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Identification of coverage of quality assurance program for maintenance naval base to the Brazilian conventional nuclear-powered submarine

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ABSTRACT

The purpose of this study is to identify the coverage of quality assurance program (QAP) to be applied on a Maintenance Naval Base to the Brazilian conventional nuclear-powered submarine. Based on literature review and documents collected at the Angra I nuclear power plant, located in Brazil, it was possible to determine the coverage of QAP for a Brazilian Naval Base that will perform maintenance services on a conventional nuclear-powered submarine. The data were complemented by 6 interviews with specialists from nuclear sector. Regarding the countries that have nuclear-powered submarines, QAP implemented in their Maintenance Bases are confidential information. Another finding, based on the field research, showed that the QAP existing at the Angra I surpassed the 13 requirements established by Standard CNEN-NN-1.16 (Quality Assurance for the Safety of NPP) and, according to the interviewees, can be adapted for the Naval Maintenance Base of the Brazilian Navy. Thus, this study points out 25 requirements that can be used for the establishment of a QAP for the Naval Base in the operation phase of the conventional nuclear-powered submarine; The lack of technical standards and academic literature on the development of QAP, this study can serve as a guideline for the development of a QAP for Maintenance Naval Bases of Nuclear Submarines by the countries interested in this military technology.

Keywords: **Maintenance and support Base, Nuclear Submarine, Quality Assurance Program.**

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1. INTRODUCTION

Brazil has an oceanic region of approximately 5.7 million km2 and a coastline of approximately 7.500 km in length. Due to the dimensions and the existing biodiversity, this region is called the Blue Amazon, in allusion to the green Amazon. This region has geostrategic importance for Brazil, in addition to its economic, scientific, and environmental importance.

In defense of the national maritime territory, the Brazilian Navy conducts the Navy Nuclear Program (PNM) and the Submarine Development Program (PROSUB), aim in gat the construction of the first conventional submarine with national nuclear propulsion [1]. For this, among other initiatives, the Naval Base for Maintenance and Support was built, with a structure capable of meeting the new needs imposed by the development of the nuclear submarine without offering risks to the health of workers, society, and the environment.

In this context, the national nuclear energy commission (CNEN), the licensing body for nuclear activities in the country, establishes mandatory requirements that determine the establishment of a Quality Assurance System (QAS). This QAS must be described through a Quality Assurance Program (QAP), which must be submitted to CNEN for purposes of licensing the nuclear plant. The QAP is the document, for licensing purposes, that describes and presents the organization's commitments for the establishment of the QAS [2].

However, CNEN does not have a regulatory framework related to the activities of using nuclear reactors used as a source of energy in means of transport or propulsion [3], nor for the licensing process for a Naval Maintenance Base for a conventional nuclear-powered submarine. To fill this gap, the Brazilian government enacted Law No. 13.976, of January 7, 2020, where it is assigned to the Navy Command to promote the licensing and inspection of naval assets and their nuclear plants shipped for propulsion, by organization independent military service for this purpose, in addition to the transportation of its nuclear fuel. Said licensing involves, as a prerequisite, the elaboration of a QAP applicable to the Naval Base for Maintenance and Support.

A detailed QAP was pioneered applied in nuclear energy technology by American Society of Mechanical Engineers (ASME), instituting a QAP for manufacturers of nuclear components, and it was applied by space programs and the US Navy Nuclear Program to the first nuclear aircraft carriers and submarines [4]. After the disaster of USS Nuclear Submarine Thresher, there was necessary to reemphasize and improvement of QAP in shipbuilding and repair yards [5,6]. However, specific coverage of this QAP is classified by Navy Forces for strategic reasons.

Considering the unprecedented nature of the Brazilian initiative and the consequent unavailability, for reasons of military secrecy, of international standards for the establishment of QAS and QAP for the licensing of conventional nuclear-powered submarines, there are no QAP in the literature developed for a Naval Base for Maintenance and Support of conventional nuclear-powered submarines. Thus, the objective of the present work is to identify the scope for the QAP of the Naval Base for Maintenance and Support of conventional nuclear-powered submarines in Brazil.

2. MATERIALS AND METHODS

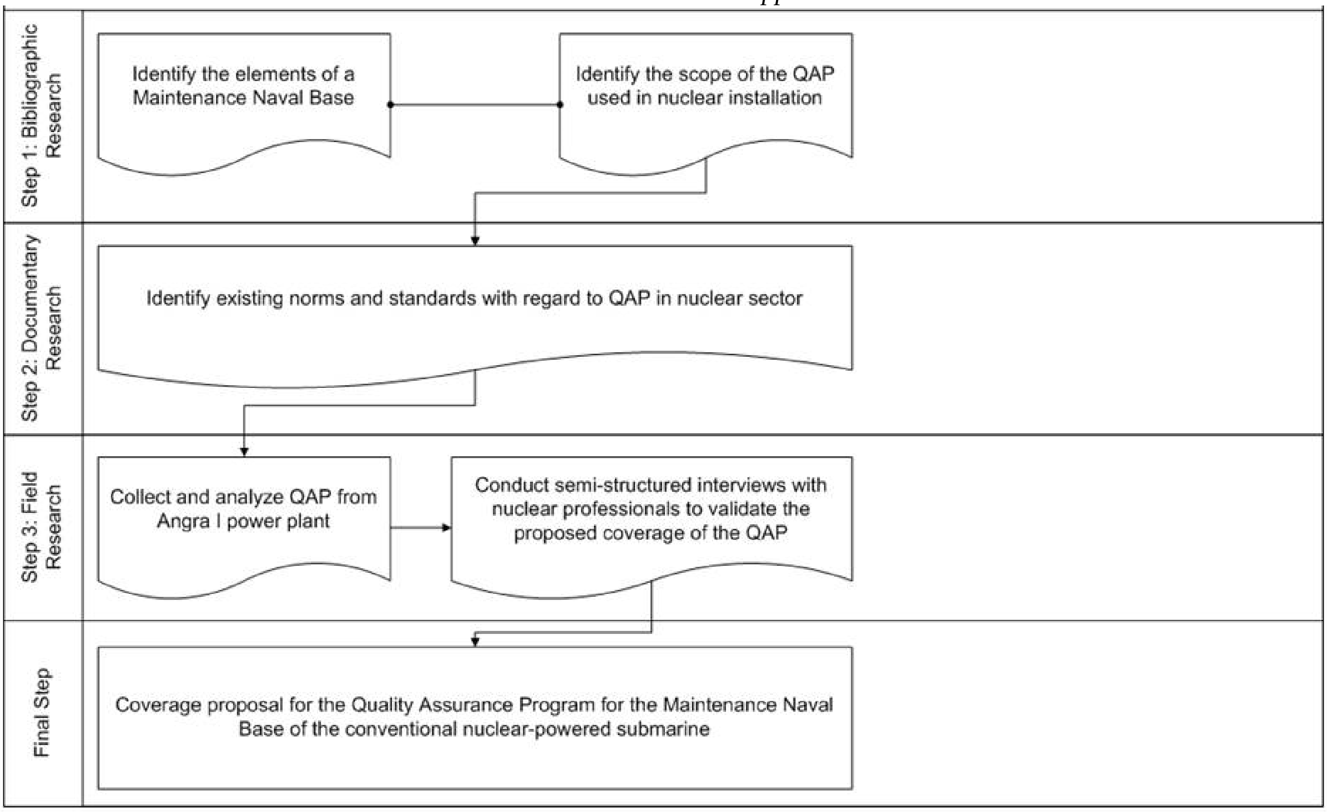
The research carried out is classified as qualitative, where it is the responsibility of the researcher to interpret the phenomena and present their meanings. The method used in the present article is the single case study research and data were collected through bibliographical and documentary research, field research with semi-structured interviews and systematic observation, summarized in Chart 1.

The bibliographic research has the objective to identify the main services that need to be present in a Naval Maintenance Base for a conventional nuclear-powered submarine. For this, were consulted databases of Scientific Electronic Library Online (SciELO), which covers a selected collection of Brazilian scientific journals, and Scopus, with abstracts and citations of peer-reviewed literature, with bibliometric tools to accompany, analyze and visualize the research. Other publications available in the following databases were also collected: Google Scholar, Theses and Dissertations Catalog from the Coordination for the Improvement of Higher Education Personnel (Capes) and Scopus.

The purpose of documentary research is to identify existing norms and standards regarding quality assurance programs in the nuclear sector. The entities surveyed were: Society of Mechanical Engineers from the United States (ASME), International Organization for Standardization (ISO), North Atlantic Treaty Organization (NATO), Naval Forces which have nuclear submarines websites; American Nuclear Society (ANS), European Nuclear Society (ENS), International Atomic Energy Agency (IAEA) and Nuclear Atomic Energy Commission (CNEN).

The Nuclear Power Plant of Angra dos Reis (Angra I), located in the Rio de Janeiro State, was selected for the case study because of the similarities with your nuclear reactor and nuclear reactor of Brazilian conventional nuclear-powered submarine. The case study was performed with field research, to collect and analyze the Angra I QAP and to validate the coverage of QAP proposed for Naval Base generated from bibliographical and documentary researches. For this, the interviews were conducted from direct observation techniques in Angra I, took place between November 16th and November 20th. In all, 6 interviews were conducted with the following professionals: 01 Quality Assurance Supervisor, 02 Maintenance Engineers of the nuclear plant, 01 CNEN resident inspector and 02 academic professionals.

Chart 1: *Research method applied*



2.1. Heading 2

Leave one blank line before the second level headings. Use 3pt space after the second level headings. Second level headings should be numbered with Arabic numerals and typed in Times New Roman, 12 pt, bold, only the first letter of the first word capitalized. Avoid using more than two heading levels.

3. RESULTS AND DISCUSSION

3.1. Main services necessary for a navy base for maintenance of conventional nuclear-powered submarines.

The Naval Base for Maintenance of conventional Nuclear-powered submarines [7], is a group composed of a construction site and a naval base, equipped with maritime and retention structures, necessary to support nuclear-powered naval submarines throughout their entire cycle life.

Were identified [8] and described the structure and systems of a support base used to provide maintenance and support services to the North American nuclear propulsion Ship NS Savannah, consisting of:

a) Nuclear Support Facilities;
b) Docks and piers;
c) Dry Dock;
d) Nuclear Maintenance Building;
e) Maintenance building;
f) Waste Management System;
g) Waste Storage Area;
h) Decontamination Area;
i) Fuel Exchange Area;
j) Packaging Storage Area; and
k) Interconnection Structure.

The authors [7] divides the Naval Maintenance Base into 4 major systems, namely:

a) Primordial Systems for serving the Conventional Nuclear-Powered Submarine;
b) Support Systems for structure, systems and components (SSC) of the Primordial System;
c) The Essential Services System (ESS); and
d) Diffuse Systems.

The Primordial Systems are the Maintenance and Repair System (MRS) and the Fuel Exchange System (FES). The MRS is divided into Aground and Dockage System (ADS), Conventional Maintenance System (CMS) and Nuclear Maintenance System (NMS).

a) **Maintenance and Repair System (MRS):** A structure should be provided to make it possible to place the ship onshore and to meet the demands for the maintenance of the conventional nuclear-powered submarine. The MRS must allow access to the nuclear structures, systems and components of the ship in order to carry out inspections, tests and replacements. Services such as changing and refilling fuel are outside the scope of this system.

i) **Aground and Dockage System (ADS):** Structure capable of transporting the Ship from the water to a dry platform, using a dry dock, or lifting equipment such as shiplift or lock system. Tug ships, pumping system and the structure that receives the ship are also part of this System.

ii) **Conventional Maintenance System (CMS):** In this system, maintenance of the ship's SSC that are not radioactive is foreseen. This maintenance can be carried out with the submarine in water or the dry, depending on the complexity of the services.

iii) **Nuclear Maintenance System (NMS):** A nuclear maintenance system must be able to perform maintenance services in SSC in hot areas. All the waste must be packaged and transported in a safe manner, or in the case of discharge of waste by dilution or dispersion, which are within the limits established in standards and regulations. For attenuation of radiation levels, natural radioactive decay can also be used.

The FES is divided into Exchange and Recharge System (ERS), New Fuel Storage System (NFSS) and Removed Fuel from Reactor Storage System (RFRS).

b) Fuel Exchange System (FES): Its objective is to change the fuel element inside the nuclear-powered naval reactor, being composed of the Exchange and Recharge Systems (ERS), New Fuel Storage System (NFSS) and Removed Fuel from the reactor storage system (RFRS). The FES should be able to remove used fuel elements and store them, as well as move new fuel elements and insert them into the reactor.

i) **Exchange and Recharge Systems (ERS):** ERS is responsible for providing all means for fresh fuel handling and use, areas and facilities to be used in refueling operation, qualification and training of personnel, testing on the refueling equipment and verification of procedures on fuel exchange.

ii) **New Fuel Storage System (NFSS):** NFSS is responsible for the proper handling and storage of new fuel elements. It is also responsible for handling and transporting material from the stored location to the place of use, using cranes, cranes, bridges, and gantries safely.

iii) **Removed Fuel from Reactor Storage System (RFRS):** RFRS is the system responsible for handling and transporting the used elements from the reactor to the storage location. The system must be capable of removing residual heat from the elements and storage in packages up to the provisional deposit (swimming pool).

The Support System is composed of Waste Management System (WMS). It consists of the Decontamination System (DS), the Low-Level Radiation Management System (LRWS) and the High-Level Radiation Waste Management System (HLRWS).

c) **Wasted Management System (WMS):** It is responsible for the activities of collection, segregation, handling, treatment, conditioning, transportation, storage, control and deposition of radioactive waste. Composed of Decontamination Systems (DS), Low-Level Radiation Waste Management System (LRWS) and High-Level Radiation Waste Management System (HRWS).

i) **Decontamination System (DS):** DS is the system equipped with means to concentrate all liquid, solid and gaseous effluents in collection points.

ii) **Low-Level Radiation Management System (LRWS):** It is a system that aims at the collection, segregation, handling, treatment, conditioning, transport, storage, control and disposal of low radioactivity waste, whether they come from nuclear-powered ships or support vessels or radiological areas of the Base, for example: workshops, radio accident wards, hot laundry, etc.

iii) **High-Level Radiation Waste Management System (HRWS):** It is a system that aims at the collection, segregation, handling, treatment, conditioning, transportation, storage, control and disposal of highly radioactive waste.

d) **Essential Services System (ESS):** It is responsible for providing services such as electricity, water, compressed air, gases, sewage collection, etc. for the entire Naval Base. It consists of the Essential Conventional Services System (ECSS) and the Essential Nuclear Services System (ENSS).

i) **Essential Conventional Service System (ECSS):** It is responsible for provide network electric power services, water, pressurized air etc., except for nuclear systems.

ii) **Essential Nuclear Services System (ENSS):** It is responsible for providing cooling water with proper temperature and pressure to remove residual heat from the reactor. It also provides electric power source, pressurized air etc. to reactor safety systems and nuclear areas.

e) **The Diffuse Systems:** are systems that permeate the others and have different functions within the structure of the Naval Base.

i) **Health Care Support System (HCSS):** This system is responsible for providing emergency health services for workers, both in cases of conventional nature and in cases of radiological nature.

ii) **Monitoring and Radiological Protection System (MRPS):** This system is responsible for maintaining control and recording of the conditions of individual protection equipment and protective barriers as well as the monitoring equipment itself. The system provides monitoring of water, gases and waste from the ship, as well as shielding installation where necessary.

iii) **Industrial Safety System (ISS):** This system is responsible for protecting the lives of workers and prevent accidents.

iv) **Nuclear Safety System (NSS):** It is responsible for nuclear safety in all areas where there is a radiological risk of the Naval Base. Also, it is responsible for enforcing the requirements of nuclear safety authority in all nuclear areas. It should be noted that the NSS team must work together with the Quality Assurance personnel of the Base, inspecting activities and procedures, and recording events and occurrences.

v) **Physical Protection System (PPS):** It aims to prevent acts of sabotage, loss of material, defense of property, etc. The System also aims to create physical barriers, preventing access by unauthorized persons.

vi) **Quality Assurance System (QAS):** It must ensure that all activities that influence safety are carried out under approved procedures. Quality assurance personnel are responsible for advising the managers of other systems on the issue of quality assurance, enforcing standards and procedures, both internal and of the licensing body, conducting inspections and audits in the areas.

3.2. Identification of coverage of quality assurance program in bibliographic research.

Wilde et al [9] comment that American nuclear plants operated by the Department of Energy (DOE) or the American Department of Defense (DOD) are licensed by the U.S. Nuclear Regulatory Commission (NRC) under a rigorous and documented quality assurance program. The authors present and list in Chart 2 the main codes and standards used in the United States, including: 10CFR50 Appendix B (Code of Federal Regulation – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants), 10CFR 830 Subpart A (Quality Assurance Requirements), American Society for Mechanical Engineering NQA-1 (Quality Assurance Requirements for Nuclear Facility Applications), DOE-RW-0333P (REV5) and DOE Order 414.

Chart 2: *Quality assurance standards used in American Nuclear Industry*

ASME-NQA-1-2000	1.Organization; 2.Quality Assurance Program; 3.Design Control; 4.Procurement Document Control; 5.Instructions, Procedures & Drawing; 6.Document Control; 7.Control Purchased Items & Services; 8.Identification & Control Items; 9.Control Processes; 10.Inspection; 11.Test Control; 12.Control Measuring & Test Equipment; 13.Handling, Storage & Shipping; 14.Inspection, Test & Operating Status; 15.Control Nonconforming Items; 16.Corrective Action; 17.Quality Assurance Records; 18.Audits
10 CFR 50, Appendix B	1. Organization; 2. Quality Assurance Program; 3. Design Control; 4. Procurement Document Control; 5. Instructions, Procedures, & Drawings; 6. Document Control; 7. Control Purchased Material; Equipment, & Services; 8. Identification & Control Materials, Parts, & Components; 9. Control Special Processes; 10. Inspection; 11. Test Control; 12. Control Measuring & Test Equipment; 13. Handling, Storage, Shipping; 14. Inspection, Test, & Operating Status; 15. Nonconforming Materials, Parts, Components; 16. Corrective Action; 17. Quality Assurance Records; 18. Audits
DOE 414 Series	1. Program; 2. Personnel Training & Qualifications; 3. Design; 4. Procurement; 5. Work Processes; 6. Documents & Records; 7. Inspection & Acceptance Testing; 8. Quality Improvement; 9. Management Assessment; 10. Independent Assessment
DOE/RW-0333P (Rev. 5)	1.Organization; 2. Quality Assurance Program; 3.Design; 4.Procurement Documents; 5.Implementing Documents; 6.Document Control; 7.Procurement Supplement/Software Control; 8.Identification & Use Items Supplement/Control Physical "Samples Supplement/Requirements Field Surveying; 9.Control Special Processes Supplement/Scientific Investigations; 10.Inspection; 11.Testing; 12.Control, Calibration & Maintenance Measuring & Test Equipment; 13.Handling, Storage, Cleaning,Packaging, Shipping, Preservation; 14.Inspection, Test, & Operating Status Items; 15.Control Nonconformances; 16.Control Conditions Adverse To Quality; 17.Quality Assurance Records Supplement/Electronic Management Data; 18.Internal & External Audits
10 CFR 830, SUBPART A	1. Organization; 2. Quality Assurance Program (NQAP-2.1); 3. Design Control; 4. Procurement Document Control; 5. Instructions,Procedures & Drawings; 6. Document Control; 7. Control Purchased Material, Equipment & Services; 8. Identification & Control Materials, Parts & Components; 9. Control Special Processes; 10. Inspection; 11. Test Control; 12. Control Measuring & Test Equipment; 13. Handling, Storage & Shipping; 14. Inspection, Test & Operating Status; 15. Nonconforming Materials, Parts Or Components; 16. Corrective Action; 17. Quality Assurance Records; 18. Audits

Source: (Wilde et al., 2008) [9]

Also according to the authors, all applicants for a construction license issued by the NRC must include in their PSAR a description of the QAP to be applied to the phases of design, manufacture, construction and testing of structures, systems and components of the installation, under code 10CFR50.34 (Contents of applications; technical information).

Besides, US applicants must include information regarding management and administrative controls to be used to ensure safe operation, such as control of: design, procurement, manufacture, handling, shipping, storage, operation, maintenance. The activities of cleaning, scaffolding, inspection, testing, replenishment and modification of materials and systems would also be included.

Salvatore [10] reports in CNEN's report 89/80, the adoption of the IAEA Code of Practice 50-C-QA - Quality Assurance for Nuclear Power Plants by CNEN for its use in the licensing of conventional reactors. Additionally, the author comments on CNEN Resolution No. 04/71 directed to the Use of Brazilian Ports, Bays and Territorial Waters by Nuclear Ships.

Guimarães [11] argues that a quality assurance program should cover the entire life cycle of a conventional nuclear-powered submarine, including the design, construction, commissioning, conducting of the operation, operational procedures, maintenance, repairs and inspections phases, and decommissioning. The QAP must ensure that the activities and materials used are following the design documents, written procedures and instructions.

Concerning specific requirements, Guimarães [11] comments that the QAP must ensure that:

a) an organizational structure is established, identifying responsibilities for the program throughout the life cycle of the conventional nuclear-powered submarine;

b) control of all documentation is maintained throughout the life cycle of the conventional nuclear-powered submarine;

c) the materials and procedures are compatible with the required quality level, which corresponds to the safety and design classes assigned to the component or system;

d) the materials and procedures are compatible with the required quality level, which corresponds to the safety and design classes assigned to the component or system;

e) the properties of the materials used are demonstrated before and during manufacture, satisfying the requirements of the approved specifications;

f) the design, procurement, manufacture, transport and handling, storage, installation, maintenance, testing and operational procedures are compatible with the required level of quality, which corresponds to the safety and design classes assigned to the component or system;

g) components and systems are manufactured, installed and maintained according to plans, drawings and specifications approved by Nuclear Safety Authority (NSA);

h) the operation of systems and components obeys the functions specified therein, particularly concerning their safety functions;

i) all basic principles, general criteria and specific requirements, in addition to other requirements of the NSA are fully satisfied; and

j) records are kept of all quality assurance procedures, manufacturing plans, inspections and tests and decisions made in cases of non-compliance.

It should also be noted that procedures must be established to control the preparation, review, approval, issuance, verification and cancellation of all documents essential to the activities that influence quality. Quality assurance records must present objective evidence that quality control has been performed, such as: review, inspection, testing, auditing, activity performance monitoring, material analysis, monitoring of operating variables, failures and deficiencies, repairs and other appropriate data [11].

Concerning project control, procedures must be established to verify the adequacy by using independent reviews, alternative methods of calculation, critical analysis of the assumptions and assumptions assumed and satisfactory performance in tests. About the control of materials, measures must be established so that the equipment and services purchased comply with the procurement specifications. These materials, including pre-assembled subsets, must be identified during installation and operation for their correct use.

As for the selection of suppliers, measures must be established to guarantee the ability to supply materials, equipment and services following the requirements and procurement documents. Regarding the tests, a program must be established containing the planning, identification, performance standards, procedures and documentation of all the tests required to guarantee the requirements of the QAP. This program may include qualification tests of procedures, equipment, qualification of prototypes, before assembly, pre-operational and in-service.

The QAP must be able to ensure that faults, malfunctions, deficiencies, deviations, defective or inappropriate materials and equipment or any other non-conformity, must be detected quickly and corrective actions must be approved and implemented [11].

Baliza [12] comments that the quality assurance requirements started in the United States in 1969, with the proposal to amend the American regulatory code 10CFR50 (Domestic Licensing of

Production and Utilization Facilities), related to nuclear energy. Thus, the code 10CFR50 appendix B - Quality Assurance Criteria for Nuclear Power Plant was intended to establish 18 basic requirements for the design, construction, manufacture and operation of SSC related to the safety of American nuclear installations.

In terms of operational safety, it is necessary to depend on compliance with regulatory and normative, technical or administrative requirements, applicable both in the design and construction phases of the unit, as well as in the operation. This will be possible by establishing the QAP under the requirements of CNEN-NN-1.16, from the design of the installation and extending to the operational phases until the decommissioning of the installation. Long-term safety is achieved by making sure that the waste treated at the facility complies with the acceptance criteria for a final deposit, established by CNEN-NE-6.09 (Criteria for Acceptance and Deposit of Low and Medium Level Radioactive Waste).

Guimarães [14] mentions that an Aging Management Program (AMP) is important to control, within an acceptable limit, the effects of aging degradation, guaranteeing the integrity and functionality of structure, systems and components (SSC) of a nuclear power plant. In the author's view, the AMP should be implemented at the plant to ensure that the SSC functions are maintained from the beginning of the operation until the end of its useful life.

Another point worth mentioning is that the AMP is necessary for the preparation of the Periodic Safety Report (PSR) and in the request for the Plant's life extension. It can be said that the PSR is the report prepared by the operator of the nuclear plant and sent to the regulatory body every 10 years, which determines the impact of the cumulative effects of aging, modifications, operational experience etc. The life extension request is the document also sent to the regulatory agency to extend the period of operation of the Plant beyond its project's useful life.

Also according to the author, there are two lines of methodology for AMP: one based on NRC’s code 10CFR54 (Requirements for Renewal of Operating Licenses for Nuclear power Plants), and another based on the IAEA Safety Guide NS-G-2.12 Aging Management for Nuclear Power Plants. Guimarães [14] adds that the AMP must include an Obsolescence Management Program (OMP) focused on the management of technological obsolescence in SSC.

Regarding the item dedication process, Baliza et al [15] argue that the plants in operation suffer from the problem of lack of qualified spare parts in the market for nuclear use. In this way, the American government, in an attempt to solve the problem, published a revision of code

10CFR21 (Reporting of Defects and Noncompliance), where the requirements for the dedication process were incorporated.

Dedication can be defined as a process that a supplier company guarantees that a commercial-grade item, that is, an item that was designed for a non-nuclear application, can perform its intended safety function in the same way as an item designed and manufactured under the requirements of code 10CFR50 appendix B. The guarantee is obtained through the identification of the critical characteristics of the product and verification of its conformity through inspections, tests or analyzes carried out by the buyer or independent third party (entity dedicator). The structures, systems and components (SSC) used in nuclear applications with safety functions must ensure:

a) The integrity of the reactor cooling system frontier;

b) The ability to shut down the reactor and keep it in a shutdown condition; or

c) The ability to avoid or mitigate the consequences of an accident.

Accordingly, only items designed and manufactured under a QAP that follows 10CFR50 Appendix B or a commercial class item that has completed the complete dedication process under the requirements of 10CFR21, can perform the safety function in a nuclear plant. It is important to note that in Brazil, all items and services acquired during the dedication process must comply with the CNEN-NN-1.16 standard [15].

Because of the above, it can be said that a Naval Base to support the conventional nuclear-powered submarine should acquire security items from companies that have a QAP implemented under the 10CFR50 appendix B code or its national equivalent (e.g. CNEN-NN-1.16) or perform the process of dedicating an item according to the requirements established in code 10CFR21.

Campos et al [16] sought the existing correlation of the regulatory requirements of CNEN-NN-1.16 and ISO-9001 in a Management System. He concludes that an integrated system between these two standards is possible since there is a correlation between them.

In another work [17], the author analyzes the benefits of using the ISO 19443:2018 - Specific requirements for the application of ISO 9001:2015 by organizations in the supply chain of the nuclear energy sector supplying products and services important to nuclear safety (ITNS). According to him, ISO 19443 brought a great contribution to the management models of the nuclear sector and is aligned with the ISO 9001 standard. The author concludes that it is possible to revise the CNEN-NN-1.16 standard by adding requirements brought from ISO 9001 and ISO 19443, such as: risk management, stakeholder management and the context of the organization.

Regarding the long-term operation, Baliza et al [15] comment that the Angra I operation authorization expires in 2024 and that to obtain an extension of the Plant's operation for another 20 years, it was necessary to fulfill the requirements of code 10CFR54 and the technical notes CNEN NT-CGRC-007/18 - Regulatory Requirements for Long Term Operation for Nuclear Power Plants and NT-CGRC-008/18 - Regulatory Requirements for Ageing Management in Nuclear Power Plants.

In this way, it was necessary to demonstrate through analysis, tests, aging management, inspections and system updates that the nuclear plant is capable of operating safely, in addition to the estimated project time. The QAP for life extension needs to include items that are not related to safety but are included in Aging Management. To apply for a license extension, in the case of Angra I power plant, the requirements set out in NRC code 10CFR54 must be followed, in that way:

a) Integrated Plant Assessment, Elaboration of the Aging Management Review and Aging Management Programs;

b) Revalidation of the Time-limited aging analyzes;

c) Changes in the current licensing base and, if they occur, during the evaluation process of the license renewal request; and

d) Supplements to the Final Safety Analysis Report (FSAR) describing the aging management program, revalidation of TLAA (Time Limited Ageing Analyses), and changes in Technical Specifications.

Also according to the mentioned authors, for the Plant's Long-Term Operation ware considered the recommendations of the technical note CNEN 07/2018, with the following topics:

a) Plant programs;

b) Qualification of environmental equipment for electrical and instrumentation and control components (US-NRC 10CFR50.49 - Environmental qualification of electric equipment important to safety of nuclear power plants);

c) Evaluation of the Maintenance Effectiveness Monitoring Program (US-NRC 10CFR50.65 - Requirement for monitoring the effectiveness of maintenance at nuclear power plants);

d) Review of Aging Management;

e) Time Limited Ageing Analyses (TLAA) revalidation;

f) Technological obsolescence program;

g) Periodic Safety Review related to the LTO (Long term Operation);

h) Final Security Analysis Report, including the Review of the Technical Specification;

i) Regulations, Codes and Standards Update;

j) A technical assessment of the physical condition of the plant;

k) An evaluation of the past operational experience in the plant related to aging,

l) Obsolescence and other security issues;

m) Storage of nuclear fuel used for long-term operation;

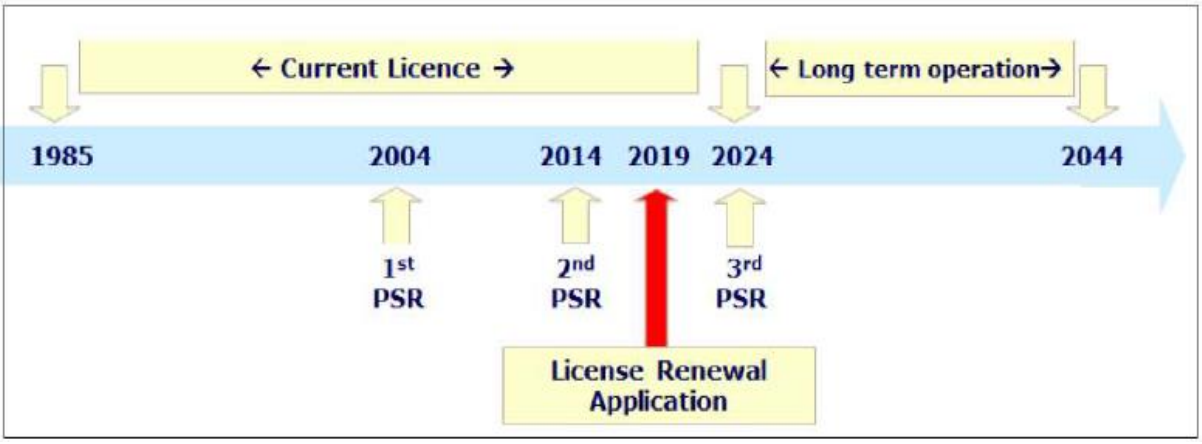
n) Management of radioactive waste for long-term operation;

o) a long-term environmental impact assessment; and

p) Human resources, skills and knowledge.

In Figure 1, it is possible to view the timelines concerning the operation period and long-term operation of the Angra I power plant.

Figure 1: *Periodic Safety Review, License Renewal Application and Long-term operation of Angra I*



Source: Baliza et. al. [15]

Both for the Renewal License and the long-term operation, it is necessary to implement a QAP in line with code 10CFR50.34, 10CFR50 Appendix B, Appendix A.2 of NUREG-1800 (Standard Review Plan for Review of License Renewal Application for Nuclear Power Plants), Appendix A-1 NUREG-1801 NRC and IAEA Safety Guide NS-G-2.12 (Ageing Management for Nuclear Power Plants).

Sneve [18] comments on regulatory cooperation in the nuclear field between the Norwegian Radiation Protection Authority (NRPA) and the corresponding Russian authorities. This partnership aimed to solve the problem in the decommissioning and dismantling of nuclear-powered submarines of the Russian Navy to guarantee nuclear safety, radiological safety, preservation of the environment etc. Guidelines were developed to:

a) improve supervision over nuclear and radiation security while managing the legacy left by military installations in northwest Russia and other regions;

b) improve the quality of the operator's actions; and

c) support the proper application of nuclear and radiation supervision and safety procedures.

Among the nuclear and radiation safety documents analyzed in the decommissioning phase of the submarines, there is the QAP for the decommissioning works. The QAP implemented in the decommissioning phase of the nuclear-powered submarine by the Russian and Norwegian authorities is composed of the following items:

a) Quality assurance policy;

b) Organizational aspects of quality assurance;

c) Recruitment and training of personnel;

d) Regulatory documents;

e) Document management;

f) Management of elements, components, materials and purchase of services;

g) Operator and subcontractor organization operations;

h) Supervision control;

i) Test control;

j) Metrological guarantee;

k) Software quality assurance and analytical methodology;

l) Guarantee of reliability;

m) Control of non-compliance;

n) Corrective measures;

o) Quality assurance documentation; and

p) Inspections.

Gasca [19] mentions the basic requirements of a QAP applied to all phases of an undertaking, as well as the specific requirements according to the phase in which the plant is located. Regarding the basic requirements applied in all phases of the project, the author mentions:

a) **Training:** Personnel must be trained and qualified to perform their functions within the organization. The training program must have the following characteristics:

- Bring the understanding of the QAP to employees;
- Describe the elements and operation of the installation;

- Provide internal training;
- Consider and observe specific qualifications;
- Ensure the state-of-the-art update;
- Periodic requalification;
- Competent instructors;
- Be subjected to continuous evaluations of effectiveness.

b) **Deviation:** All deviations found must be recorded and evaluated in order to implement corrections and prevent their recurrence. Measures must be established to identify, classify, analyze and correct elements, processes and behaviors that are outside of the plan.

c) **Documentation:** All procedures and documents that describe the processes must be prepared, reviewed, approved, issued, distributed, authorized and, if necessary, validated. Records that reflect compliance with the requirements must be specified, prepared, reviewed, approved and maintained in good condition for an established period of time.

d) **Work Management:** The work and activities performed must be planned and executed under pre-established administrative requirements and controls. The documents used must be periodically approved and reviewed. The following aspects must be taken into account: personal competence, adequacy of tools, equipment and materials, control and supervision of work, applicable documents and working conditions.

e) **Design:** The initial design and subsequent modifications must be based on established standards, codes, requirements and design bases. The suitability of the project must be verified and validated by additional groups, that is, by personnel different from those who designed it. Design changes must be justified and controlled effectively.

f) **Acquisition:** Suppliers must be evaluated and selected according to specific criteria. Besides, they must be evaluated periodically. The items or services purchased must meet specific pre-established requirements. Service providers must be supervised and controlled according to the importance of the activity performed.

g) **Inspection and testing:** Inspection and testing activities must be conducted under the administrative control and pre-established criteria. It is necessary to establish a methodology to identify which activities demand inspections and tests and the technique to be applied.

h) **Assessment:** The adequacy and effectiveness of the QAP must be assessed at different scopes, levels and frequencies. All processes must be evaluated for their effectiveness. The flaws in the program must be identified and corrected, the barriers that prevent the fulfillment of the quality objectives must be removed. Audits, reviews, verifications and other applicable methods should be conducted by personnel not involved in the work to identify gaps and opportunities for program improvement.

Regarding the specific requirements applied in the operation phase of the project, Gasca [19] comments that the QAP must maintain criteria applied to the previous steps, as the project, construction and commissioning are still present in the operation phase, but on a smaller scale. Added to this is the fact that the QAP of the operation phase should be more focused on operational activities, with a focus on three pillars:

a) The large amount of energy stored in the reactor;

b) The need to remove residual heat from the reactor for a long time; and

c) The handling of radioactive products.

The author cites as an important reference, although obsolete, the document Quality Assurance in Operation - 50-SG-Q13 (1996), published in 1996 by the IAEA.

Concerning waste storage, the Naval Base must have a Waste Management System (WMS) to receive the spent fuel from nuclear-powered Naval Resources that are carrying out repairs in the nuclear part or performing a fuel change.

In this context, Ferreira Junior and Campos [20] comment that in the absence of a national standard, CNEN endorsed the regulatory requirements of the NRC code, 10CFR72 Subpart G, in the establishment of a Safety Analysis Report to obtain the building permit for an Independent Spent Fuel Storage Installation (ISFSI).

In Table 1, the authors compared the requirements of code 10CFR72 Subpart G (Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-related greater than Class C Waste – Quality Assurance) with the CNEN-1.16 standard. They concluded that there was a correspondence between the standards, that is, that the Brazilian standard meets the requirements of the American code, about the establishment of a QAS for an Independent Spent Fuel Storage (ISFSI).

Table 1: Correlation between the requirements of CNEN 1.16 and 10CFR72 Subpart G

CNEN–NN–1.16	USNRC 10CFR Part72 Subpart G
4.1	72.140–72.142 – 72.144– 72.150 –72.152–72.154
4.2	72.140–72.144
4.3	72.142–72.144
4.4	72.152
4.5	72.144–72.146 – 72.150
4.6	72.148–72.150 – 72.154
4.7	72.156–72.160 – 72.166
4.8	72.144–72.158
4.9	72.144–72.150 – 72.160– 72.162 – 72.164–72.168
4.10	72.170
4.11	72.172
4.12	72.174
4.13	72.176

Source: (Ferreira Junior and Campos) [20]

It should be noted that the CNEN-NN-1.16 standard is not intended for the establishment of a QAP for a radioactive waste storage facility. As a result of the comparison, Ferreira Júnior and Campos [20] identified two cases in which the CNEN standard did not have the same requirements and nine requirements that proved to be more demanding (Table 2). It is worth mentioning that, according to the authors, these differences do not diminish the effectiveness of the use of CNEN-NN-1.16 for the establishment of a QAS for an ISFSI.

Table 2: Result of the comparison between code 10CFR70 Subpart G and CNEN-NN-1.16

Requirements	USNRC 10CFR Part72 Subpart G	CNEN–NN–1.16
Quality Assurance Requirements	more demanding	---
Quality Assurance Organization	equivalent	equivalent
Quality Assurance Program	equivalent	equivalent
Project Control	---	more demanding
Control of Procurement Documents	---	more demanding
Instructions, procedures and drawings	equivalent	equivalent
Documents control	equivalent	equivalent

Purchase control of materials, equipment and services	more demanding	---
Identification and control of materials, parts and components	---	more demanding
Control of special processes	---	more demanding
Licensee inspection	equivalent	equivalent
Test Control	---	more demanding
Measurement control and test equipment	---	more demanding
Handling, storage and transport control	equivalent	equivalent
Inspection, testing and operational status	equivalent	equivalent
Non-conforming materials, parts or components	---	more demanding
Corrective action	equivalent	equivalent
Quality Assurance records	---	more demanding
Audits	---	more demanding

Source: Adapted from (Ferreira Junior and Campos) [20]

3.3. Identification of the scope of the quality assurance program found in documentary research.

In the documentary research carried out, 03 main standards were identified aimed at establishing a management system for a nuclear installation: CNEN-NN-1.16 (Quality Assurance for the Safety of Nuclear Power Plants and other installations), ASME NQA-1 (Quality Assurance Requirements for Nuclear Facility Applications) and IAEA GSR Part 2 - Leadership and Management for Safety. Other standards were also identified: CNEN-NE 1.21 (Maintenance of Nuclear Power Plants), CNEN-NN-2.02 (control of nuclear materials), CNEN-NE-1.04 (Licensing of Nuclear Installations), CNEN-NN-2.03 (Fire Protection in Nuclear Power Plants), CNEN-NE-1.26 (Safety in the Operation of Nuclear Power Plants), IAEA-TECDOC-1209 (Risk Management: A tool for improving nuclear power plant performance), SSG-25 (Periodic Safety Review for Nuclear Power Plants), GSR Part 2 (Leadership and Management for Safety), NP-T 3.3 Industrial Safety

Guidelines for Nuclear Facility (IAEA) and Management Strategies for Nuclear Power Plant Outages (IAEA Technical Report Series number 449).

As stated earlier, Baliza [12] comments that the 18 requirements of the ASME NQA-1 standard are contained in the 13 requirements of the CNEN-NN-1.16 standard, as shown in Figure 4. This comes from the fact that both documents are based on the code 10CFR50 Appendix B (Code of Federal Regulation – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants) of the NRC, the American licensing body.

Also, the first Brazilian nuclear power plant, Angra I, is a project by the American company Westinghouse. With its construction in the early 1970s, CNEN chose to establish standards on which the designer himself was based, to avoid any non-conformities. Thus, CNEN chose to develop its standards in line with the American model. Therefore, the quality assurance requirements of both CNEN and NRC are the same.

On the other hand, the IAEA standard found is not aimed at quality assurance, but at an integrated management system, with requirements different from those established by CNEN and ASME standards.

The first IAEA standards, 50-C-QA (1978) and 50-C/SG-Q (1996) focused on quality assurance. Over time, the IAEA has directed its efforts towards increasing the level of organizational requirements and decreasing the level of detailed quality requirements, as shown in Figure 2.

Figure 2: *The IAEA management standards Evolution*

Source: IAEA [21]

Besides, it emphasizes leadership for safety, management for safety, an integrated management system and a systemic approach, that is, an approach that takes into account the interactions between technical factors, human factors and organizational factors. All of this is taken into account for the application of safety measures and in the promotion and strengthening of the safety culture within the organization.

The IAEA standard establishes 14 requirements within 6 distinct areas: Responsibility for safety, leadership for safety, management for safety, culture for safety, measurement, assessment and improvement. These requirements can be seen in Figure 3.

Figure 3: *IAEA GSR Part 2 requirements*

Kibrit [22] ensures that there is a tendency for organizations in the nuclear sector to adopt an integrated management model to guarantee greater gains. This was proven through the author's analysis of Brazilian installations in this sector. This evolution can also be seen in the normative framework of the IAEA, which in 1978 adopted a model based on quality assurance and today adopts an integrated management model (Figure 2).

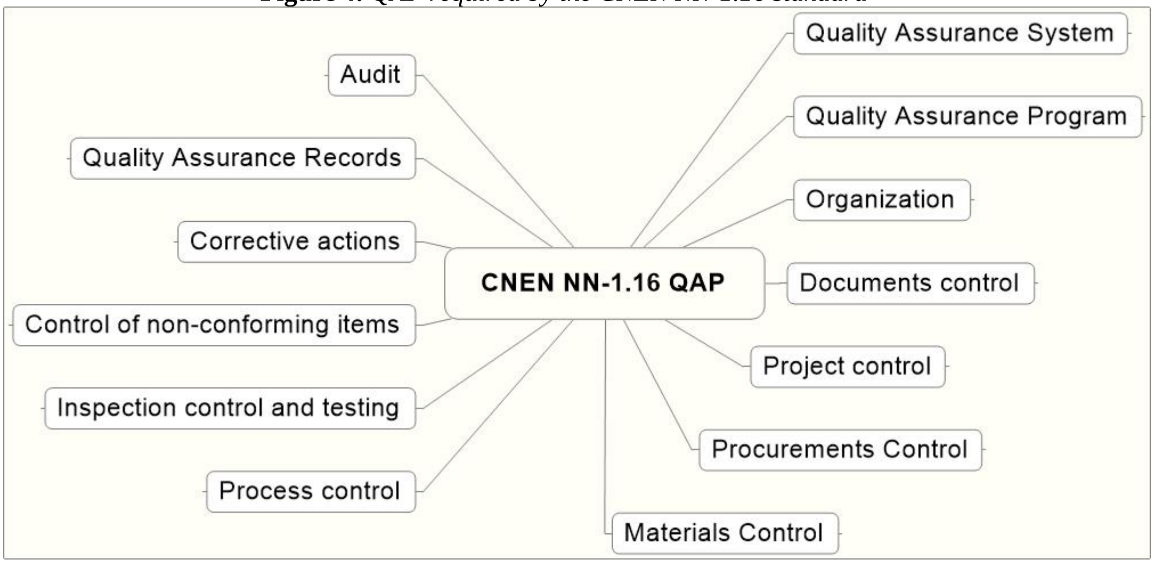
There is a difference between the CNEN standards and the ASME standard concerning the IAEA standard. For the establishment of a Maintenance Base, it is mandatory to comply with the mandatory requirements of CNEN. This does not prevent other additional requirements from being added.

A strong point of the IAEA standard, which is not addressed in the CNEN-NN-1.16 nor the NQA-1, is the safety culture. Among other things, the IAEA standard states that senior managers must promote a management and leadership system that fosters and sustains a strong safety culture in the organization. In addition, the standard emphasizes that everyone in the organization must promote and sustain a strong safety culture.

3.4. Identification of the scope of the quality assurance program for the angra I nuclear power plant.

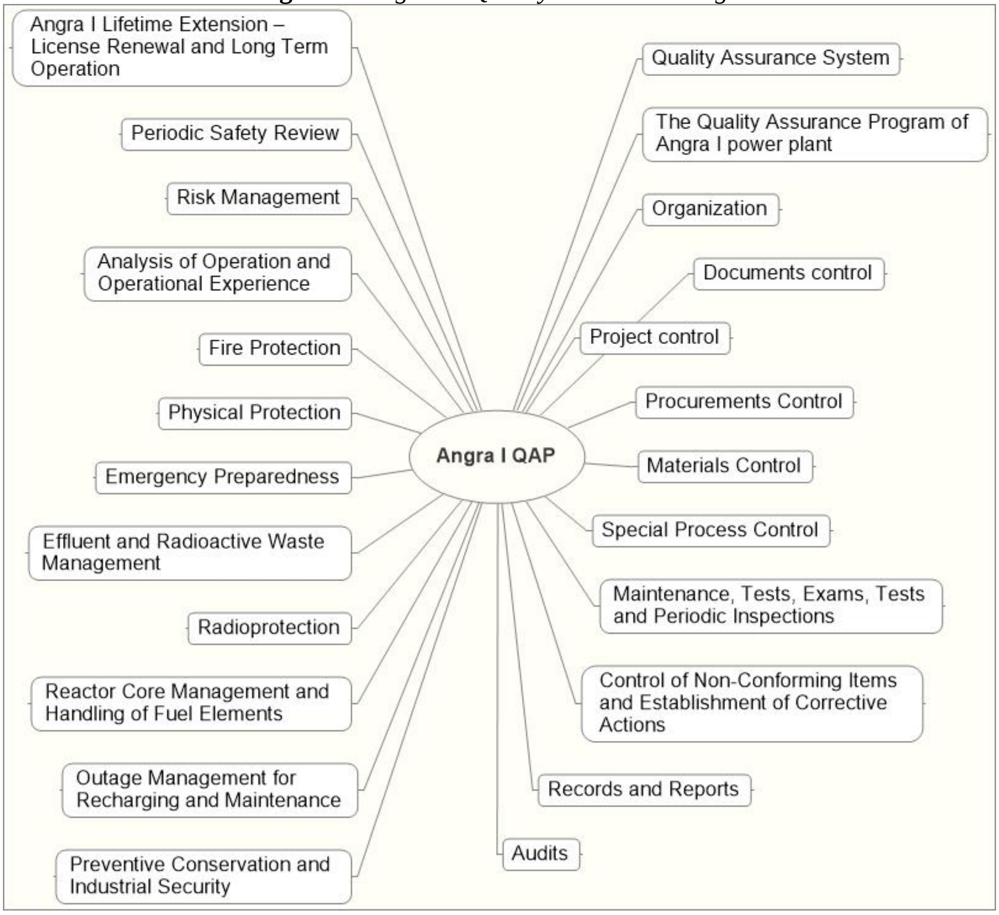
During the visit to the Angra I Nuclear Power Plant, the Quality Assurance Program (QAP) for the operation phase was collected. As stated earlier, to be able to operate, the Plant must satisfy the 13 requirements established by CNEN-NN-1.16, shown in Figure 4.

Figure 4: *QAP required by the CNEN NN-1.16 standard*



However, it became evident that the QAP of Angra I has the 13 requirements established by CNEN-NN-1.16 plus 12 additional requirements, totaling 25 requirements. It can be seen that requirements 10 and 11 of the CNEN were joined in a single requirement in the Angra I QAP, show in figure 5.

Figure 5: *Angra I's Quality Assurance Program*



In this way, the field research was carried out at the Almirante Álvaro Alberto Nuclear Center, at the Angra I unit, due to technical similarities in the type of reactor used, allowing the researcher to access information and knowledge on how to structure a Quality Assurance System. As for the interviews, a total of six people were interviewed, 01 from the quality area, 02 interviews from the maintenance area (together), 01 interview with the resident inspector of the regulatory body and 02 interviews with members of academia with experience in quality assurance. quality in the nuclear sector.

Respondents were asked about what requirements in the Angra I QAP should be present in the QAP of the Naval Maintenance Base of the conventional nuclear-powered submarine, with disagreement in only two items: Preventive Conservation and Industrial Security, and Angra I Lifetime Extension - License Renewal and Long-term Operation.

Concerning Preventive Conservation and Industrial Safety, according to one of the experts, it should not be present in the QAP of a Naval Maintenance Base. About the Useful Life Extension, according to the same interviewee, this requirement is not essential due to the Naval Maintenance Base being a new facility, different from the Angra I Plant, with almost 40 years of operation.

As a result of this research, the authors proposes a QAP based on some of the requirements found in Angra I's QAP, using essentially CNEN's existing standards, in addition to the concomitant use of IAEA and ASME NQA-1 standards. Thus, the following model of QAP with 25 requirements for the Naval Base for maintenance of conventional nuclear-powered submarines, as shown in table 3.

Table 3: The coverage proposal for the QAP for a Maintenance Naval Base of conventional nuclear-powered submarines

ITEMS	REFERENCES
Purpose and field of application	CNEN-NN-1.16
General	CNEN-NN-1.16
Definitions and Acronyms	CNEN-NN-1.16
1 Quality Assurance System	CNEN-NN-1.16 CNEN-NE-1.26
2 Quality Assurance Program	CNEN-NN-1.16
3 Organization	CNEN-NN-1.16
4 Document Control	Angra I Power Plant Operation Manual CNEN-NN-1.16 CNEN-NE-1.21
5 Project Control	CNEN-NN-1.16 CNEN-NE-1.21 CNEN-NE-1.26
6 Control of Acquisitions	CNEN-NN-1.16 CNEN-NE-1.21 CNEN-NE-1.27
7 Control of Materials	CNEN-NN-1.16 CNEN-NE-1.21
8 Process Control	CNEN-NN-1.16
9 Inspection and testing control	CNEN-NN-1.16
10 Control of non-compliant items	CNEN-NN-1.16
11 Corrective Actions	CNEN-NN-1.16
12 Quality Assurance Records	CNEN-NN-1.16 CNEN-NE-1.21 CNEN-NE-1.26
13 Audits	CNEN-NN-1.16 CNEN-NE-1.21
14 Maintenance Control	CNEN-NE-1.21
15 Essential Software Control and	NQA-1 Subpart 2.7

Management	
16 Industrial Safety and Conservation	CNEN-NE-1.21 NP-T 3.3 Industrial Safety Guidelines for Nuclear Facility (IAEA)
17 Outages Management for Recharging and Maintenance	Management Strategies for Nuclear Power Plant Outages (IAEA Technical Report Series number 449)
18 Reactor core management and handling of combustible elements	CNEN-NE-1.26 CNEN-NN-2.02
19 Emergency Preparedness	CNEN-NE-1.04 CNEN-NE-1.26
20 Environmental Monitoring	CNEN-NE-1.2
21 Fire Protection	CNEN-NN-2.03
22 Radiological Protection	CNEN-NE-1.26
23 Risk Management	CNEN-NE-1.26 IAEA-TECDOC-1209 (Risk Management: A tool for improving nuclear power plant performance)
24 Periodic Safety Review	CNEN-NE-1.26 SSG-25 (Periodic Safety Review for Nuclear Power Plants)
25 Safety Culture	GSR Part 2 (Leadership and Management for Safety)

4. CONCLUSION

The problem presented in this article arises from the lack of national and international norms and standards aimed at establishing a QAP for a Naval Maintenance Base and support for the conventional nuclear-powered submarine. To fulfill this objective, bibliographical, documentary and field research at the Angra I nuclear power plant was necessary.

The bibliographic research conducted also showed several works and their respective uses of quality assurance within the nuclear area, such as: conventional nuclear power plant, research reactors, manufacture of fuel element, production of radiopharmaceuticals, radioactive waste storage unit, and the nuclear industry supplying industries.

Within this context, the need for Brazilian organizations in the nuclear sector was identified in the initial implementation of a QAP based on the CNEN-NN-1.16 standard and, subsequently, to add the environmental management requirements, since some of these organizations suffer double licensing (CNEN and IBAMA). Another point is that the environmental impacts resulting from the use of nuclear energy are high, which leads institutions to have programs for monitoring effluents, monitoring the dose rate of fauna and flora in the surrounding areas etc.

That said, it would be plausible that the QAP of the Naval Base, in addition to meeting the requirements of CNEN-NN-1.16, has requirements for at least environmental monitoring, including the measurement of environmental radioactivity through the collection of water, sediment and effluents.

Another point addressed by the bibliographic research was on the Aging Management Program (AMP) and the Obsolescence Management Program (OMP). The Naval Base is an organization dedicated exclusively to maintenance and support, so it is justifiable to have an AMP and an OMP within the scope of the QAP, helping to monitor the level of degradation of structure, systems and components (SSC). It is possible to create an item in the QAP called maintenance control containing the AMP, OMP and others activities related to maintenance.

Within this reasoning, the importance of the item dedication process was also identified, a fundamental step in the process of acquiring commercial items for application in nuclear installations, to guarantee the safe operation of the Plant. Thus, the presence of this item in the scope of the QAP for a Naval Base is valid.

The documentary research pointed out that the scope of the QAP proposed by CNEN contemplates the 18 requirements listed in the code 10CFR50 appendix B (Code of Federal Regulation – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants), thus being in line with American practices. It is interesting to note that these requirements are also present in the CNEN-NN-1.16 standard (items 4.1 to 4.13 of the standard). It can be said that this is the minimum content for the establishment of a QAS for any Brazilian nuclear facility.

Regarding the field research, the QAP of the Angra I Nuclear Power Plant showed that despite the mandatory fulfillment of the requirements proposed by CNEN, additional requirements of the IAEA and ASME standards were included. In total, it was observed that the Angra QAP contains the 13 mandatory requirements of the CNEN standard and an additional 12 extra requirements, as shown in Figure 9. Another point observed was the incisive influence of the American Nuclear Regulatory Commission (NRC) codes in Brazil, arising from the experience of the United States in the construction and operation of nuclear power plants, as well as the fact that the Angra I nuclear power plant, the first Brazilian nuclear power plant, was created based on an American project, conceived based on the requirements of the American regulatory agency.

As for the extension of the plant's useful life, the objective is to develop a set of activities designed to demonstrate and guarantee the safety and quality of the plant's operation for another 20 years of operation. This topic proves to be important due to the end of the plant's operating license in 2024. The project was designed to operate for 40 years, requiring the extension of this period for the continuation of its activities.

In addition to the useful life extension being addressed in the QAP, there is a supplement, that is, a second QAP just describing the activities related to the Plant's useful life extension. It is correct to say that a QAP could be designed that already involved the extension of useful life for the case of the Maintenance Base, even though it is a new organization.

As for the observations made during the field research at the Angra I Plant, there was a strong safety culture and a commitment by all employees to safety. However, this requirement is not present in the QAP of the Plant, being an item that can be added to the QAP of the Naval Base.

As a result, this article proposes a QAP based on some of the requirements found in Angra I's QAP, using essentially CNEN's existing standards, in addition to the concomitant use of IAEA and ASME NQA-1 standards.

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