BJRS
BRAZILIAN JOURNAL OF RADIATION SCIENCES
doi.org/10.15392/2319-0612.2024.2591
2024, 12(4B) | 01-22 | e2591
Submitted: 2024-08-06
Accepted: 2025-05-06

Proposal for Safety Classification of SSC for Land-Based Facilities to Support Nuclear-Powered Submarines

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Abstract: The design of land-based facilities to support nuclear-powered submarines involves complex regulatory challenges due to the unique combination of nuclear, military, and naval aspects. The focus of this paper is the proposal for the safety classification of SSC (Structures, Systems, and Components) in these facilities, described as "non-conventional". These SSC are initially designed for maritime/naval operations but due to their structural or functional interface with nuclear aspects of the supported submarines, require a more thorough evaluation to define their significance for safety and the need for additional requirements. The proposal evaluates specific conditions of joint operation between the land support SSC and the submarine's inherent SSC, based on American Nuclear Society (ANS) standards, to establish a simplified procedure for the preliminary safety classification of non-conventional SSC. This analysis emphasizes the importance of considering additional requirements to preserve structural integrity and ensure the safety of these facilities. Overall, the proposed safety classification procedure aims to provide guidance for the design and licensing of land-based facilities that support nuclear-powered submarines. As a result, a safety classification proposal is presented for the following SSC (non-conventional for a nuclear facility): quays, pontoons, fenders, crane, dry dock, dry dock gate (caisson), keel blocks, dry dock drainage system, electric power system for the submarine (at quay and the dry dock), cooling water system for the submarine (at quay and the dry dock), and Additional containment (to access the reactor section).

Keywords: nuclear-powered submarines, safety classification, non-conventional SSC, nuclear support facilities.

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Proposta para Classificação de Segurança de SSC para Instalações Terrestres de Apoio a Submarinos com Propulsão Nuclear

Resumo: O projeto de instalações terrestres para apoiar submarinos com propulsão nuclear envolve desafios regulatórios complexos devido a combinação única de aspectos nucleares, militares e navais. O foco do presente artigo é a proposição da ponderação no uso de uma metodologia para a classificação de segurança dos SSC (*Structures, Systems, and Components*) dessas instalações denominados "não convencionais", os quais decorrem exatamente da combinação de aspectos marítimos e nucleares, avaliando sua interação (funcional e estrutural) com o submarino apoiado. A proposição avalia condições específicas de operação conjunta entre os SSC de suporte terrestre e os SSC próprios do submarino, baseado-se em normas da American Nuclear Society (ANS) para estabelecer um esquema simplificado, para definir preliminarmente a classificação de segurança dos SSC não convencionais. Nesta análise, destaca-se a importância da consideração de requisitos adicionais para preservar a integridade estrutural e garantir a segurança dessas instalações. No geral, o esquema de classificação de segurança proposto visa fornecer uma orientação para o projeto e licenciamento de instalações terrestres que apoiam submarinos com propulsão nuclear. Como resultado, apresenta-se uma proposta de classificação de segurança para os seguintes SSC (não convencionais para uma instalação nuclear): Cais, pontões (flutuante), defensas, guindaste, dique, porta do dique (Batel), picadeiros, sistema de drenagem do dique, sistema de energia elétrica para o submarino (no cais e no dique), sistema de água de resfrimento para o submarino (no cais e no dique) e contenção adicional (para acesso ao reator do submarino).

Palavras-chave: Submarinos com propulsão nuclear, classificação de segurança, SSC não convencionais, instalações de suporte nuclear.

1. INTRODUCTION

In addition to the complexity of designing land-based facilities and systems to support nuclear-powered submarines, these present a unique regulatory challenge, combining the nuclear nature with military and naval aspects. As highlighted in a previous study [1], when exploring the interactions between maritime/naval systems and operations, it becomes clear that the specific purpose and characteristics of these facilities go beyond the conventional nuclear regulatory framework. Their structures, systems, and components (SSC), unlike those found in conventional nuclear facilities, lack specific criteria or considerations, and there is no predefined guidance for their safety classification according to existing standards. Therefore, not all aspects and particularities of this type of facility can be adequately addressed by applying standards and requirements intended for other nuclear installations without careful evaluation and further analysis. However, beyond naval elements with nuclear interfaces that require analysis regarding the applicability of nuclear standards in their designs, there are broadly applicable concepts in the nuclear domain that can guide the design of these SSC, ensuring the appropriate level of safety without resulting in an excessively conservative safety classification. Consequently, this study presents a proposal for the safety classification of non-conventional SSC for land-based facilities to support nuclear-powered submarines.

2. MATERIALS AND METHODS

Based on the premise that nuclear-powered submarines are fundamentally independent facilities, equipped with all necessary SSC to fulfill their safety functions (from normal operation to design basis events), this study proposes to assess specific scenarios involving the interface and joint operation of land support SSC and the submarine's inherent

SSC. Therefore, the operations and corresponding land support SSC can be grouped into four main situations [2], as described in Table 1. An analysis was conducted for each of these SSC, categorizing them into two groups: “nuclear” (commonly found in nuclear facilities) and “non-conventional” (specific to this type of installation and not commonly found in nuclear installations). The safety classification proposal presented in this paper focuses only non-conventional SSC (primarily arising from naval/maritime aspects), as it is understood that conventional SSC, even in theses land-based facilities to support nuclear-powered submarines, would have a safety classification equivalent to that of SSC performing similar functions in other nuclear installations, such as a nuclear power plant, for example.

Table 1 : Description of each interface situation with the submarine

Situation		Description	SSC	SSC type*
I	Land-based facility supporting in the absence of the submarine	In this scenario, the SSC in operation can be essentially described as conventional, given that there is no interface or support for any function or operation of the submarine. The SSC described in this case will also be present in all other situations	• Spent fuel storage pool • New fuel storage • Waste treatment and management systems	Nuclear
II	Submarine at the quay[1]	The submarine will be at the quay, possibly receiving or not receiving resources from the land-based facilities. It is assumed that in the event of land support system failures, the onboard systems must act immediately [2]. Thus, land support systems are not responsible for ensuring the submarine’s safety functions	• Quays • Pontoons • Fenders • Cooling water supply systems for the submarine • Electrical power supply system for the submarine	Non Conventional

[1] In this condition, given that the land support systems for cooling water and electrical power do not perform a safety function, these could be classified as not important to safety, as proposed in this study.

	Situation	Description	SSC	SSC type*
III	Submarine at the dry dock[2]	The submarine would depend on land resources to ensure its safety functions, as its onboard systems would be unavailable (due to repair/ maintenance) or with limited use, primarily because of water restrictions for the direct operation of its systems	• Dry dock • Dry dock gate • Keel blocks • Drainage Pump station • Cooling water supply systems for the submarine • Electrical power supply system for the submarine	Non Conventional
IV	Refueling	The submarine will be in dry dock, under the aforementioned conditions, undergoing nuclear refueling	• Additional containment	Non Conventional

* The types presented in this column are the proposal of the present paper.

2.1. Land-Based Facilities to Support Nuclear-Powered Submarines

For the purposes of this study, the following definition will be considered for land-based facilities to support nuclear-powered submarines:

> "*All SSC located on land to provide support, resources, and all necessary assistance to nuclear-powered submarines during maintenance activities, repairs, refueling operations, storage of new and irradiated fuel elements, and processing and storage of waste (solid, liquid, and gaseous).*"

This definition involves land-based support facilities for nuclear-powered submarines, which are a combination of structures serving both naval and nuclear purposes. These facilities may have a functional or structural interface with the submarine. Despite their military and nuclear nature, which involves strategic and defense aspects, it is important to recognize that these installations perform operations within a well-established spectrum of nuclear activities, similar to those found in conventional nuclear facilities, suck as power

[2] In the condition of the docked submarine, without the availability of its systems to perform safety functions, the submarine cooling water systems and electrical power systems that will perform these safety functions for the submarine should be classified as important to safety, according to the proposal in this study, unless another solution is envisaged.

plants. These activities, commonly referred to as "nuclear" in the nuclear context, include the main nuclear operations conducted by land-based support facilities for nuclear-powered submarines [2], [3]:

- Storage of irradiated fuels;
- Storage of new fuels;
- Processing of radioactive waste (solid, liquid, and gaseous); and
- Initial storage of radioactive waste.

For these activities, it was considered that the involved SSC have requirements/criteria similar to those of known nuclear facilities, with adjustments made for differences in power and all associated circumstances (heat source, decay heat, reaction time, accident consequences, etc.). Thus, the following nuclear SSC [2] can be listed:

- Spent fuel storage pool;
- New fuel storage building;
- Waste storage building;
- Waste processing facility; and
- Radiological monitoring and protection systems.

In addition to nuclear SSC, there are also those initially designed for predominantly maritime/naval applications. However, because these systems interface with a nuclear-powered submarine, wish uses a nuclear reactor for propulsion, they require a more thorough evaluation of their structural or functional interaction with the submarine, as well as an assessment of the the potential hazards they may pose. In this work, these SSC are referred to as "non-conventional".

2.1.1. "Non-conventional" SSC

The integration of naval and nuclear aspects required for land-based support of nuclear-powered submarines leads to unique SSC designs and the development of operational procedures that are not found in nuclear power plants or other nuclear facilities. As a result, these SSC and operations are classified as "non-conventional". While some of these operations may have counterparts in nuclear power plants, they differ because they require specific procedures or specialized SSC to accommodate the naval requirements of the facilities. The following activities are listed as "non-conventional" operations:

- Refueling and movement of nuclear fuel;
- Access and maintenance of items within containment;
- Land-based electrical support;
- Land-based cooling systems support; and

To meet the demands arising from the characteristics of the supported submarines, several SSC deemed non-conventional were identified:

- Additional confinement structure;
- Water supply systems for submarine system cooling; and
- Power supply systems for submarine systems.

Even structures primarily naval designed to support other types of vessels, when used by nuclear-powered ships, require additional assessment of potential hazards to the reactor due to their functional or structural interface. Based on this assessment, the nuclear safety classification of these structures or the need for additional requirements is determined, if applicable. Thus, these structures also contribute in some way to operations previously classified as non-conventional:

- **Quays**
  - ✓ Civil structure;
  - ✓ Pontoons;
  - ✓ Fenders; and
  - ✓ Crane.
- **Dry Docks**
  - ✓ Civil structure;
  - ✓ Dry dock gate;
  - ✓ Keel blocks; and
  - ✓ Drainage Pump systems.

2.2. Use of Quays by Nuclear-Powered Submarines

As nations considered in this study: USA, UK, and France, mooring their respective nuclear-powered submarines at quays constructed prior to acquiring these submarines. Therefore, it is reasonable to assume that these quays were not built with additional (nuclear) requirements in mind due to the presence of an onboard nuclear reactor. Additionally, such nuclear-powered submarines have already moored at various quays in allied nations, where it is known that these quays did not undergo, for instance, a licensing process with their respective nuclear regulatory bodies.

Thus, the US nuclear fleet has moored at over 150 ports in more than 50 countries, including Brazil [4]. In December 2020, the newly commissioned USS Vermont moored at one of the quays at the Ilha da Madeira naval base, as shown in Figure 1. It is worth noting that, as far as is known, this quay did not undergo nuclear licensing or have additional structural requirements assigned to its design.

Figure 1: USS Vermont moored at the naval base on Ilha da Madeira (December 2020).

Source: https://portalbids.com.br/2020/12/14/uss-vermont-participa-de-exercicios-com-o-submarino-tupi/

One can also mention the occasion of the celebration of the 100th anniversary of the Submarine Force (ForSub) of the Brazilian Navy, where some nuclear-powered submarines from friendly nations were present: SNA "Améthyste" (France), USS "Dallas" (USA), and HMS "Ambush" (UK). On this occasion, as shown in Figure 2, all these nuclear-powered submarines moored at the quays of the Brazilian Navy Arsenal of Rio de Janeiro (AMRJ), where it is recognized that the moored structures do not have additional requirements or have undergone any nuclear licensing process.

Figure 2: SNA Améthyste, USS Dallas e HMS Ambush Moored at the Brazilian Navy Arsenal of Rio de Janeiro - AMRJ (July 2014).

Source: https://www.revistaoperacional.com.br/marinha/100o-aniversario-da-forca-de-submarinos-da-esquadra/

Initially, it can be assumed that there is a type of mooring where the nuclear submarine does not necessarily require "nuclear" land support. In this case, its own systems would be sufficient to ensure the execution of safety functions, allowing the submarine to operate autonomously at the quay. In this scenario, the submarine could potentially receive conventional (non-nuclear) land support, such as electrical power and cooling water systems, to save operational hours of its onboard nuclear systems. In the event of an emergency, it could quickly restore these resources independently, ensuring the execution of its nuclear safety functions through its onboard systems.

The hypothesis of autonomy of nuclear submarines at quays could explain the absence of land support through "nuclear" systems. However, it does not exclude considerations regarding the potential threat that the failure of a conventional civil structure could pose to the nuclear submarine's safety.

However, based on operational practices observed in these navies, both at their own quays and at quays in other nations, the hazards associated with a potential failure of the civil structure of the quays may not necessarily lead to radiological consequences. This could be due to the buoyancy of the submarine itself and the presence of interface structures (such as pontoons and fenders) between the quay and the submarine. These structures provide degrees of freedom to the moored submarine, attenuating or absorbing potential forces from adverse interactions with the quay.

Thus, in structural and operational terms, the quays supporting nuclear-powered submarines would not be different from quays used by other ships with conventional propulsion (Diesel-electric), except for the need for emergency planning in case of accidents involving releases of radionuclides and certain aspects of radiological monitoring. Therefore, the quays used by nuclear-powered submarines would not be structures requiring safety classification.

2.3. Use of Dry Docks by Nuclear-Powered Submarines

Longer and more complex maintenance periods for ships generally require docking. In conventional naval activities, docking is essential as it provides access to the entire hull, allowing unrestricted disassembly and maintenance of systems and components related to the vessel's watertight integrity, among other aspects.

In the context of nuclear and radiological operations, a dry dock provides the necessary stability and support for the submarine, allowing interaction with supporting structures that ensure the safety and proper execution of these operations. It is within the dry dock (Figure 3) that activities related to the support, maintenance, and refueling of the nuclear reactor and its associated systems occur, often resulting in the highest degree of unavailability of the submarine's systems.

Figure 3: The attack submarine USS Greeneville in dry dock.

Source: https://breakingdefense.com/2017/10/15-subs-kept-out-of-service-177-months-of-drydock-backups/

Thus, unlike in quays, where submarine systems ensuring safety functions, in dry docks there might be unavailability of the submarine's systems ensuring the execution of its safety functions. This circumstance can essentially be resolved in two ways:

- Provision of land-based systems that perform these safety functions in place of submarine's systems; and/or
- Bringing the submarine's reactor to an inherently safe condition where heat decay is sufficiently low to be completely dissipated passively into the environment (*Thermal Rollover* [5]) without need a active system to do this.

The time for the nuclear submarine's reactor to reach inherently safe condition (Thermal Rollover) unequivocally varies based on factors such as power, duration and fuel burn-up profile, and others. However, the time required for submarine preparation and other naval operations necessary for docking operations (scheduled according to maintenance timelines), during which the submarine's reactor would be shut down, could at least ensure a longer interval from the moment of a failure to the occurrence of an incident/accident. Thus, even if the submarine's nuclear plant has not yet reached Thermal Rollover condition, shutting down and cooling the reactor during the pre-docking stages would likely provide sufficient margin of safety (time extension) in case an event occurs during this period. Due to the significance of this condition, it should undoubtedly be defined in the submarine's maintenance/refueling technical specifications.

Finally, considering the potential docking conditions, it is through dry docks that the additional containment structure operates, enabling operations such as nuclear refueling, removal of radioactive waste, maintenance of systems within the submarine reactor containment, etc.

2.4. Use of Additional Confinement Structure by Nuclear-Powered Submarines

The additional confinement structure is part of the land-based support infrastructure for nuclear-powered submarines. It is an essential component for the maintenance/repair of items within the onboard nuclear plant and primarily for refueling these submarines. Its main function is to provide access to the section of the submarine where the nuclear reactor and other primary components are installed, ensuring confinement, a controlled environment, and additional space adjacent to the submarine reactor. These are crucial for safely conducting all operations necessary to maintain the operational readiness of the submarine's nuclear propulsion plant.

As shown in Figure 4 (France) and Figure 5 (United Kingdom), these additional confinement structures are typically used in dry docks, where submarines are sustained on the bottom of the dock, supported by keel blocks.

Figure 4: Additional confinement in operation at the dry dock in the Cherbourg naval base (France).

Source: https://lemarin.ouest-france.fr/industries-navales/a-cherbourg-premiere-divergence-du-reacteur-du-sous-marin-suffren-6222aaf7-1990-4d8e-b260-8786671ddc25

Figure 5: Additional confinement at the dry dock at the Devonport naval base (United Kingdom).

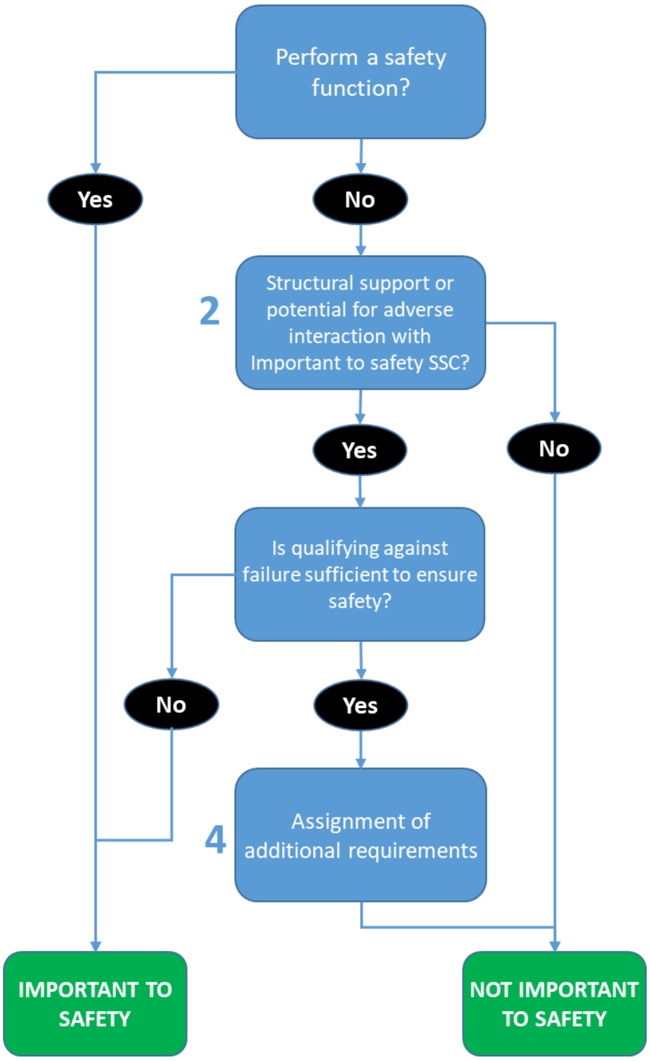
Source: MALCOLM SMITH. The D154 Project - Redevelopment of the Submarine Support Facilities at Devonport Royal Dockyard [6]

After the submarine is docked, the additional confinement structure is positioned directly above the reactor section and connected to the submarine via a coaming securely attached to the hull. This creates a robust barrier to prevent the release of radioactive material in case of accidents. The additional confinement structure is designed to be large enough to accommodate the necessary operations, qualified to withstand earthquakes, and supported by beams fixed in the dry dock. It is equipped with internal cranes, overhead cranes, and other weight handling systems to facilitate the movement of equipment into and out of the structure. During refueling operation, for instance, this structure is used to remove irradiated fuel elements from the reactor core and prepare them for transport to the spent fuel pool. Similarly, new fuel elements are inserted into the submarine's reactor core, along with additional movement of irradiated and contaminated components and equipment [7].

2.5. Safety Classification Proposal

Regarding the safety classification of SSC, defining criteria to identify which SSC are important to safety in the nuclear area is a complex challenge, as noted in [8]. To address this, Brazilian experience with American Nuclear Society (ANS) standards was leveraged. A simplified procedure, shown in Figure 6, was developed to support the preliminary definition of safety classifications and additional requirements for non-conventional SSC in land-based facilities designed to support nuclear-powered submarines.

Figure 6: Proposal for a (simplified) procedure for defining the safety classification



Source : Authors.

For the purposes of this paper, the terminology "important to safety" will be adopted as equivalent to the "safety related" terminology used in [9][3]. Thus, in step 1 of this procedure shown in Figure 6, the safety functions were established according to the definition of ANSI/ANS 58.14 - Safety and pressure integrity classification criteria for light water reactors [9]:

[3] For a detailed discussion on these terminologies and their correlations, it is recommended to refer to the article in [10].

> ***Safety-related**: Applies to a function, SSC, or part that is relied upon during or following a DBE to ensure these functions[9]):*
> *(1) the integrity of the RCPB;*
> *(2) the capability to shut down the reactor and maintain it in a safe shutdown condition; or*
> *(3) the capability to prevent or mitigate the consequences of accidents that could result in potential off-site exposures comparable to*
> *the guideline exposures in 10 CFR 50.34(a)(1), 10 CFR 50.67(b)(2), or 10 CFR 100.11, as applicable.*
> *This is the regulatory definition of "safety related".*
> *[9]) Parts (1), (2), and (3) are the three basic safety-related functions.*

Regarding step 1 as proposed in the procedure of Figure 6, in addition to defining the safety functions, specific sections of the standard [9] were identified for their relevance to the proposal of this paper, such as items (5) and (6) of section 4.3.2 [4]:

> ***4.3.2 Specific functional criteria***
> *Besides the plant-level safety-related functions identified in Sec. 3.3.2, specific supporting functions shall be identified and classified safety related for specific DBEs, for example:*
> …
> *(5) providing functional support, such as cooling water or lubricating oil, to ensure that a safety-related item can perform its safety related function;*
> …
> *(7) providing structural support for a safety related item to ensure that the item can perform its safety related function.*

However, considering its applicability to Light Water Reactors, establishing safety classification according to Ref. [9] involves several aspects and considerations that require some adjustment or consideration for their use in the type of facility proposed in this paper, based on its functions and previously established interfaces. In this context, it is important to define, even initially, the scope and applicability of these definitions.

Therefore, for steps 2, 3, and 4 proposed in the procedure of Figure 6, certain excerpts from Ref. [9] were considered, which in the specific application context of the standard

[4] It is important to note that throughout the reading of the standard ANSI/ANS 58.14 [9], the interpretation of the term "support", as in the excerpt "...does not perform or support a safety-related function..." (in its item 4.5.2), refers to the concept of "subsidizing" and not as "structural support".

would not conflict with what is presented in its section 4.3.2 (shown above). However, considering the applicability within a broader context, such as the proposal of this work, one could consider the content of its sections 4.1.6, 4.5.3.6, and 4.5.6 below:

> ***4.1.6 Impairment of safety related functions***
>
> *An item that does not perform or support a safety related function, but whose failure could prevent the satisfactory accomplishment of a safety related function, shall be classified safety related unless otherwise justified (see Sec. 4.5.2).*
>
> ***4.5.3.6 Supports***
>
> *Supports whose failure could prevent the accomplishment of a safety related function of the supported item shall be classified safety related unless otherwise justified (see Sec. 4.5.2).*
>
> ***4.5.6 Structural components or parts***
>
> *Structural components or parts (including panels, cabinets, or enclosures) that are relied upon to physically support or protect an item in the performance of its safety related function shall be classified safety related unless otherwise justified (see Sec. 4.5.2).*

According to the excerpts mentioned above, as an alternative for the safety classification of these SSC, considering the content of section 4.5.2, it presents the possibility of not assessing the consequences of failure of an SSC qualified against the type of failure in question, as following:

> ***4.5.2 Credibility of failures of components and parts***
>
> *When evaluating failures of a component or part that does not perform or support a safety related function, any potential failure of the component or part shall be deemed credible unless justified otherwise in accordance with an established basis. Such justification may be based upon the following:*
>
> *(1) The failure is not physically possible for the functional or environmental conditions that would exist during or following a DBE;*
>
> *(2) The component or part has been qualified to resist the failure. For example, for a component or part that is Seismic Category I or II, failures due to a SSE do not need to be assessed. For a component or part that is environmentally qualified, failures due to environmental conditions for which it has been qualified do not need to be assessed;*
>
> *(3) A probability evaluation shows that the frequency of occurrence for the DBE sequence including the failure is $<10^{-7}$/year or $<10^{-6}$/year if when combined*

with reasonable qualitative arguments, the realistic frequency can be shown to be lower;

(4) A documented basis exists for declaring the failure incredible (e.g., catastrophic reactor vessel failure).

The commonly established propositions and normative requirements may not fully address the SSC of a facility designed for its intended function, potentially leading to an excessively conservative safety classification. Alternatively, [11] provides details on the structural aspects of a dry dock for supporting nuclear submarines in the United Kingdom. Despite having a safety philosophy based on "safety cases", different from the one adopted in ANS standards, it is understood that it might be used as a reference to weigh its prescriptive aspects, especially for evaluating the specific type of installation relevant to this paper. Finally, it is proposed that the design of these facilities providing structural support to the docked submarine should consider resistance to extreme natural phenomena and events caused by human activities, to prevent unacceptable failure or adverse interaction with the docked submarine or any "important to safety" (IS) SSC. Thus, the proposal is for these structures to be classified as "not important to safety" (NIS), but their designs should consider equivalent constructive parameters as structures classified as important to safety[5]. For example, this decision could be supported by graduated approaches, as allowed by the normative framework of the United States Department of Energy (U.S.DOE). This approach enables greater flexibility in applying criteria by relying on less prescriptive regulations.

[5] The assignment of additional requirements does not change the safety classification and does not give rise to a subclassification of SSC "not important to safety". The assignment of additional requirements is a way to ensure that these SSC will meet sufficient and necessary design criteria to ensure their structural integrity for design basis events equivalent to those of SSC classified as "important to safety".

3. RESULTS AND DISCUSSIONS

Table 2 presents an overview of safety classification proposals for non-conventional SSC. When necessary, additional requirements should be implemented to ensure the structural integrity of each SSC, addressing all natural or anthropogenic phenomena that might result in failure.

Table 2 : Proposal for classification of non-conventional SSC

SSC	Safety function	Structural support	Safety classification	Potential for adverse interaction	Additional requirements
Quays (civil structure)	No	No	NIS	Yes	Yes
Pontoons	No	No	NIS	No	No
Fenders	No	No	NIS	No	No
Crane	No	No	NIS	Yes	Yes
Cooling water system for the submarine at quay	No	No	NIS	No	No
Electric power system for the submarine at quay	No	No	NIS	No	No
Dry dock wall	No	Yes[(a)]	NIS	Yes[(b)]	Yes
Dry dock floor	No	Yes	NIS	Yes	Yes
Dry dock gate	No	No	NIS	Yes	Yes
Keel blocks	No	Yes	NIS	Yes	Yes
Cooling water system for the submarine at dry dock	Yes[(c)]	No	IS[(c)]	-	-
Electric power system for the submarine at dry dock	Yes[(c)]	No	IS[(c)]	-	-
Dry dock drainage system	No	No	NIS	No	No
Additional containment	Yes	(d)	IS	(d)	(d)

(a) It was assumed that the dry dock wall would serve as the structural support for the additional containment structure.
(b) Depending on the facility's design, adverse interaction could occur with the submarine itself or, according to the premise in Note (a), with the additional confinement structure.
(c) In the case of the submarine going to dry dock in a thermal rollover condition, heat removal would not necessarily be a safety function, so these SSC could be classified as NIS. Having classification and other requirements fully in accordance with those of the quay.
(d) There is no need to assess the existence of structural support or adverse interaction with another SSC, as the safety classification already stems from the confinement function.

4. CONCLUSIONS

The results presented in this work (Table 2) constitute a proposal for the safety class of non-conventional SSC for land-based support of nuclear-powered submarines: Quays, Pontoons, Fenders, Crane, Dry dock, Dry dock gate, Keel blocks, Drainage pump station, Electric power system for the submarine (at quay and the dry dock), Cooling water system for the submarine (at quay and the dry dock), and Additional containment (to access the reactor section). This safety classification was proposed through the establishment of a procedure (Figure 6) based on the concepts and definitions of the ANSI/ANS 58.14 standard.

ACKNOWLEDGMENT

Authors would like to acknowledge the Diretoria de Desenvolvimento Nuclear da Marinha (DDNM), Coordenadoria-Geral do Programa de Desenvolvimento de Submarino com Propulsão Nuclear (COGESN), Amazônia Azul Tecnologias de Defesa S.A. (AMAZUL), and the Fundação para o Desenvolvimento Tecnológico da Engenharia (FDTE).

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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