deals with theory about quality in higher education, Part 3 presents the research method and documents the research process, Part 4 presents the findings of the literature review, while in Part 5 the findings are discussed and a conceptual framework for nuclear education is presented. Part 6 consists of the conclusion and part 7 suggests issues for further research.

2 Quality of teaching and learning in higher education.

This study concerns the education of engineering officers for the operation and maintenance of nuclear-powered vessels. Since the current officer education is often carried out by universities, it is natural to adopt the perspective of quality in higher education.

The Bologna process has led to the development of the Qualification frameworks for the European Higher Education Area and the European Qualification Framework for Lifelong Learning. The foregoing initiatives have led to the introduction of national qualification frameworks, implying that the education programs must define their learning outcomes in terms of knowledge, skills and general competence. The goals of these frameworks are to harmonize the education in Europe and ensure that academic institutions become proactive to the needs of the labor market in terms of defining learning outcomes and qualifications (Strømsø et al., 2016). These frameworks focus on preparing students for their professional careers, as well as access to quality-based higher education (Biggs & Tang, 2011).

In higher education, a qualification framework is a tool to develop existing and new study programs and document what the students have learned and what skills they have acquired through their course of study (Strømsø et al., 2016). Learning outcomes are statements and descriptions of the level of understanding and knowledge the students have achieved, as well as what they are capable of performing in terms of the qualifications defined for bachelor, master and doctoral levels in the qualification framework. This implies that teaching and learning in higher education are becoming outcome based and student orientated (Biggs & Tang, 2011).

The Bologna Follow-Up Group has updated the framework for qualifications of the European higher education area. The framework describes the bachelor and master degree programs in terms of first and second cycle learning outcomes and European Credit Transfer and Accumulation System (ECTAS). The first cycle, typically a 180 ECTS bachelor degree, describes what competences the students have acquired on completion of the program e.g. problem solving, reflection and communication skills and the ability to apply knowledge and understanding in their professional work. The second cycle, typically a 120 ECTS Master's degree, is expected to build upon the first cycle and enhance the level of skills, i.e. handle higher forms of complexity and apply problem-solving, communicative and reflective skills in unfamiliar contexts with limited information (Bologna Follow-Up Group, 2018).

The ECTS measures both the study load and learning outcomes of a course of study. Normally, one academic year is defined as 60 ECTS and is divided into several different subjects or units. One ECTS corresponds to approximately 25 to 30 hours of work based on one academic year of 1500 - 1800 hours (Bologna Follow-Up Group, 2015).

It is the desired learning objectives, not necessarily the subjects, that will govern how the education is planned and executed. The students must be assessed according to the various learning objectives and ideally, the learning itself should use the learning objectives as part of the teaching. Various skills must be developed and used in the process, inter alia, problem solving and communication skills and the ability to work in teams. It is therefore essential to produce clear learning outcomes and to teach and assess in compliance with them (Biggs & Tang, 2011).

In the context of educating for industry needs, functioning knowledge is the term used for describing knowledge where theory is used for analysing and solving problems as well as planning and designing new products. Functional knowledge differs from purely theoretical, also called declarative knowledge, which is characterised by the fact that the student can list or reproduce information in their own words, based on what is presented to them in a lecture. To stimulate the learner for real understanding which is in line with the professional needs, the examination and assessment methods should reflect the concept of functional knowledge. The methods of assessment need to be aligned with the learning outcomes that should reflect the needs of industry (Biggs & Tang, 2011).

Developing an understanding of theories and the ability to apply them in the real world constitute a gradual learning and maturing process. Thus, it is essential to define the level of understanding in relation to what is acceptable for each individual level in a degree program.

The SOLO taxonomy, i.e structure of the observed learning outcomes, is a systematic model developed to describe and determine learning outcomes and their levels, as well as to measure the level at which the student masters the intended learning outcomes. Each stage in the model incorporates the former stages, adding further concepts as the levels increase in complexity. “SOLO describes a hierarchy, where each partial construction becomes the foundation on which further learning is built” (Biggs & Tang, 2011, p. 90)

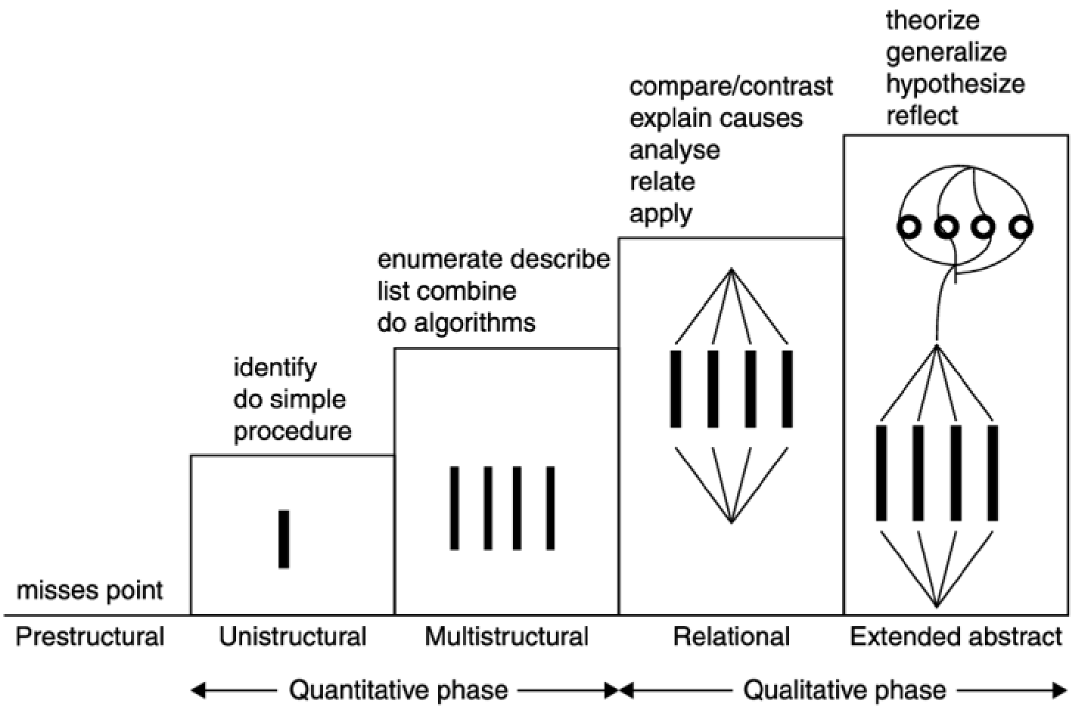

Figure 1- SOLO taxonomy in five levels

SOLO taxonomy in five levels. Adapted from (Biggs & Tang, 2011, p. 91 , Figure 5.1)

As a student accumulates knowledge, the cognitive complexity can be reflected in moving from the quantitative phase to the qualitative phase. As the qualitative level increases, so does the complexity of the learning outcomes. The SOLO taxonomy promotes the use of verbs to describe learning outcomes, different verbs are used to describe the different levels of understanding. These are verbs that the student must be able to master in practice to prove what level of knowledge they have achieved. (Biggs & Tang, 2011). The same model can be used in developing and accessing skills, i.e. students progress from being spectators of skills to being able to exercise these by themselves. This is a process that involves practicing skills with support to becoming more and more independent and finally on their own. This can culminate in the student being able to support others in obtaining the same skills. By describing learning outcomes with active verbs, the student's progression can be measured through observation of the student's behavior and ability to apply the desired skills (Strømsø et al., 2016).

The frameworks promote a methodology that it is not so much about what the teacher does, but focuses rather on what the student does. In this context, the concept of constructive alignment can contribute significantly. “Constructive, stems from the constructivist theory that learners use their own activity to construct their knowledge as interpreted through their own schemata, Alignment is a principle in curriculum theory that assessment tasks should be aligned to what is intended to be learned, as in criterion-referenced assessment." (Biggs & Tang, 2011, p. 97). In this context, the teacher's role is to enable the student to exercise the learning objectives and be assessed accordingly. It is the alignment of the intended learning outcomes (ILO) and the teaching and learning activities with the assessment tasks that stands out in constructive alignment.

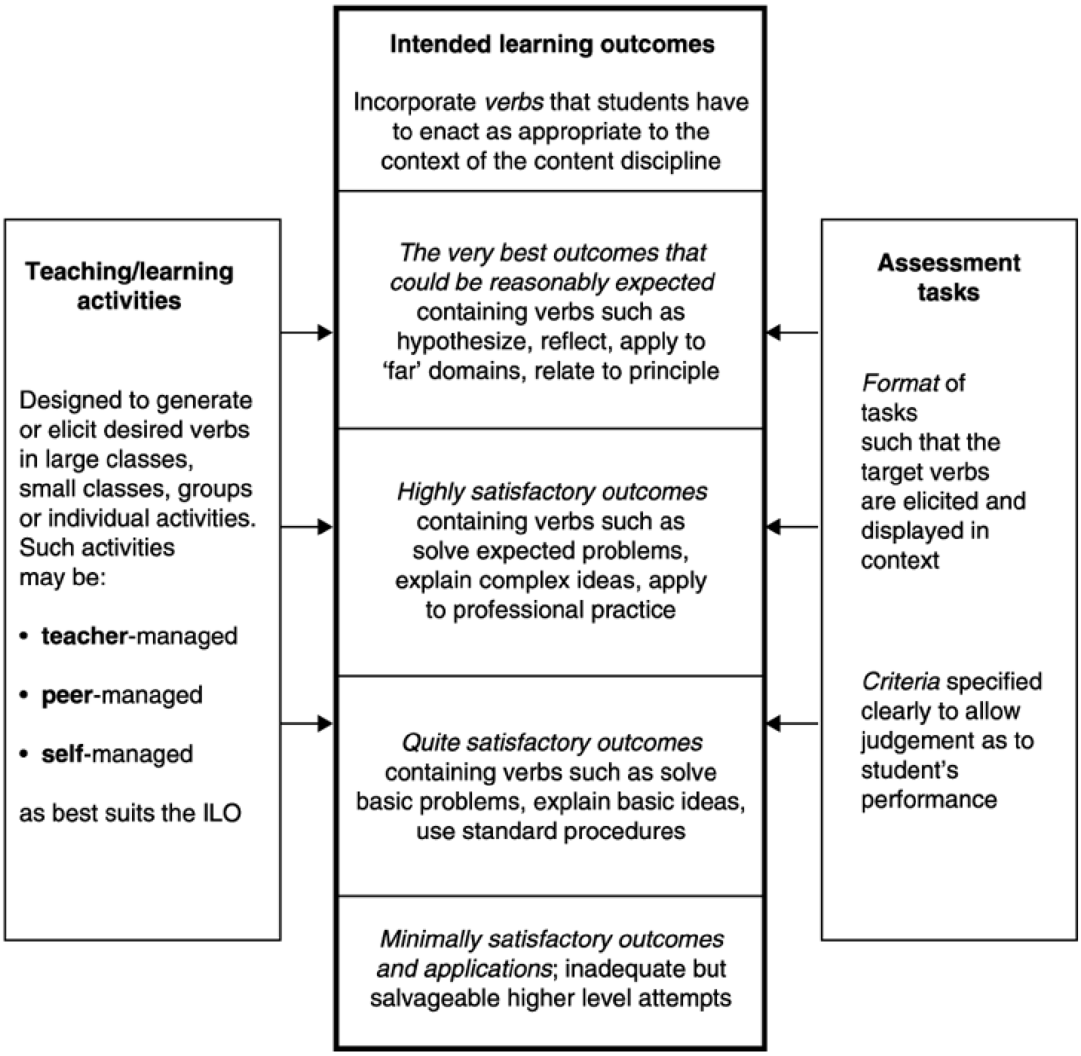

Figure 2 - Aligning intended learning outcomes, teaching and assessment tasks

Aligning intended learning outcomes, teaching and assessment tasks. Adopted from (Biggs & Tang, 2011, p. 105 , Figure 6.1)

3 Research method

Research methodology is a set of different procedures and guidelines for analysing, evaluating and observing information with the aim of uncovering facts (Maruyama & Ryan, 2014). The path to an acceptable scientific result is through the choice of the right methodology for the research being conducted (Nola & Sankey, 2006). Literature review as a methodology is a structured path to gather and analyse previous research, regardless of the type of study. The process of assessment and analysis has to be well organized in order to obtain credible and accurate results in the research being conducted (Snyder, 2019).

The integrative or narrative literature review, as a research method, aims at evaluating and extracting representative information on the subject of inquiry. The purpose is to produce new perspectives or frameworks (Torraco, 2005). The characteristics of the narrative literature review are "comprehensive narrative syntheses of previously published information" (Green et al., 2006). By searching through relevant literature, the author can synthesize the assessed information gathered into one study and provide information for stakeholders on the subject of inquiry (Green et al., 2006).

3.1 Research design and method

This study aims to review and synthesize literature on the requirements and recommendations for competence, educational level and training for the engineering officers of merchant nuclear-powered ships. Since there are currently no merchant vessels using modern small modular reactor technology as propulsion, it is not expected to find any updated information. Hence, the topic is to be considered as an emerging field of research, thus increasing the need for conducting an integrative literature review instead of the more traditional systematic literature review (Torraco, 2005). Owing to shortcomings in the scientific literature, a more creative approach is applied to supplement the findings from journal articles (Snyder, 2019) by providing relevant information from other sources, inter alia, conference papers, publications, reports, and recommendations from policymakers (Green et al., 2006).

Close attention and thorough assessment were applied when selecting the databases best suited for conducting the searches and the relevance of the search terms to the research problem. It was imperative not to limit the searches too much, so that valuable information for the research was not omitted, since this may lead to a distorted outcome of the review.

The author has striven for transparency and clear documentation of how the research has been conducted, as this is vital to the credibility of this study. To clarify various decisions made by the author, the review is explained in steps and stages. The author describes the process as it unfolds in this document, with the aim of gathering information from many sources and presenting it in one format (Green et al., 2006).

For a literature review to be successful, several criteria must be met and several questions should be answered (Snyder, 2019). The review should " be well structured, synthesize the available evidence pertaining the topic, and convey a clear message" (Green et al., 2006) When conducting the actual literature search, a strategy for the choice of databases, keywords and selection of inclusion and exclusion criteria is vital (Ferrari, 2015). Boundaries have to be set to make the study feasible, as the research is limited to time and personnel, so narrowing down is essential. Articles are browsed by reading abstracts before the final selection of inclusion, thus making the process qualitative (Green et al., 2006).

Caution has been exercised in relation to bias. Through good research methods, reduction of bias is achievable. The review must not become a proclamation of own opinions with references, as the goal is an objective presentation of the data collected. In the synthesis of the data from the literature review, it is essential that this process is transparent, clear and objective, as this is where the research findings are presented (Green et al., 2006).

3.2 Literature search strategy and database selections

This literature review follows the steps and guidelines described in the following works: Literature review as a research methodology (Snyder, 2019), Writing narrative style literature reviews (Ferrari, 2015), Writing narrative literature reviews for peer-reviewed journals (Green et al., 2006) , Writing integrative literature reviews (Torraco, 2005) and analysing the past to prepare for the future: writing literature review (Webster & Watson, 2002). The structure of the review is listed in Table 1, Literature framework, as recommended by (Ferrari, 2015), and the review process is illustrated in Figure 3, Literature review process.

Table 1- Literature review framework.

Introduction
Background
Method
Results
Discussion
Conclusion
Suggestions for further research

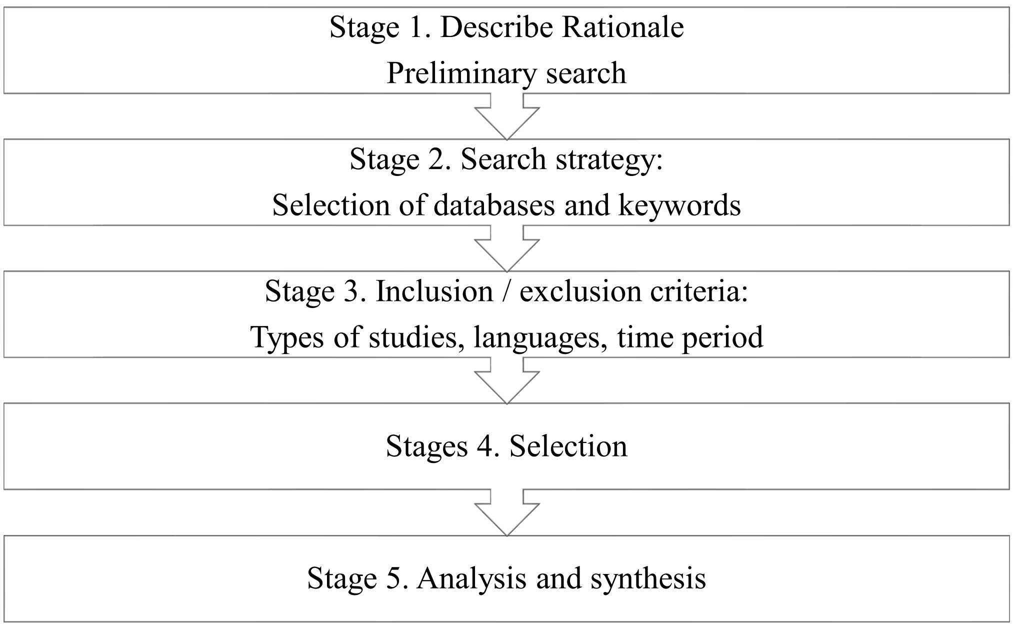

Figure 3 - Literature review process.

Rationale and preliminary search

The rationale for this study, as outlined in the introduction, is the growing interest in nuclear propulsion for deep sea fleets as a means of achieving international emission reduction targets and ongoing research projects, such as the Maritime Nuclear Application Group (The National Reactor Innovation Center, 2022) and the NuProShip project. See The Research

Council of Norway (The Research Council of Norway, 2023) for an in-depth account of the study. Other sources include initiatives such as the UK-based maritime and technology company, Core Power (Core power, 2023), which promotes advanced nuclear solutions for the maritime sector and is currently collaborating with Lloyd’s Register (Lloyd’s Register, 2022) on a quality assurance framework for molten salt reactors for maritime applications. When nuclear power becomes actual for the merchant fleet, it will create a new need for education and training of seafarers.

Search strategy and database selections

The selection of databases and search terms was conducted in part by consultation with the senior librarian and faculty members at the University of South-Eastern Norway. The search strings were developed on a trial-and-error basis as described in the next stages of the process. The following databases available through Oria were selected for this study:

1. Scopus
2. Web of Science

Searches in the International Atomic Energy Agency (IAEA) publication databases and Regs4Ships were conducted for the purpose of documenting existing rules, regulations, recommendations and guidelines from policymakers on the subject of research.

3. Regs4Ships
4. IAEA

Search criteria

To filter out the most relevant articles for this study, the database searches were performed using Boolean operators like OR, AND, and NOT, see Table 2 for combinations of search strings and key words. Searches were first performed individually with different key words and then combined. For example, search A: (Key words), B: (Key words) and C: (Key words) then combined the three searches in one search combination: A AND B AND C.

Table 2 - Search strings Table.

Search	Key Words
A	(nuclear propulsion OR nuclear power* OR reactor* OR smr*)
AND B	(ship* OR maritime OR naval OR navy OR marine)
AND C	(education* OR training)
D	(((education* OR training)) AND ((ship* OR maritime OR naval OR navy OR marine)) AND ((nuclear AND propulsion OR nuclear AND power* OR reactor* OR smr[2]*)))

The decisions concerning search boundaries, year of publication, language, papers and publications, were discussed with the senior librarian and other faculty members at the University of South-Eastern Norway. The selection criteria for the searches are listed in Table 3.

Table 3 - Selection criteria.

N	Criteria	Included	Excluded
C.1	Language	English	Other
C.2	Time period	1/1/1970 – 1/1/2023	Other
C.3	Search within	Titles, abstract, keywords.	Other
C.4	Subject Area	See Table 2.	Healthcare /Medicine/Aero Space/ etc.

[2] According to IAEA, Small modular reactors (SMRs) is a generic term for advanced nuclear reactors with a power ratio up to 300 MW(e) and does not differentiate them any further IAEA. (2023b). *What are Small Modular Reactors (SMRs)?* IAEA. https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs

C.5	Type of publication	Articles, conference paper, publications, and reports	Other
C.6	Manually read abstracts		
C.7	Relevant to marine nuclear propulsion, education and training of engineering officers.	Relevant to the research questions	Other
C.8	Duplicates from other searches		

To prevent any loss of valuable information, the search results were reviewed manually before all the search criteria were used (if there were not too many hits, e.g. over 100). Results that obviously belonged to other fields, such as health, medicine and aerospace, were discarded.

3.3 Literature search process and analysis

The literature from the database searches was stored in folders that correlated with the search terms as well as stored in EndNote. Next, the abstracts from the most relevant articles from the searches were read and only the most relevant to the research questions were chosen for further investigation. Finally, the reference lists in the selected articles were scanned for relevant papers and publications that could be included in the study..

Ideally, more than one person should review the articles in question to ensure quality and impartiality (Snyder, 2019). However, in this study the final selection of criteria and articles for review was performed solely by the author.

Table 4 presents the search results from the databases Scopus (search N=1) and Web of Science (search N=2) with the search strings from Table 3.

Table 4 - Literature search Table.

N	Database	Key Words	Results	Date
1	Scopus	(TITLE-ABS-KEY ((education* OR training))) AND (TITLE-ABS-KEY ((ship* OR maritime OR naval OR navy OR marine))) AND (TITLE-ABS-KEY ((nuclear AND propulsion OR nuclear AND power* OR reactor* OR smr*)))	156	6/2/2023
1.2		Filtered by criteria C1-C7	17	

N	Database	Key Words	Results	Date
2	Web of Science	(((education* OR training))) AND ((ship* OR maritime OR naval OR navy OR navy OR marine)) AND ((nuclear AND propulsion OR nuclear AND power* OR reactor* OR smr*))	13	6/2/2023
2.1		Filtered by criteria C1-C7	2	
2.2		Filtered by criteria C8	0	

The selected literature from the database searches in Table 4 is collated in the literature search result, Table 20 (see Appendix 1). The rationale for the selection of these articles is the assumed relevance to the research questions after reading the abstracts of the articles from the search in the databases.

The search performed in Regs4ships (search N=3) is presented in Table 5. The search functions of the Regs4Ships database are completely different from those in Scopus and Web of Science, thus the search strings had to be altered to give relevant results in relation to the research questions.

Table 5 - Literature search Regs4Ships.

N	Database	Key Words	Results	Date
3	Regs4Ships	Nuclear	14	7/2/2023
3.1		Filtered by criteria C1-C7	3	

The selected publications from the database searches in Table 5 are listed in the literature search result Table 20 (see Appendix 1). The rationale for this selection is the direct relevance to the research questions.

The searches (search N=4,5,6,7) performed in IAEA`s scientific and technical publications are presented in Table 6. Since the search functions of the IAEA`s database are also completely different from those in in Scopus and Web of Science, the search strings had to be modified and changed to give relevant results in relation to the research questions.

Table 6 - Publication search IAEA.

N	Database	Key Words	Results	Date
4	IAEA	Education	82	7/2/2023
4.1		Filtered by criteria C1-C7	1	
5	IAEA	Small modular reactors	11	
5.1		Filtered by criteria C1-C8	1	
6	IAEA	Staffing	12	
6.1		Filtered by criteria C1-C8	1	
7	IAEA	Training	189	
7.1		Filtered by criteria C1-C8	2	

The selected literature from the database searches in Table 6 is listed in the literature search result Table 20 (see Appendix 1). Due to the large number of hits, the selected literature spans from 2000-2023. The author presumes that this is the most relevant literature since it addresses themes directly relevant to the research questions and is the latest revision.

Additional relevant reports and articles obtained from other sources than the database searches in Scopus and Web of Science are listed in Table 7. These originate from the preliminary search phase of the study.

Table 7- Additional reports and articles

Retrieved from	Year	Comments
ScienceDirect	2011	(Safieh et al., 2011)
National Nuclear Security Administration	2020	Naval Reactors annual reports
Department Of Transportation USA Coast Guard	1976	Qualification recommendations
Total reports and articles		**3**

3.4 Literature selection and description

The articles, publications and reports from the various searches are listed in Table 20, literature search results table (see Appendix 1). Table 20 presents the literature that the author has selected for full-text review for potential inclusion in the final literature review (see Table 8) as well as those that have been excluded.

Altogether, twenty-five articles, publications and reports were included in the qualitative full text review for potential inclusion (see Table 20). The selected literature was synthesized in a literature matrix in Excel by categorizing the selected articles (Webster & Watson, 2002).

The literature review process is presented as a flowchart in Figure 4, showing the databases and the number of articles that emerged from the searches, number of abstracts and full texts read by the author for potential inclusion, as well as the amount of literature included. Table 8 lists the final literature for inclusion in the review after full-text evaluation and relevance for the research questions. Table 8 categorizes the literature according to author, year and subject matter.

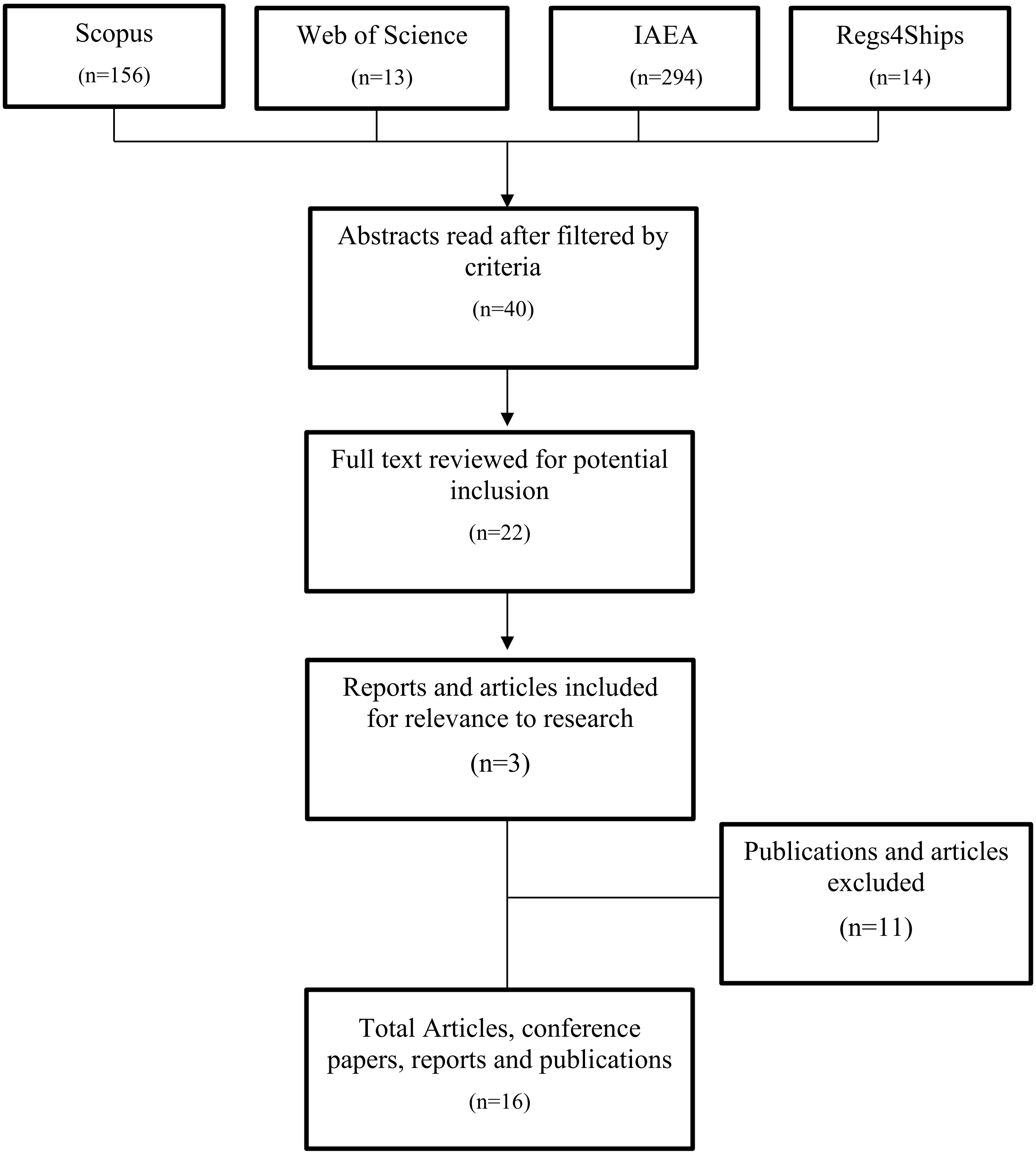

Figure 4 - Flow chart of the literature selection process

Table 8 - Final literature for inclusion in the review.

Author / Year	Theme	Comments
(Miller et al., 2017)	Naval nuclear-power training units in The Naval Nuclear Propulsion Program (NNPP)	The study evaluates the allocation of the students in the NNPP
(Thunem et al., 2012)	Safety culture, education and training in the maritime and nuclear domain	The study compares the education, culture and practice of seafarers and Nuclear operators
(Safieh et al., 2011)	Education and training in nuclear engineering and science	ENEN`S work and master program in nuclear related activities
(Phil Beeley et al., 2004)	Education and training of crew for nuclear vessels in the British Navy	Training facilities, teaching aids and methods
(Brushwood et al., 2002)	Education and training of crew for nuclear vessels in the British Navy	Training facilities, teaching aids and methods
(Lakeey; et al., 1986)	Education and training of crew for nuclear vessels in the British Navy	Training facilities, teaching aids and methods
(Head; et al., 1986)	Education and training of crew for nuclear vessels in the British Navy	Training facilities, teaching aids and methods

(Sasaki, 1973)	Education and training of crew for experimental nuclear-powered merchant vessels	Training facilities, teaching aids and methods
(UK Government, 2022)	Regulations for nuclear ships	Regulations for safety, survey, operation, training etc. requirements
(Maritime & Coastguard agency, 2022)	Guidance on regulations for nuclear ships	Marine guidance note on regulations and requirements for nuclear ships
IMO 1981	Regulations for nuclear ships	Regulations for safety, survey, operation, training etc. requirements
(National Nuclear Security Administration, 2022)	The Naval Nuclear Propulsion Program, Nuclear training in the US Navy	Naval Reactors annual report on the NNPP
(Hall et al., 1976)	Education and training of crew for experimental nuclear-powered merchant vessels	Recommendations on education and training of crew for nuclear ships
IAEA 2022	Education and training in the nuclear domain	Education, training and qualifications for Nuclear staff

IAEA 2021	Education and training in the nuclear domain	Systematic approach to education and training
IAEA 2001	SMRs operations	SMR, staffing and training requirements
	Total articles, reports and publications for full text review	**16**

The total amount of literature included in the literature review is divided into 16 articles, reports and publications spanning over a period from 1973 to 2022, as shown in Figure 5, Literature distribution over time.

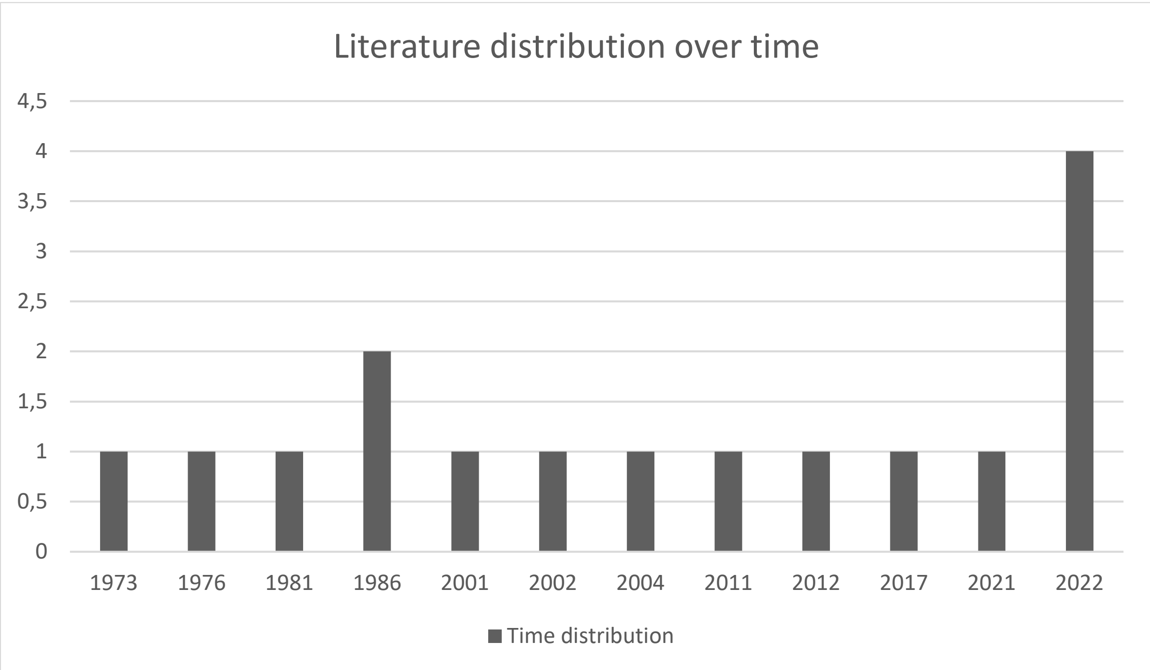

Figure 5 - Literature distribution over time

The literature comprises journal articles, conference papers, publications, rules and regulations and reports. The distribution is illustrated in Figure 6.

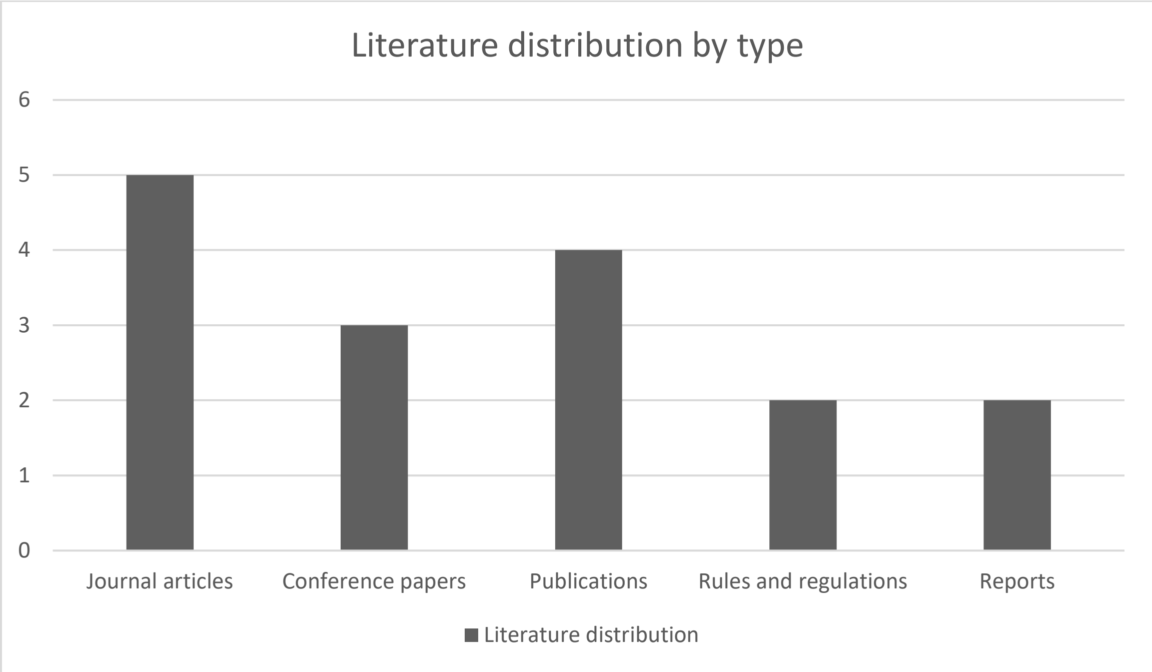

Figure 6 - Literature distribution by type

The main body of the literature deals with education and training in the U.K and U.S navies, as well as the merchant vessels NS Savannah and Mutsu. In addition, guidelines from regulatory bodies, inter alia, the IMO, MCA and IAEA, have been highlighted. The author has decided to include an article about the European Nuclear Education Network's (ENEN) master's degree in nuclear engineering, as this provides insight into the current status of education for the nuclear power industry in Europe.

Certain weaknesses are revealed when reviewing the literature, especially when it comes to descriptions. The study programs are, often described in terms of the themes of the courses, the subject content and course unit duration, instead of stating the learning objectives and learning outcomes for each course of study in the education and training programs. Further, it is unclear which cognitive levels the candidates are expected to achieve in terms of knowledge, skills and competences.

There are challenges regarding literature on SMRs since they are currently in the research and development phase, so there is little empirical data concerning education and training in the use of this technology.

Another challenge in sourcing literature dealing with military activities is that a lot of the material is classified as secret and thus not freely available to the general public.

Although some of the literature dates back to 1973 and 1976, the author considers it valid since it records pioneering activities relating to nuclear-powered merchant ships.

The author has endeavoured to maintain objectivity and source as much relevant literature as possible to include in the framework of this study, subject to the constraints of time and resources.

4 Presentation of research findings

This section presents the research results. Firstly, the regulations and recommendations from the IMO, MCA and IAEA are reviewed. Secondly, experiences from the experimental ships, the NS Savannah, The Department of Transportation’s report, Recommendations for Qualifications of Engineering Personnel of Nuclear-Powered Ships and the NS Mutsu are presented. Thirdly, the education and training from the U.K and U.S navies are reviewed, followed by a comparative study of the maritime and nuclear domains and finally, a presentation of ENEN's work with higher education of nuclear personnel.

4.1 The International Maritime Organisation Regulatory Policy and Recommendations for Merchant Nuclear Ships

The International Maritime Organisation (IMO), developed resolution A.491 (XII), The Code of Safety for Nuclear Merchant ships in 1981. This resolution aimed to give guidance to stakeholders on internationally accepted standards for merchant nuclear ships. It outlines recommendations for the safe operation of nuclear merchant ships and covers “the design, construction, operation, maintenance, inspection, salvage and disposal of nuclear merchant ships” (The Nuclear Code, 1981, p. 6). The purpose of the code was to give guidelines and recommendations for flag states.

According to chapter seven in the code, crew members should have sufficient competence to perform their assigned duties on board the vessel and fulfil the requirements in the operating manual for the relevant reactor to be used on board the vessel. In the case of merchant ships with nuclear propulsion, the following additional skills listed in Table 9 are requirements for the engineering officers and should be part of an education and training program approved by the administration (The Nuclear Code, 1981, p. 87).

Table 9 - Additional requirements for engineering officers on nuclear ships.

Principles of nuclear engineering and nuclear reactor theory
Radiation physics, including radiological effects on health and the environment, principles of radiological protection and radiation monitoring
Design and operating principles of the Nuclear steam supply system (NSSS), its monitoring, control and protection systems; engineered radiation safety features of the ship and nuclear propulsion plant (NPP), and particulars of the ship's hull structure
Detailed study of a NSSS of the type fitted on the ship for which the officer is being trained and study of the Safety Assessment, Operating Manual and operating instructions for the NPP equipment.
Practical training in startup, shutdown and control of the NSSS, in normal and simulated emergency conditions, including maintenance, checking and survey procedures.
Principles for safe operation of NPP including maintenance inspections, surveys, core refueling and waste management.

Adopted from (The Nuclear Code, 1981, pp. 87-88)

The code stresses that the practical training should be performed on the type of nuclear power plant that the student will be qualified to operate. Such training can be achieved by simulators or on-the-job training on a live reactor. The trainee should be able to perform reactor startups and shutdowns during normal and abnormal conditions. The code also states the importance of updating skills and emphasizes retraining in the operation of the nuclear power plant on board the ship (The Nuclear Code, 1981). The code is a supplement to existing qualification requirements for seafarers in the STCW.

4.2 The Maritime and Coastguard Agency Regulatory Policy and Recommendations for Merchant Nuclear Ships

These recommendations are substantiated by the The Maritime and Coastguard Agency (MCA) as reflected in the Marine Guidance note MGN 679 (M) Nuclear Ships, which provides guidance for the application of the Merchant Shipping (Nuclear Ships) Regulations 2022 (*MGN 679 (M) Nuclear Ships* 2022). In addition to IMO`s recommendations, The Maritime & And Coastguard Agency recommend study of national and international safety requirements applicable to nuclear ships and their nuclear propulsion plant. All training courses should be approved by the administration. MCA also states that education and training of staff should be in accordance with the operating manual of the specific reactor to be installed and operated on board the vessel (*MGN 679 (M) Nuclear Ships* 2022).

4.3 The International Atomic Energy Agency recommendations on training and education of nuclear personnel

IAEA safety standard (IAEA, 2022), reflects international agreements on high-level safety for protection against radiation and recommends a systematic approach to training nuclear facility personnel. The standard provides detailed recommendations for the education and training of nuclear power plant personnel. The overall goal is the safe operation and maintenance of nuclear power plants through a robust safety culture.

With regard to the technical and engineering department of a nuclear power plant, the recommendations for operator personnel, managers and technical specialists are, in this study, the most relevant. These positions manage technical operations, maintenance and repair. The standard divides the education and training into three parts: academic qualifications, previous work experience, preliminary and ongoing training.

Based on the statement of IAEA's safety standard SSR-2/2 (*Safety of Nuclear Power Plants: Commissioning and Operation*, 2016), "The operating organisation shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons" (IAEA, 2022, p. 3). Competence is defined by the IAEA as “the ability to apply skills, knowledge and attitudes in order to perform an activity or a job to a specified level in an effective and efficient manner” (IAEA, 2022, p. 9). To prepare for further training and achieve the desired level of competence, the education program must ensure that the individual acquires the requisite knowledge, skills and attitudes.

The IAEA underlines the importance of recruiting personnel with the right motivation, attitude and values in relation to the position to be filled and the requirements of a robust safety culture. It is essential that individuals possess the requisite knowledge and skills to perform security-related tasks. Emphasis is put on mental and physical health and zero tolerance for the use of alcohol and other drugs. Communication skills and the ability to work in a team under normal/abnormal conditions and emergency situations, as well as analytic and problem solving skills are paramount and should be prioritized (IAEA, 2022).

The IAEA advocates a closer cooperation between academia, the nuclear industry and regulatory bodies. Such cooperation demonstrates the alignment of the education program with the needs of industry. In addition to professionals being able to contribute to the teaching and learning process, internships should be established between students and industry partners. The industry can contribute with training material, simulators, facilities and joint research projects can be established (IAEA, 2021)

The systematic approach to training (SAT) process addresses the distinct stages in an education and training scheme.

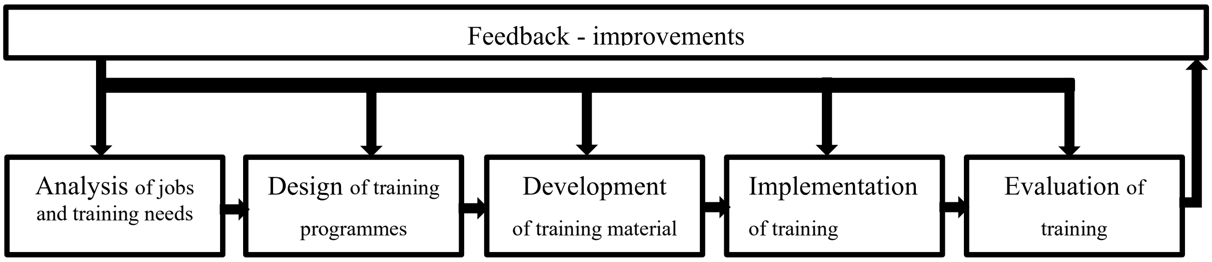

Figure 7- Overview of the SAT process

Overview of the SAT process. Adapted from (IAEA, 2021, p. 18).

The analysis stage scrutinises the knowledge, skills, attitudes and competencies required for a particular job or task leading up to intended learning outcomes. In the design stage, the process of synthesising the data obtained from the analysis is done to further develop the learning outcomes, teaching and learning activities and assessment tasks. In the development stage the training material required to achieve the results from the design stage is compiled. Next, the education and training are executed in the implementation stage, followed up by the evaluation stages that evaluate the entire process from analysis to execution with the intention of improving the program (IAEA, 2021).

The SAT model is specially developed for operational organisations and serves as a tool for developing internal additional training beyond what the candidates have received from academia to ensure the correct level of competence.

One example of a general training program for a nuclear power plant is illustrated in Table 10 below, adapted from (IAEA, 2021, p. 99).

Table 10 - Typical content and duration of a generic nuclear training program

Department	Position	Induction (4 weeks)	Nuclear fundamentals (6-12 weeks)	Plant systems and processes (6-12 weeks)	Role specific (1-6 years)
Engineering	Design engineer System engineer	The exact duration of each segment will vary, depending on the role requirement			
Operations	Plant operator Reactor operator Shift manager				

Table 11 - Topics of nuclear fundamentals

Topics	Institution provider
Nuclear physics	Operating organisation
Reactor physics	
Thermodynamics	
Hydrodynamics	
Heat transfer	
Basic facility design	
Radiation protection	
Chemistry	
Nuclear safety	
Electrical fundamentals	
Instrumentation and control	
Material science	
Regulations	

Table 11 - Topics of nuclear fundamentals, lists the nuclear subjects that provide students with the basic theoretical understanding required to develop the right knowledge, skills and competences for further training in the program (IAEA, 2021, p. 99)

It is recommended that the academic qualifications for supervisors and managers be at university level with a degree in management, engineering or science. More specifically, a typical technical engineering education or civil engineering degree should include topics such as nuclear technology, reactor physics, radiation protection and nuclear safety. Control room operators should hold a university degree, college degree in engineering or background from a technical college (IAEA, 2022).

When an organisation is establishing a new nuclear power plant with distinctive technological facilities, the IAEA standard Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, advises that employees are recruited before the plant comes on stream. The operators can then, as a part of induction training, gain knowledge from the contractors involved in the different stages from design to commissioning of the plant. In cases when the operating organisation has to recruit directly from academic institutions, the need for simulator training and practical work on relevant systems and equipment is essential (IAEA, 2022).

Due to the more modular design and standardised equipment of new SMRs, the qualification requirements are predicted to be lower for some facilities than for the more traditional nuclear power plants. The amount of staff required for the safe operation and maintenance of SMRs is not necessarily reduced, although there are exceptions (IAEA, 2001).

4.4 Education and training for earlier nuclear-powered experimental merchant ships

This part describes the education and training of the engineering officers for the nuclear ships, Savannah and Mutsu and The Department of Transportation report, “Recommendations for Qualifications of Engineering Personnel of Nuclear-Powered Ships”.

Training of the engineering officers for the nuclear ship Savannah

The New York Shipbuilding Corporation designed the Engineering Officer Qualification program “to certify the competence of the licensed States Marine Lines operating engineers in the operation of the NS Savannah reactor and steam plant systems” (Hall et al., 1976, p. F1). The objective of the program was to man the vessel with well-trained personnel who possess the knowledge and skills required for the safe operation of the reactor on board and its associated thrust line. Further, the program aimed to ensure that the crew had the requisite skills to understand the construction and operation of nuclear propulsion systems under normal and abnormal conditions. (Hall et al., 1976).

In order to qualify for the education and training for the NS Savannah, special prerequisites were placed on the positions of chief engineer, first, second and third engineer when it came to sailing time and experience. The chief engineer needed 20 years of experience in the maritime profession, whereas 15 years had to be at sea on relevant ships. The experience requirement for the first and second engineers was from 10 to 20 years at sea on relevant vessels. For the third machinist, the requirements in addition to the standard ones, included, inter alia, minimum 3 years' sailing time on steam vessels or graduation from the U.S. Merchant Marine Academy or equivalent academic qualifications and the required cadetship completed (Hall et al., 1976).

Those officers who fulfilled the prior knowledge requirement had to pass an examination arranged by the U.S. Coast Guard to demonstrate the required competencies in the relevant subject areas related to the duties required. The degree of difficulty and the content of this examination were adapted to the position the officer was to hold on the vessel, e.g. Chief engineer, first, second and third engineer (Hall et al., 1976).

The education and training program comprised academic lectures, simulator training and attendance during construction and commissioning of Savannah's nuclear propulsion plant. The assessment was carried out in two sessions before the final examination and certification. The first session consisted of an oral exam and simulator assessment of the officer’s ability to master not only the terminology and operation of the nuclear propulsion system components in and outside the control room, but also to possess both practical and theoretical knowledge of reactor operation and function. The second part was performed on the vessels in operation, whereby the candidate had to demonstrate the competence to operate the nuclear power plant on board . After successfully completing the first two parts, the candidate had to pass a written examination and conduct an interview with a representative of the program. Those candidates who completed and passed the program were certified and licensed in accordance with the code of Federal Regulations, 10CFR55, nuclear reactor operator licence (Hall et al., 1976).

The Engineering Officer`s Qualification program developed by the New York Shipbuilding Corporation was reliant on close cooperation with the U.S. Nuclear Regulatory Commission, U.S Coast Guard, the US military and nuclear power industry representatives to develop the education and training program and provide access to simulators and training facilities (Hall et al., 1976).

The Department of Transportation

The Department of Transportation sponsored the report, Recommendations for Qualifications of Engineering Personnel of Nuclear-Powered Ships (Hall et al., 1976), which provides a basis for further development of detailed qualification requirements and a curriculum for marine engineers on nuclear-powered ships. The methodology is based on experience from the NS Savannah, the utilities industry and the U.S. Navy nuclear program using Functional Job Analysis (FJA).

The foregoing report recommends a module-based training system that includes the various nuclear power-related tasks. The training system is function-based and requires the candidates to acquire the education and training that meet the requirements set for seamen in the engine department of non-nuclear ships, e.g. the US Coast Guard's requirements for education and training of engine room staff.

The education and training are divided into modules that address a total of twelve different functions within the differentiated operational tasks and management tasks. The management positions, such as watch supervisor and overall supervisor, must complete all the modules, having acquired an in-depth knowledge of the entire nuclear system on board. However, the operational tasks are less comprehensive and divided into operation of nuclear systems, steam propulsion systems and reactor auxiliary systems, as well as maintenance and repair functions.

On completion of the education and training, the candidates should fulfil the licensing requirements of the Nuclear regulatory Commission regarding nuclear reactor system operations and the supervisory categories, watch supervision and overall supervision (Hall et al., 1976). Table 12 is adapted from “Recommended requirements for nuclear training of ship personnel” (Hall et al., 1976) and lists the modules for the total system operations supervisory functions.

Table 12 - Total system operations supervisory function modules

Application Area	Module title
General systems knowledge	Principles of reactor operation
	System design of the specific reactor installed on board the ship
	General and specific plant operating characteristics
	Nuclear power plant system operation
	Nuclear instrumentation and control
	Safety and emergency systems
	Normal, abnormal and emergency operation procedures
	Radiation control and safety
	Nuclear theory
	Radioactive material handling
	Administrative procedures, conditions and limitations
	Health physics and radiation protection
	Power plant chemistry
Nuclear reactor subsystem, Steam propulsion subsystem, Reactor auxiliary subsystem	Nuclear Plant startup from subcritical to escalating power to normal steaming mode
	Making major power changes of greater than 10%
	Maneuvering watch and mooring
	Nuclear plant shutdown from at-sea mode to reactor subcritical mode
	Simulation of emergency and abnormal conditions
All subsystems of nuclear power plant	Maintenance manuals and operating procedure manuals
	Preventive maintenance checklists
	Fault finding techniques and approved repairs
	Systems specifications and drawings

The report clearly concludes that provided a detailed curriculum for engineering officers can be finalised and approved by regulatory bodies, further work needs to be done on the development of a regulatory framework specifically for nuclear merchant ships with detailed qualification requirements. The recommendations for education and training in the report can only be seen as a basis for further work on detailed curriculum development. The report proposes that the courses combine classroom lessons, laboratory work and practical exercises using simulators (Hall et al., 1976).

Training of the engineering officers for the nuclear ship Mutsu

The basic education and training program of the engineering officers for the nuclear ship Mutsu was conducted in accordance with the SOLAS Convention (1960) and planned by the Japan Nuclear Ship Development Agency (JNSDA). To ensure the optimal safe operation and performance of the vessel, the personnel selected for the training scheme comprised experienced marine officers and engineers from Japanese state institutions for maritime education and recognized shipping companies.

The education and training were arranged by a combination of state and private institutions and consisted of classroom lessons, laboratory exercises and simulator training (Sasaki, 1973). The basic theoretical and practical education on subjects relating to nuclear energy was generally given at university level, see Table 13 Curriculum for the training of the engineering officers for the Mutsu.

Table 13 - Curriculum for the training of the engineering officers for the Mutsu.

Nuclear physics
Reactor physics
Reactor engineering
Reactor chemistry
Radiation control and protection
Electronics and instrumentation
Reactor operation
Plant management

The subjects taught to the engine department were arranged in different courses and with different duration. Table 14 is adapted from (Sasaki, 1973) showing the type of courses, provider and duration.

Table 14 - Courses for the training and education of engineering officers for Mutsu

Course	Institution provided	Duration
Nuclear reactor general course	Nuclear reactor school, Japan Atomic Energy Research Institute (JAERI)	6 months
Reactor plant Operation and Management	JAERI	6 months
R1. Advanced Course (Engineering branch or Radiation control and Protection course)	Radio isotope school, JAERI and National Institute of Radiobiological Sciences (NIRS)	2 months
Instrumentation course	System manufacturers	1 month
Orientation Simulator training Damaged control & Miscellaneous	Japan Nuclear Ship Development Agency (JNSDA)	3 months

An important part of the training was familiarisation with the nuclear systems and related equipment on board Mutsu. This was conducted in collaboration with subcontractors to the shipyard and the yard. The crew supervised and participated in installation, testing and commissioning of the various systems on board.

Emphasis was placed on simulator training to ensure that the engineering officers were prepared for operations under all conditions: normal, abnormal and emergency. The simulator was designed by the reactor supplier and based on the same reactor fitted on board the Mutsu.

Extra training in health physics and reactor plant management was arranged for some of the officers. To gain more experience with projects and sailing on nuclear-powered vessels, the chief engineers and masters went to the United States and Germany.

4.5 Naval nuclear education and training

This part describes the education and training of the UK and US Naval Nuclear personnel.

United Kingdom's Naval Nuclear Propulsion Program

The Nuclear Department (Royal Navy, 2014) was formed at HMS Sultan (Defence School of Marine Engineering and the Royal Naval Air Engineering and Survival School) in 2001, and gathers most of the UK`s Naval Nuclear Propulsion Program (NNPP) at one site. All education, training and research facilities for the United Kingdom`s NNPP, both for civilian and naval personnel, are based here (Brushwood et al., 2002; Phil Beeley et al., 2004).

The institution provides a wide range of academic courses in nuclear science and technology. Of particular interest with this study are the courses offered for junior and existing marine engineering officers that are based on the US Navy`s Nuclear Propulsion Program.

A marine engineering officer can enrol on the Nuclear Reactor Course (NRC) which will provide the officer with additional competences of nuclear propulsion and nuclear reactor technology for further qualification and training for nuclear submarine support and operational positions (Phil Beeley et al., 2004). The academic course lasts six months and awards the student a postgraduate diploma in nuclear reactor technology. Table 15 gives an overview of the NRC subjects.

Table 15 - Nuclear Reactor Course subjects

Syllabus	Institution provided
Atomic and nuclear physics	Nuclear Department
Reactor physics	
Reactor engineering	
Reactor dynamics and system design	

Chemistry
Materials
Radiation protection and shielding
Mathematical methods
Numerical analyses and statistics

Adapted from (Phil Beeley et al., 2004)

For a junior marine engineer with a degree in a relevant science or engineering, the training pipeline is conducted through the Systems Engineering Management Course (SEMC). This education and training program usually lasts 130 weeks, including sailing time, simulator use and oral exams before the cadet is ready to hold the position of Engineer Officer of the Watch on a nuclear submarine. In addition to the 26-week NRC, the cadets take Officer Nuclear Operators Courses (ONOC) 1 & 2 which last 7 and 10 weeks respectively, covering instrumentation, operations, safety philosophy, basic health physics and reactor operations. The ONOC 2 course focuses on simulator training and assessment. On completing these courses, the candidates are scrutinised in all disciplines using simulator exercises and listening tests. They also participate in the Initial Sea Qualification (ISQ) on a nuclear submarine for six months. After examinations, those who succeed can proceed to on-job-training (OJT) on a nuclear submarine for approximately 5 months. After serving OJT, candidates undergo final tests and examinations before qualifying as an Engineer of the Watch on a nuclear submarine (Phil Beeley et al., 2004).

The facilities of the Nuclear Department include various simulators and research laboratories. There is a real time PWR nuclear submarine simulator for plant operations and responses, as well as a nuclear submarine maneuvering room simulator. These facilities enable simulations of normal and abnormal conditions, emergency and accident scenarios that provide the student with training in situations that would not be possible on a real nuclear reactor (Brushwood et al., 2002; Phil Beeley et al., 2004). There are comprehensive laboratory facilities covering radiation protection, nuclear physics, steam and engineering systems. These provisions give the students practical knowledge of reactor neutronics, radiation monitoring and measurements, instrumentation and calibration, as well as highpressure steam boiler operations, steam generators and auxiliary equipment (Phil Beeley et al., 2004).

A practical approach is paramount considering that ships operate in remote places. The students must be able to understand and be competent to operate the nuclear propulsion system both in normal and abnormal conditions. They must have an in-depth understanding of the main and auxiliary systems to enable them to interpret abnormal conditions and act accordingly (Head; et al., 1986; Lakeey; et al., 1986)

Before the Nuclear Department was formed at HMS Sultan, the education and training were arranged, inter alia, at the Royal Navy College Greenwich, London (Phil Beeley et al., 2004). The training in nuclear reactor operations took placed at the Royal Naval College Department of Nuclear Science and Technology, where a similar nuclear reactor course held for Marine Engineer Officers consisted of a six-month course (NRC) covering nuclear science and technology. The course combined theoretical teaching with practical laboratory work (Lakeey; et al., 1986). On completing the NRC, the students took a ten-week course in nuclear operations: the Officer Nuclear Operations Course (ONOC). This course gave the students in-depth teaching in nuclear submarine operations. It also provided training on a fully-fledged machinery and reactor control room simulator, designed specifically for the submarine class they were to serve on (Lakeey; et al., 1986). On completing the ONOC, the students enrolled in the practical training program for watchkeeping on a submarine. To qualify for the position of Engineer Officer of the Watch (EOOW), the student had to complete several real nuclear facility operations, as well as practical simulator and oral examinations. The practical training facilities consisted of a training and research reactor, laboratories, simulators, system components models, full-scale operator control room and workshops (Head; et al., 1986).

Nuclear submarine operators are mostly naval engineering officers. They have an education in electrical and mechanical engineering and have completed special courses in submarine training, submarine machinery and steam systems for surface ships. In addition, they have education and training in nuclear power operation (Lakeey; et al., 1986).

The United States Naval Nuclear Propulsion Program

The National Nuclear Security Administration is powering the naval nuclear fleet through Naval Reactors also known as the Naval Nuclear Propulsion Program (NNPP) (Miller et al., 2017). The program includes all civilian and military activities supporting the nuclear-powered naval fleet, its establishments and the full-life cycle assessment, from resource extraction to disposal phase (Miller et al., 2017; National Nuclear Security Administration, 2022).

Parts of the education of the NNPP are arranged at the Nuclear Field “A” School and the Nuclear Power School in Charleston, South Carolina. In addition, training is provided at the moored training ships in Charleston and the shore-based MARF prototype and S8G prototype at Kesselring Site West Milton, New York (Miller et al., 2017; National Nuclear Security Administration, 2022).

The students receive comprehensive academic and practical training as well as OJT as cadets under the supervision of highly qualified personnel for safe operation of nuclear vessels under all conditions (Miller et al., 2017; National Nuclear Security Administration, 2022)

There are several paths to take in the military educational system to sail on vessels with nuclear power, either as an enlisted sailor or an officer. If the candidate does not select the Nuclear Propulsion Officer Candidate Program (NUPOC). The Nuclear Field “A” School is an alternative to become an enlisted sailor (National Nuclear Security Administration, 2022).

The academic level is known to be top notch and on par with the best educational institutions in nuclear power. The study program consists of six months academic training and 6 months practical training (National Nuclear Security Administration, 2022).

The educational prerequisite for entering the NUPOC is having a degree from either an accredited college or university in the United States with a major in science or engineering (National Nuclear Security Administration, 2022).

In addition, all candidates must undergo interviews and tests. The candidates are evaluated in mathematics, physics and other technical subjects, as well as communication skills and motivation. The interviews are conducted by the admiral in charge of the Naval Nuclear Propulsion Program and the Director of Naval Reactors in Washington, D.C. (National Nuclear Security Administration, 2022).

The nuclear training starts at the Nuclear Power School, which is a 24-week training program consisting of the subjects listed in Table 16. The Nuclear Power School is one of the

Navy`s most demanding academic programs and the students spend between 60 – 80 hours a week studying while attending the program (National Nuclear Security Administration, 2022).

Table 16 - Syllabus for the Nuclear Power School

Syllabus	Institution provided
Nuclear reactor technology	Naval Nuclear Power Training Command (NNPTC)
Mathematics	NNPTC
Nuclear physics	NNPTC
Health physics	NNPTC
Reactor principles	NNPTC
Chemistry	NNPTC
Material science and metallurgy	NNPTC
Electrical power theory and generating equipment	NNPTC
Thermodynamics	NNPTC

Adapted from (Hall et al., 1976; National Nuclear Security Administration, 2022)

On completion of the Nuclear Power School, the students proceed to the more practical training program at the Nuclear Power Training Unit (NPTU), either on the anchored training vessels at Charleston or on the S8G prototype in New York. This is a 24-week training program. The students get practical and in-depth teaching in nuclear reactor operations. The course is divided into 2 phases: a seven-week classroom tuition period and a seventeen-week practical reactor and simulator training period (Miller et al., 2017). This course gives the students in-depth knowledge of a naval nuclear propulsion plant system and its operation requirements. They learn how to operate it in normal and abnormal conditions. After completing an examination, the student qualifies as a propulsion plant operator (Miller et al., 2017).

4.6 Comparison of the maritime and nuclear industries

There are several similarities between the maritime and nuclear domains, concerning both organisational and operational tasks, technical skills and knowledge of maintenance, operation and repair of technical equipment. These domains share the need for teamwork, communication skills, human factors regarding more automated processes and new technologies, e.g. the dynamic positioning operator on a ship and the nuclear plant operator in a nuclear facility. Safety culture and leadership are emphasised in both domains and both industries are governed by rules and regulations and supervised by public authorities (Thunem et al., 2012).

Although there are similarities between these two domains there are also differences, especially cultural ones. Some research points out that the mariners have a more flexible attitude towards management documents and procedures, while the nuclear power plant personnel are more rigid in this respect (Thunem et al., 2012).

In terms of education and qualifications, nuclear engineering is recognized as having higher levels of theoretical as well as applied science, whereas the seafarers' educational background is rather more practical than theoretical (Thunem et al., 2012).

4.7 The European Nuclear Education Network

Recent studies have shown that Europe is at great risk of losing valuable expertise in research, development and operation of nuclear power. It has also been realized that there is a shortfall of professional personnel and a decrease in the educational opportunities in the European nuclear industry. To counter this development, The European Nuclear Education Network (ENEN), a non-profit regulatory agency, was established on a mission to safeguard existing competence and further develop new competences in the nuclear field through higher education and training (Safieh et al., 2011).

ENEN aims include harmonising education within nuclear engineering and science, as well as supplying qualified personnel to the nuclear industry. Through the Euratom Framework Programs and collaboration with universities and organisations in the nuclear power industry as well as the IAEA, ENEN has come to a common understanding of an educational path in nuclear professions, namely, the European Master of Science in nuclear Engineering (EMSNE). To ensure that high quality is attained, ENEN, together with its members and associates, has introduced a course description containing admission requirements, curricula and a certification of achievement for its graduating students. Some of the core objectives of the EMSNE are to harmonise the safety culture, education and training in different nuclear technologies and policies in Europe (Safieh et al., 2011).

For Universities to be able to qualify students for the certification, The European Master of Science in Nuclear Engineering, the following minimum requirements must be met:

> "The total course load leading to the master degree in nuclear engineering, or equivalent, must be at least 300 ECTS (European Credit Transfer System) at university level, of which at least 60 ECTS credits must be in nuclear sciences and technologies, preferably engineering. The master programme must have been a balanced nuclear engineering programme consisting of at least a profound coverage of the following subjects: reactor engineering, reactor physics, nuclear thermal hydraulics, safety and reliability of nuclear facilities, nuclear materials, radiology and radiation protection, nuclear fuel cycle and applied radiochemistry. The applicant must have successfully defended a nuclear engineering master thesis project. At least 20 ECTS of nuclear engineering courses or a master thesis project must have been taken at an academic ENEN member institution situated in another country than the home institution" (Safieh et al., 2011)

The master's program must include the following subjects listed in Table 17, Compulsory subjects for the EMSNE.

Table 17 - Compulsory subjects for the EMSNE

Subjects
Reactor engineering
Reactor physics
Nuclear thermal hydraulics
Safety and reliability of nuclear facilities
Nuclear materials
Radiology and radiation protection
Nuclear fuel cycle
Applied radiochemistry

Adapted from (Safieh et al., 2011)

5 Discussion

The goal of this study is twofold: firstly, to explore what level of competence should the engineering officers on a modern nuclear-powered ship possess and secondly, to examine how education and training can be executed. The objective is to create a basis for further research into crew competence, training and education for merchant ships with SMRs nuclear propulsion.

This discussion section provides answers to the research questions by means of incorporating the main findings from the analysis and by forming a conceptual education model for the engineering officers of merchant ships with nuclear-power.

5.1 Education and training of engineering officers on nuclear-powered ships

This study has examined how the education and training of engineering officers for nuclear-powered vessels have been carried out and what the training has consisted of in the US and UK naval forces and in the early experimental nuclear-powered ships the NS Savannah and NS Mutsu.

Characteristics of the programs

This investigation has revealed several common features.

Firstly, the reviewed literature mainly describes the subjects that are taught, not the intended learning outcomes of the various subjects. Despite a lot of descriptive material pointing in the direction of outcome-based learning and assessment, e.g. safe operation of the ship and its nuclear power plant under normal and abnormal conditions, there are few clear descriptions of the learning outcomes leading up to this competence, see Figure 2- Aligning intended learning outcomes, teaching and assessment tasks.

The means and methods used to achieve the intended objectives are also quite similar, i.e. the use of classroom teaching in combination with simulators and practical training aids. The reviewed programs also focus on examinations and assessment of the desired knowledge, skills and competences.

There is a lot of material that indicates the courses being in line with the principles of outcome-based learning (see Figure 2- Aligning intended learning outcomes, teaching and assessment tasks). The training is designed specifically to fulfil the job requirements set for candidates. There are various competences that are described with verbs that correspond with the qualitative phase in the SOLO taxonomy (see Figure 1- SOLO taxonomy in five levels). For the merchant experimental nuclear ships, education and training were clearly in line with the regulations of the national administration of both maritime and nuclear affairs. The engineering officers operating and supervising the reactor on Mutsu and Savannah were licensed by the maritime and the nuclear authorities.

Secondly, the prerequisites for officer training in the navy and for the chief, first and second engineers in the merchant fleet showed several similarities. They had either a degree in science or were already marine engineers or officers in the navy. The additional curriculum being taught to the mariners in the navy and for the engineers in the merchant ships also shared the same fundamental principles.

Thirdly, the naval nuclear propulsion programs of the US and UK include both military and civilian nuclear activities, such as education and training, as well as research and development. Further, the education and training are managed by the same organisation that has the overall responsibility for the entire nuclear program of the Navy, inter alia, the Nuclear Department and Naval Reactors.

Fourthly, this study reveals that close cooperation is essential between the operating organisation, the regulatory bodies, equipment vendors and the education and training provider, regarding the development of learning objectives, teaching and learning activities and assessment tasks.

The importance of classification societies and program revision

The MCA has chosen to consider the approval of education and training programs for manning of nuclear-powered ships on a case-by-case basis because IMO does not cover this in the STCW. The MCA states “the approval of qualifications and training requirements will be considered on a case-by-case basis, taking into account the requirements of paragraph 7.6 in Chapter 7 of the Nuclear Code, and, where appropriate, any available training standard related to the specific nuclear technology under consideration” (*MGN 679 (M) Nuclear Ships* 2022, p. 7).

There are certain weaknesses with the IMO's chapter 7 of the Nuclear code requirements for additional education of seafarers on nuclear ships.

1. It lists subjects that should be a part of a course curriculum without specifying the intended learning outcomes regarding knowledge, skills and competencies to be

achieved from such a course (see Table 9 - Additional requirements for engineering officers for nuclear ships).

2. The nuclear code is based mainly on pressurised water reactor technology. Currently, there are other reactor designs that are just as relevant to use, e.g. HTGR and MSR
3. The Code has not been updated since 1981 and needs to be harmonised with current international nuclear safety standards, e.g. IAEA`s Safety Standards.

The MCA also states that recognized organisations and certifying authorities can act on behalf of the administration regarding safety assessment and certification. The administration regards classification societies to be such an organisation.

The deep-sea fleet must comply with international accepted rules and regulations, as well as national laws, concerning both the maritime and nuclear-related activities. The recognized classification societies, e.g. members of the International Association of Classification Societies (IACS, 2023) can play an important role regarding certification and quality assurance. They serve as an independent third party that can interact with the various regulatory bodies and the institutions providing education and training and the operating organisations. Classification societies can contribute as follows:

1. Develop learning outcomes for education and training requirements for crew operating and maintaining ships with nuclear propulsion. As well as class standards, guidelines and recommended practice for manning and safe operation of nuclear seagoing IMO vessels

2. Act as a 3rd party verification partner in accordance with IMO MSC.1/Circ.1455 guidelines[3].

3. Play a key role in the process of harmonising nuclear safety management system standards with the maritime international safety management system requirements, The International Safety Management (ISM) Code[4].

[3] For the purpose of not restraining innovation, IMO. (2013). *Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments, MSC.1/Circ.1455*. Were established.

[4] IMO established the ISM Code to provide international standards for pollution prevention and safe management and operation of ships IMO. (2019). *The International Safety Management (ISM) Code*. IMO. https://www.imo.org/en/ourwork/humanelement/pages/ISMCode.aspx

Interaction of stakeholders

The literature review shows that collaboration between research and development institutions of nuclear technology and equipment suppliers is important, not only for keeping up with new technologies but also for developing teaching aids, such as simulators, teaching models and laboratory equipment and on-the-job training. The exchange of knowledge and experience among existing nations that already have nuclear power technology has proven to be invaluable and is a major contribution to supporting new nuclear activities, for instance, the US navy shared its technology with the UK and the crew of Mutsu travelled to the US and Germany for further education and updating.

The US Naval Reactors and the UK Nuclear Department incorporate most of these activities in their organisations through their respective naval nuclear propulsion programs. Further, they are responsible for research and development, building and testing of reactors, as well as education and training. The Japan Nuclear Ship Development Agency cooperated with several organisations and agencies, inter alia, the Maritime Safety Agency and shipping companies (see Table 14 - Courses for the training and education of engineering officers for Mutsu.) in the development of the education and training program of the crew for NS Mutsu.

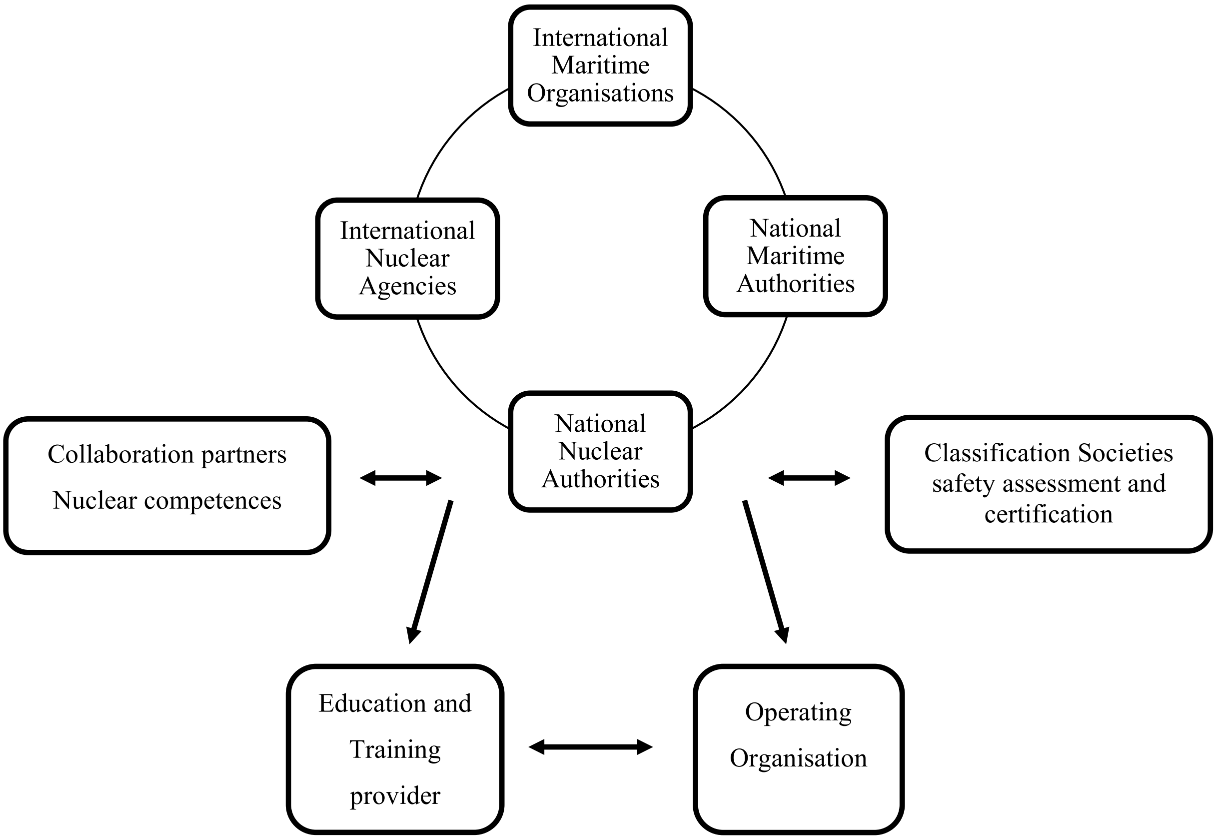

Figure 8 - Interaction of stakeholders

The above figure illustrates interested or concerned parties influencing the performance of the maritime nuclear industry. The stakeholders identified in this review are national and international regulatory bodies for the nuclear and the maritime industries. In particular, international organisations such as the IAEA and IMO stand out as primary organisations. Regulatory bodies such as ONR, U.S NRC and NRA cover the nuclear regulations whilst the U.S. Coast Guard, Japan Coast Guard and U.K Maritime and Coastguard Agency cover the maritime domain. The operating organisations identified in this review are for the US navy, Naval Reactors and for the U.K, the Nuclear Department. The Japan Nuclear Ship Development Agency was responsible for Mutsu, the New York shipping building company was responsible for the NS Savannah. Typically, the operating organisations for the merchant nuclear-powered fleet will be shipowners or ship managers, since they will serve the same role of responsibility as nuclear facilities and nuclear operators. Other interested parties illustrated as collaboration partners and nuclear competences are identified as being research and development companies of nuclear technology, equipment suppliers and shipyards, as well as education and training providers. The recognized classification societies, e.g. IACS members, play a vital role in the maritime industry regarding certification and quality assurance, referred to by the IMO and MCA see section, The importance of classification societies and program revision.

To ensure that graduates of an education and training program for nuclear-powered vessels acquires the requisite knowledge, skills and competence, it is vital that competences and knowledge are shared when developing an education and training scheme. Education and training providers need to deliver what the industry demands in cooperation with the stakeholders of the industry (see Figure 8 - Interactions of stakeholders).

Finally, it is imperative to instil a new trait of safety culture in ship management companies since there are distinctive variations between operating diesel engines and nuclear powerplants. Research also indicates notable differences in culture regarding management, communication and safety in the nuclear and maritime domain that need to be addressed.

5.2 Conceptual model for education and training for merchant nuclear-powered ships

To develop an educational path for the merchant nuclear fleet, the STCW`s requirements for engineering officers need to be fulfilled. Even if the ship is to have nuclear power as its main propulsion, STCW requirements for engineering officers on ships powered by main propulsion machinery of 3000 KW or more will most probably apply.

In order to fulfil STCW requirements for officer certificates in the merchant marine fleet, several educational institutions in Europe offer this education as a bachelor degree in marine engineering, e.g. Chalmers University in Sweden, University of South East Norway and Escola Superior Náutica Infante D. Henrique, Portugal. These universities are committed to following the European qualification framework for higher education and the standards and guidelines for quality assurance in the European Higher Education Area as well as the STCW.

In addition, the student must complete relevant safety courses and practical work training before becoming a cadet on board a ship to obtain the necessary required sailing time to achieve a valid certificate.

To evaluate the workload of the courses designed for the Mutsu`s engineering officers that were given at university level using ECTS, the following calculation applies:

One academic year is between 1500 and 1800 hours, which corresponds to 60 ECTS, for simplicity 1650 hours is used. Breaking it further down based on the same calculations 1 ECTS is about 27.5 hours (1650 hours / 60 ECTS).

The duration of the nuclear power-related education for Mutsu's engineering officers was 18 months, ranging from 35 to 50 hours a week of workload. Assuming that the average weekly working hours is 42.5 hours this will give approximately 170 hours a month, based on a 4 -week month (42.5 hours x 4 weeks = 170 hours/month). One month will then correspond to approx. 6 ECTS (170 hours pr month / 27.5 hours pr ECTS). Table 18 – Course workload for Mutsu engineering officers with ECTS, supplements Table 14 - Courses for the training and education of engineering officers for Mutsu with ECTS.

Table 18 - Course workload for Mutsu engineering officers with ECTS

Course	Institution provided	Duration	ECTS
Nuclear reactor general course	Nuclear reactor school, Japan Atomic Energy Research Institute (JAERI)	6 months	36
Reactor plant Operation and Management	JAERI	6 months	36
R1. Advanced Course (Engineering branch or Radiation control and Protection course)	Radio isotope school, JAERI and National Institute of Radiobiological Sciences (NIRS)	2 months	12
Instrumentation course	System manufacturers	1 month	6
Orientation Simulator training Damage control & Miscellaneous	Japan Nuclear Ship Development Agency (JNSDA)	3 months	18
Total Duration and ECTS		18 Months	108 ECTS

This corresponds almost to two full academic years, equivalent to 120 ECTS. Sasaki states that the program could have been carried out in a more efficient way if, for instance, it had been arranged in its entirety at one university (Sasaki, 1973).

Against this background, it becomes clear that all maritime nuclear power-related education and training for engineering officers needs to be covered in addition to the STCW`s requirements. This is supported by the training of the engineering officers for the earlier experimental nuclear merchant ships, Mutsu and the NS Savannah. For engineering officer positions, crew members with extensive experience either as chief, first or second engineer officer certificate or equivalent competence, were selected for further nuclear education and training (Hall et al., 1976; Sasaki, 1973). This is also the practice of the UK Navy, where the prerequisite for the nuclear reactor course is experience as marine engineering officer or participation in the systems engineering management course (Phil Beeley et al., 2004). Admission in the navy for students wishing to start the officer education and training at the nuclear power school requires graduation from college or a university within the academic technical fields or specialisation in mathematics, engineering, physics or chemistry(National Nuclear Security Administration, 2022).

Additional Nuclear education and training for engineering officers

When developing a program for additional nuclear education and training there are several high priority skills that should be the learning objectives of such a program, namely, management, leadership and communication, problem solving, analytic and critical thinking, engineering, technology, as well as safety skills. The IAEA stresses that comprehensive skills in problem solving, analyses and communication are vital. These skills correspond with the qualitative phase of the SOLO taxonomy (see Figure 1- SOLO taxonomy in five levels). There is also a large regulatory body of both the maritime and the nuclear domains, covering procedures and standards on how various tasks are to be executed that needs to be integrated with the program.

The ENEN`s European Master of Science in Nuclear Engineering is in line with international regulations regarding safety standards for nuclear operations onshore and covers a wide range of different nuclear technologies. Hence this program can be a steppingstone towards achieving compliance with the needs of the maritime and the nuclear industry requirements and regulations (see Figure 8 - Interaction of stakeholders).

It is expected that program graduates are capable of safely managing, operating and maintaining a nuclear-powered ship in normal and abnormal circumstances, including emergencies in remote areas.

A conceptual educational model that should cover the maritime and nuclear domain can point in the direction of a master of science, e.g. Master of Science in Maritime Nuclear Operations. In this case, nuclear and maritime regulatory bodies, operating organisation and technology makers (see Figure 8 – Interaction of stakeholders) actively participate in developing learning outcomes and assessment tasks to ensure that the learning outcome of such a program serves its purpose. This can be achieved through the implementation of SAT (see Figure 7- Overview of the SAT process) in combination with the SOLO taxonomy (see Figure 1- SOLO taxonomy in five levels). Thus, the program is developed within the framework of the qualitative phase of the SOLO taxonomy and the second cycle qualification of the Qualifications Framework for the European Higher Education Area. The program should incorporate proper methods for assessment ensuring that the students have achieved the expected level of knowledge, skills and competencies through constructive alignment (see Figure 2- Aligning intended learning outcomes, teaching and assessment tasks) as illustrated in Figure 9, conceptual educational framework for maritime nuclear operations.

Bachelor Marine Engineering **180 ECTS**	→	**Master of Science in Maritime Nuclear Operations** **120 ECTS**
Bachelor program covering IMO`S STCW requirements and additional prerequisites for Master programs in nuclear engineering (e.g. Calculus based mathematics and physics 1 & 2 and introduction to nuclear engineering) Teaching and learning activities and assessment tasks are aligned with learning outcomes (see Figure 2- Aligning intended learning outcomes, teaching and assessment tasks)		Master program covering ENEN`s requirements for the European Master of Nuclear Engineering and maritime management and technology (see Table 19 - Master of Science in maritime nuclear operations) Teaching and learning activities and assessment tasks are aligned with learning outcomes (see Figure 2- Aligning intended learning outcomes, teaching and assessment tasks)
Intended learning outcomes Intended learning outcomes relevant to the first cycle qualification of the Qualifications Framework for the European Higher Education Area Using level 4 in the qualitative phase of the SOLO taxonomy to develop learning outcomes with verbs like compare, contrast, explain, analyse, relate, apply (see Figure 1- SOLO taxonomy in five levels) based on knowledge, skills and competences defined by IMO`S STCW and prerequisites for Master programs in nuclear engineering		Intended learning outcomes Intended learning outcomes relevant to the second cycle qualification of the Qualifications Framework for the European Higher Education Area Using level 5 in the qualitative phase of the SOLO taxonomy to develop learning outcomes with verbs like theorise, generalise, hypothesise, reflect, apply, relate in addition to level 4 verbs (see Figure 1- SOLO taxonomy in five levels) based on knowledge, skills and competences defined by nuclear and maritime regulatory bodies, operating organisation and technology makers (see Figure 8 – Interaction of stakeholders)

Figure 9 - Conceptual educational framework for maritime nuclear operations.

The model presupposes the development of an updated set of rules and regulations that blends the maritime domain with the nuclear domain, namely the IMO and the IAEA. The Master of Science of Maritime Nuclear operations (MSMNO) program, could then cover the necessary additional requirements for the safe operation of merchant nuclear-powered vessels. One possibility is to harmonise MSMNO with the recommendations and qualification requirements of the European Nuclear Education Network`s framework for the European Master of Science in Nuclear Engineering (EMSNE), which is already in line with IAEA recommendations.

The total course load leading to the ENEN`s master degree in nuclear engineering must be at least 300 ECTS (European Credit Transfer System) at university level, of which at least 60 ECTS credits must be in nuclear science and technologies, preferably nuclear engineering. (Safieh et al., 2011).

Students of the European Master of Science in Nuclear Engineering, who are exchange students at an academic ENEN member institution, are able to apply for The European Master of Science in Nuclear Engineering Certification. This requires a master's thesis or 20 ECTS in some of the compulsory subjects.

A master of science program in maritime nuclear operations incorporating the European master of science in nuclear engineering could take the form of Table 19, Master of Science in maritime nuclear operations, blending the nuclear and maritime domains.

Table 19 - Master of Science in maritime nuclear operations

60 ECTS Covering:	60 ECTS Covering:
ENEN`s European master of science in nuclear engineering (see Table 17)	Maritime management, Maritime technology and engineering Research methods and Master Thesis

On completing academic education, further training in the form of cadet time must be provided by the operating organisation, which must ensure practical training for the cadets on relevant nuclear propulsion plant under the supervision of qualified approved instructors.

The cadet must then validate the achievement of proper knowledge, skills and competences according to the intended learning outcomes to the certifying authorities, issuing certificates satisfying the administrations requirements in the maritime and the nuclear domains as illustrated in Figure 10 – On-the-job training and certification.

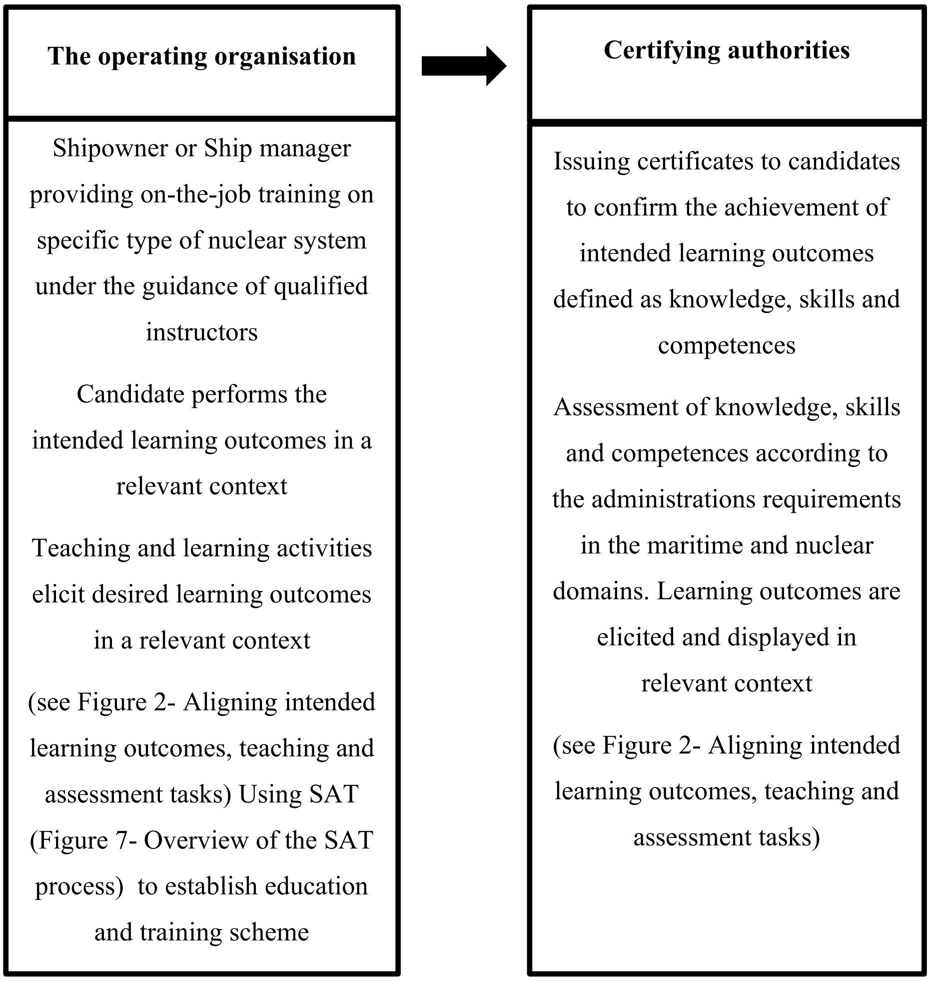

Figure 10 – On-the-job training and certification

The rationale of such a comprehensive educational model is that the marine engineering officers are responsible for all technical systems related to the engine department, both nuclear and non-nuclear main and auxiliary systems. The engineering officers are expected to supervise and operate these systems and manage the technical crew. They must have a thorough understanding of how the systems and processes work and interact with each other in miscellaneous scenarios, for instance, at sea, where changing conditions such as wind and waves affect the operation. The engineering officers are expected to perform leadership that promotes the highest standards regarding safety culture and team management and ensure compliance with steering documents and procedures satisfying both the nuclear and the maritime domains. When considering crew size, it is important to note that when comparing naval nuclear surface vessels with the merchant fleet, the latter, due to economic reasons, will most likely have the minimum number of crew required to operate the ship in a safe manner. This places extra demands on the engineering officers with regard to knowledge, skills and competences, which is quite similar to the demands placed on nuclear submarine officers for operating the nuclear power plant and its auxiliary equipment, as well as managing the crew of a submarine.

The Nuclear Reactor Course arranged by the Royal Navy at HMS Sultan awards a post-graduate diploma in Nuclear Reactor Technology engineering (Phil Beeley et al., 2004), thus it is aligned with the second cycle qualification of the qualifications framework for the European Higher Education Area. Considering that ships operate in remote places, the candidates of such a program must have an in-depth understanding of the nuclear propulsion system and be competent to operate it under normal, abnormal and emergency conditions. To quote Admiral Rickover, a pioneer in the development of naval nuclear power who led the Nuclear Propulsion Program for 33 years, "the nuclear propulsion plant operators must know more than simply what to do in any given situation, they must understand why." (National Nuclear Security Administration, 2022, p. 21)

6 Conclusion

The goal of this study was twofold: firstly, to explore what level of competence should be acquired by engineering officers on a modern merchant nuclear-powered ship, secondly, to determine how an appropriate program could be structured and executed in the future.

The objective was to create a basis for research projects concerning competence, training and education for engineering officers on nuclear-powered merchant ships. The research questions developed to achieve this goal are explained below:

RQ 1 What can be gained from studying current US and UK Naval Nuclear Propulsion Programs concerning education and training of engineering officers?

Firstly, education and training in the naval nuclear fleet are part of one organisation that is responsible for the whole life cycle of the nuclear propulsion program, ranging from research and development activities to construction, commissioning, maintenance, operation and disposal. Secondly, there are many indications that the education and training are given at a higher academic level that corresponds with the first and second cycles of the qualifications framework for the European Higher Education Area.

These education and training programs consist of teaching and learning activities, such as classroom lessons, laboratory work, simulator training and on-the-job training. Unfortunately, the literature reviewed does not clarify the specific learning outcomes and objectives in terms of knowledge, skills and competence, but rather outlines the subjects that are taught.

RQ 1.1 What rules and regulations apply to the education and training program of engineering officers on nuclear-powered vessels?

Regarding the rules and regulations for the education and training of engineering officers on nuclear-powered ships, in addition to the STCW, Resolution A.491 (XII), The Code of Safety for Nuclear Merchant ships applies. The Maritime & Coastguard Agency has adopted IMO`s Code of Safety for nuclear merchant ships in The Merchant Shipping (Nuclear Ships) Regulations 2022.

However, IAEA has several updated publications and safety standards addressing the education and training of nuclear power plant personnel e.g. “Systematic Approach to Training for Nuclear Facility Personnel, Processes, Methodology and Practices, 2021” and “Recruitment and Qualification and Training of Personnel for Nuclear Power Plants, 2022”.

Should the IMO update its Code of Safety for Nuclear Merchant ships, the foregoing standards and publications could have an impact on the education and training programs of engineering officers on nuclear-powered vessels.

RQ 1.2 What themes and elements were contained in the education and training program for engineering officers on earlier merchant nuclear-powered ships and how was the programs carried out in the past?

This study reviews the education and training of the engineering officers of the former nuclear-powered experimental ships, NS Savannah and NS Mutsu and The Department of Transportation's report, Recommendations for Qualifications of Engineering Personnel of Nuclear-Powered Ships. This review reveals that the education and training were carried out by a combination of state and private institutions but coordinated by one organisation in collaboration with regulatory bodies and equipment developers and suppliers. The education and training comprised teaching and learning activities such as classroom lessons, laboratory work, simulator training and on-the-job training and outlines the subjects that were taught. Unfortunately, the literature that has been reviewed does not clarify the specific learning outcomes and objectives in terms of knowledge, skills and competencies.

RQ 1.3 What should future education and training programs for engineering officers on merchant nuclear-powered ships contain and how should they be structured and executed?

This study proposes a conceptual model of a Master of Science in Maritime Nuclear Operations for the education and training of engineering officers for merchant nuclear-powered ships. Furthermore, it suggests a modernised bachelor's degree in marine engineering incorporating the STCW requirements for engineer officers and the prerequisites for Master programs in nuclear engineering.

7 Suggestions for further research

A common denominator of the nuclear propulsion fleet over the years is that the reactor technology mostly is mainly a form of pressurised water reactor (PWR). Although the PWR is a very well-tested reactor, it is not necessarily the optimal choice for merchant shipping. For instance, the molten salt reactor might be more suitable for merchant vessels because it has certain advantages over PWRs, such as passive safety, low weight and low cost (Freitas Neto et al., 2021). Since most of the literature found in this study deals with PWR, it is reasonable to compare PWR technology with SMRs characteristics in order to reveal certain differences and similarities that may be decisive factors when determining a possible educational path.

Research needs to be done into evaluating which reactor technology is the safest and most suitable for merchant nuclear-powered propulsion. It is important to ascertain whether future technology adopted by merchant shipping will have significant consequences for any education and training program.

Due to the safety aspects of the nuclear power and maritime industries and considering that shipping is an international concern, it will be natural for the existing rules and regulations of the maritime and nuclear domains to be revised and harmonised, particularly emerging nuclear technologies. The results of such initiatives may have a material impact on the design of education and training programs for engineering officers on nuclear-powered merchant vessels.

There may also be a need to elucidate the contrast existing between work cultures of the maritime industry and the nuclear power industry, especially regarding safety culture. Further, solutions to alleviate such contrasts should be generated for the benefit of the upcoming nuclear-powered merchant fleets.

Research needs to be done into developing detailed learning outcomes, teaching and learning activities and assessment tasks with ECTS that fulfil the needs of the industry and the regulatory bodies of the maritime and nuclear domains. This initiative assumes that the preferred reactor technology is in place, together with the associated regulatory framework. Before a detailed program description for the education and training of the crew of nuclear-powered vessels can be developed, efforts should be made by national and international authorities concerning maritime and nuclear regulations for achieving updated and harmonised rules and regulations.

Research should be conducted into the political and economic feasibility of implementing such a learning and training program, in addition to seeking international collaboration regarding education and training for future advanced maritime nuclear technology.

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9 Appendix 1, Literature search results table

The articles, publications and reports from the various searches are listed in Table 20, literature search results table. Table 20 presents the literature that the author has selected for full-text review for potential inclusion in the final literature review (see Table 8) as well as those that have been excluded.

Table 20 - Literature search result table

Author	Year	Comments	Source
Wang, C., Wang, Z., Xu, S.	2022	Full text reviewed by author for potential inclusion	Scopus
Miller et al.,	2017	Full text reviewed by author for potential inclusion	Scopus
Beller, D., Sanders, C., Hua, F.	2013	Full text reviewed by author for potential inclusion	Scopus
Thunem, et al.,	2012	Full text reviewed by author for potential inclusion	Scopus
Kmec et al.,	2011	Excluded, not available	Scopus
Tipping, T.N.	2011	Full text reviewed by author for potential inclusion	Scopus
Narabayashi et al.,	2009	Excluded, not available	Scopus

Beeley, P., Harrop, I., Lockwood, R.	2004	Full text reviewed by author for potential inclusion	Scopus
Coe, R.	2003	Full text reviewed by author for potential inclusion	Scopus
Brushwood et al.,	2002	Full text reviewed by author for potential inclusion	Scopus
Lakey, J.R.A., Roust, C.B.	1988	Full text reviewed by author for potential inclusion	Scopus
Lakey et al.,	1986	Full text reviewed by author for potential inclusion	Scopus
Head et al.,	1986	Full text reviewed by author for potential inclusion	Scopus
Sasaki, Shuichi	1973	Full text reviewed by author for potential inclusion	Scopus
UK Government	2022	Full text reviewed by author for potential inclusion	Regs4Ships
Maritime & Coastguard agency	2022	Full text reviewed by author for potential inclusion	Regs4Ships
IMO	1981	Full text reviewed by author for potential inclusion	Regs4Ships

IAEA	2022	Full text reviewed by author for potential inclusion	Iaea.org
IAEA	2021	Full text reviewed by author for potential inclusion	Iaea.org
IAEA	2021	Full text reviewed by author for potential inclusion	Iaea.org
IAEA	2021	Full text reviewed by author for potential inclusion	Iaea.org
IAEA	2001	Full text reviewed by author for potential inclusion	Iaea.org
NISA	2022	Full text reviewed by author for potential inclusion	Energy.gov
Safieh et al.,	2011	Full text reviewed by author for potential inclusion	Science Direct
Hall et al.,	2017	Full text reviewed by author for potential inclusion	Oria
Total articles, publications and reports for full text review for potential inclusion			25