

Article

Approaching Nuclear Safety Culture in Fission and Fusion Technology

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Featured Application: The following paper is applied in the field of nuclear safety and radiation protection.

Abstract: The topic of Nuclear Safety Culture touches several different aspects with contributions from the main organizations involved in nuclear projects and belonging to vendors, utility and regulators. Two nuclear safety directives issued by the European Commission emphasize the fundamental principle of national responsibility for nuclear safety and are implemented in each member country's legislation. An example of fission implementation is highlighted, referring to the Czech Republic legislation; an example of application in fusion technology is the implementation of the Nuclear Safety Culture in the ITER project, located in Cadarache, in the south of France. The aim of the paper is to highlight the importance of this field, pointing out the cross reference between fission and fusion technology as applied in two countries, with concrete experiences and future prospects for nuclear technologies.

Keywords: nuclear safety; Nuclear Safety Culture; fission; fusion



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1. Introduction

Nuclear safety (NS) refers to all the technical dispositions and the organizational measures taken to prevent accidents or to limit the effects during the manufacturing, functioning, cessation and disassembly of nuclear installations with ionizing radiation sources, as well as during the transport of radioactive substances. Nuclear organizations consider NS the top priority over other competing goals such as time and budget when dealing with nuclear projects. All the possible measures should be considered to protect the population, workers and the environment from the harmful effects of ionizing radiation [1–7].

Nuclear Safety Culture (NSC) refers to the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety to ensure protection of people and the environment [5]. NSC applies to every stage in the nuclear plant's life cycle, including design, construction, operation, shutdown and decommissioning. The purpose of NSC is to limit the impact of a failure in a nuclear installation on people's health and the environment in the long run; hence, the necessity of particular attention being paid to NS for all installations.

Ensuring NS and a strong NSC is a fundamental expectation of each organization involved in nuclear activities, including those that deal with the fission and fusion fields [1–10].

The highest level affecting nuclear plant safety is the legislative level, at which the national basis for NS is set. Safety policies and their implementation, promoted at all levels within nuclear organizations, create the working environment and conditions for individual behaviors.

All organizations involved in nuclear activities make their responsibilities well known and understood to all staff, with the public commitment of the management to NSC.

NSC relies on:

- The management's commitment to give priority to the safety principles in their decisions;
- The individual responsibility to report with full transparency;
- A questioning attitude (understanding the purposes and knowing the limits of procedures);
- A rigorous and cautious approach for each person—duty of alert exercised;
- The know-how and competences proved by training, accreditation and qualification;
- The person's motivation for setting goals, recognitions and penalties.

Figure 1 presents the NSC cycle: the top of the NSC structure is the policy level, secondly managers and finally employees. The structure is presented as a cycle in which there is a continuous feedback between all the levels, because all levels and their interaction must be considered; top-down from the managers and bottom-up from the employers.



Figure 1. Nuclear Safety Culture (NSC) cycle.

Open communication is one of the fundamental aspects of NSC and assures the interaction inside and between all levels.

The importance to understand safety in order to avoid accidents in nuclear power plants remains one of the key issues for the international expert community [11]. One of the main problems, which was underlined during the severe accidents that happened in the nuclear power plants of TMI [12], Chernobyl [13] and Fukushima Daiichi [14], was the lack of the NSC represented in obsolete design issues, lack of maintenance or emergency operation procedures. As already anticipated, according to the IAEA [15], NSC is the assembly of characteristics and attitudes in organizations and individuals, which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance. Although each of the mentioned severe accidents caused a crisis in building new units or in developing future nuclear technology, they provided important information to improve the safety culture in each country that hosts these facilities. For this reason, this topic is in continuous evolution and evaluation worldwide, increasing the reliability of nuclear installations.

In the following, particular attention is given to the implementation of the NSC methodologies in fission and fusion installations, where the Czech Republic and ITER [16] are used as examples.

The Czech Republic is a country where nuclear installations are already used for electricity production and for research purposes. In addition, new nuclear installations are

under preparation and construction in order to research in the fission and fusion fields, to implement additional nuclear power for reducing the number of existing old carbon power plants and to replace old nuclear power installations. In particular, the Dukovany 5 and 6 (with its expected commissioning after 2037) is planned to be the replacement for Dukovany 1–4 (with its expected shut down in 2036–2039, in the case of a 50 year lifetime).

ITER [16] is located near Cadarache in southern France, in a huge complex of research infrastructures hosting several institutions, such as CEA and IRSN. France is the country with the highest NPP number in Europe. ITER represents the biggest worldwide experiment developed in order to assess and to investigate the possibility to implement fusion for energy production purposes.

Starting from these examples, the aim of this paper is to give some examples of the application of NSC implementation in Europe with a particular emphasis on legislation issues. The paper would like to point out the importance of gained experience from the existing facilities for future new nuclear installations cross-referring between fission and fusion technologies.

2. Nuclear Safety Culture in Fission

2.1. Czech Republic Nuclear Power Plants and Research Reactors

The Czech Republic is characterized by a large density of nuclear facilities located in the whole country, as shown in Figure 2. It hosts six NPP units placed in the Temelin [17] and Dukovany sites. The two in Temelin are VVER 1000/320, while in Dukovany four VVER 440/213 units EDU [18] are placed. In addition, in both the Temelin and Dukovany sites, the future construction of new units is planned based on future tenders. The sites of Temelin and Dukovany can host two new units each, with an installed power of approximately 2400 MWe in each site [19,20].

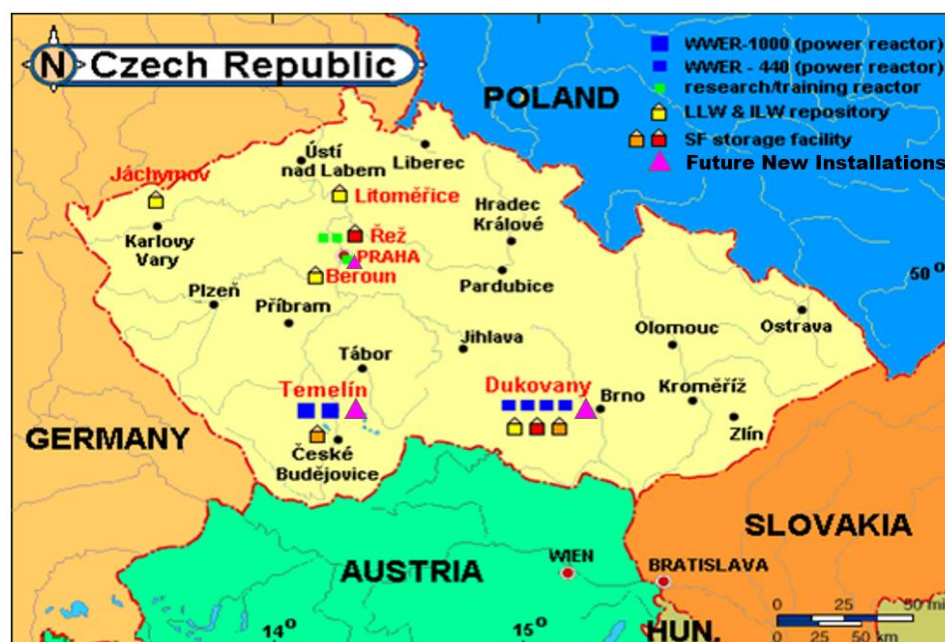


Figure 2. Czech Republic nuclear facilities map.

Several research facilities have been built in order to perform research activity and isotope production. In Husinec Rež, the CVR hosts two research reactors, LVR-15 [21] and LR-0 [22]. The first one is one of the main suppliers of isotopes in Europe, also used for several different campaigns for material testing under radiation damage, for Boron Neutron Capture Therapy research and it hosts several different loops and an irradiation channel built into the framework of the SUSAN project, supported by the European Commission [23]. The LR-0 is scaled 1:1 radially of VVER 440 and VVER 1000. It

is used for neutronic benchmarking activity, codes validation and neutron flux experiments on activity detection. An additional research reactor, VR-1 [24], is located inside Prague in the Faculty of Nuclear Engineering and Physics (FJFI). This 0-power research reactor is used mainly for experimental activities and student/training programs.

In the Czech Republic, future new experiments are under preparation. The FJFI is building a new sub-critical experiment called VR-2 [25]. Certain interest is also being given in the Czech Republic to the new fusion research facility, which is going to be designed and constructed in the Institute of Plasma Physics—Czech Republic (IPP-CR) [26] and named COMPASS-U [27].

Nuclear energy is well accepted by the public in the Czech Republic [28]. In addition to the growing interest in energy self-sufficiency, this phenomenon may also be based on the fact that this is a well-established energy source and a traditional research field in the Czech Republic. Nuclear research in the Czech Republic has been going on since the 1950s (the first research institute in the field of nuclear energy and NS was established in 1955 and the first nuclear research reactor was commissioned in 1957 [29]).

Additionally, the fact that science is perceived positively in the Czech Republic in the long term may be a contributing factor. On the other hand, the construction of a new NPP is a delicate topic in the Czech Republic, given that it is not only a question of nuclear safety, energy self-sufficiency or strategically selected national energy mix, but also a burning issue in the political scene.

2.2. NSC in Fission: The Czech Republic Implementation

The continuous upgrading of nuclear perspectives in the Czech Republic has led to continuous updates of the current legislation also, based on the information and harmonization acquired from the international community [1,30,31]. NSC is an important and long-developed topic at the international level, supported by the activities of the largest international organizations in the field of NS (IAEA, EC, OECD, NEA, etc.). Due to this, it has been given relevant importance in the Czech Republic for the last two decades.

NSC is not only a topic related to NPP and its license holder and its subcontractors, but also to other related stakeholders. The requirements for the establishment and development of NSC also apply to the license holders of other nuclear facilities in the field of research, nuclear material handling, etc. Likewise, other organizations are involved in the system of the establishment and development of safety culture: the nuclear regulatory body and its technical support organization, universities and research and engineering companies, whether private or established by the state. Certain contributions to the system are also made by the state through its support of science, research and development in the field of nuclear safety through organizations such as TAČR [32], GAČR [33], etc.

In the previous legislation (dated 1990s), NSC was not yet determined. Safety culture implementation and development was required by the national regulatory body based on § 17 par. 1 of Act 18/1997, as amended [34]. According to that requirement, the license holder had to systematically assess NS at the present state of the art level, which in the field of safety culture in practice was considered in particular IAEA documents (some of them also translated into Czech [35–37]) and the WENRA document [38], part C7.

In the current legislation, the NSC topic is addressed inside the Czech Atomic Act [39] and subsequent 20 decrees. In the Atomic Act, from authorization, the license holder is obliged to implement the safety culture principles directly in the management system. Through it, the management must continuously develop and evaluate the characteristics and attitudes of persons performing activities related to the use of nuclear energy. Such attention is referred to as the “safety culture” and the extent and manner of ensuring the development and evaluation of the safety culture is stipulated in the subsequent decree.

In order to endorse the NSC, the main requirements are addressed in [40]. The NSC should be addressed in a continuous development of the management system via ensuring the management system understanding, explaining, improving and collecting effective

information and sharing it with both managers and employees, and ensuring that safety culture principles are comprehensible to both managers and employees.

Due to these requirements, the subject which is implementing the management system (e.g., the license holder) must ensure that the managers contribute to the continuous improvement and development of the safety culture and carry out regular self-assessment of the safety culture according to their procedural role.

The regular evaluation of the safety culture must be carried out at least once a year and its results and the measures to mitigate the non-conformities must be documented. In addition, the results of the safety culture assessment must be communicated to each employee.

Safety culture must be taken into account also in other activities: according to [41], the license holder must, among other issues, evaluate the impact of the safety culture on the operational event as part of an operational incident and accident investigation. In addition, periodic safety assessments must be performed [42], among others, in the area of organization and management, with particular attention paid to the overall level of safety culture. In addition, this includes the human factor [42], and whether the human factor does not increase the risk of the initiation event, including an assessment of whether the overall personnel policy and its management are in accordance with the requirements of the safety culture [43,44].

Safety culture is also the subject of State Office for Nuclear Safety Czech Republic (SONS) inspections. All nuclear safety inspectors participate in the inspection, collecting findings related to the safety culture (so-called safety culture characteristics) from license holders and their subcontractors during their daily work (e.g., other inspections, documentation assessment, administrative proceedings). The used methodology is based on observing personnel behavior, discussion and argumentation, problem and issue solving, working atmosphere, quality of work and documentation assessment and overall working observation. Each single finding is collected including its context and must be independently understandable by all participants.

The safety culture characteristics are marked using four grades:

- A—positive manifestation of safety culture;
- B—expected condition;
- C—non-compliance with the healthy safety culture attribute;
- D—denying of the healthy safety culture attribute.

Findings are collected using a database. Specialized inspectors process them to form the output for inspection purposes (Inspection Report), and for the benefit of the license holder. The license holder obtains, four times a year, information about the safety culture assessment: the report and the periodical meetings between the management and the SONS underline the main positive and negative findings, which are explained to the license holder.

In the processing, data are strictly anonymized (also from the language and communication style point of view) to avoid and prevent worries of personnel or inspectors with regard to expressing freely their concerns, opinions and attitudes.

Some methodologies are widespread worldwide to assess safety culture. The most generally known are the US NRC methodology [45] and GRS [46], but some other methodologies [47] have been developed in other countries, too.

SONS describes the process of collecting safety culture characteristics in its internal document [48]. Findings are collected in 10 areas using the “10 Traits” reference framework created by the US NRC [45] and also recommended by the IAEA [49].

The “10 Traits” reference framework is applied to different structures (organization, work groups, supplemental personnel and independent oversight organizations) and at different levels for organizational roles and positions (individuals, leaders, executives, managers, senior managers, supervisors, individual contributors), as shown in Figure 3. The assessment is focused on them, their relations and communication from a different perspective. The “10 Traits” assessment method brings complex and simple ways to

evaluate the existing safety culture and its manifestation in an organization. The “10 Traits” consist of attributes, for which there is some example or description.

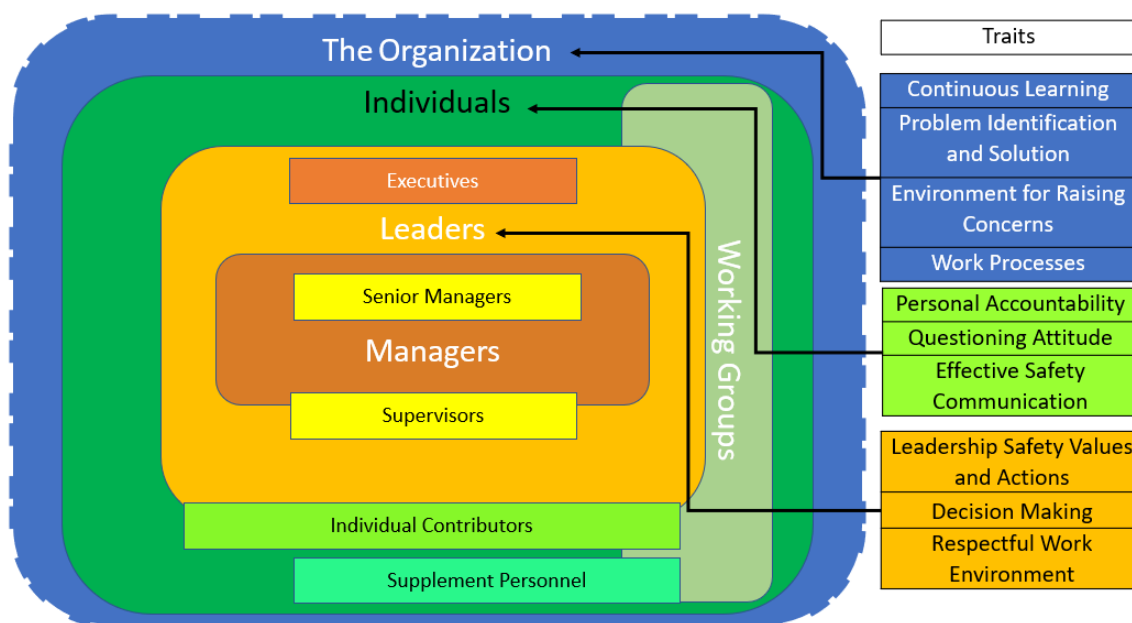


Figure 3. “10 Traits” reference framework integrated in the safety culture implemented in the organization structure.

The traits and their content can be described as follows [45] (see also Figure 3):

1. “Leadership Safety Values and Actions”—whether leaders demonstrate their commitment to safety in decision making and behavior;
2. “Problem Identification and Resolution”—whether issues, which can potentially impact safety, are promptly identified, evaluated, addressed and corrected commensurate with their safety significance;
3. “Personal Accountability”—whether all individuals take personal responsibility for safety;
4. “Work Processes”—whether the process of planning and controlling work activities is implemented to maintain safety;
5. “Continuous Learning”—whether emerging opportunities to learn about ensuring safety are sought out and taken;
6. “Environment for Raising Concerns”—whether a healthy environment exists for personnel feel free to raise safety concerns without fear;
7. “Effective Safety Communication”—whether communication maintains a focus on safety;
8. “Respectful Work Environment”—whether the organization trusts and respects individuals;
9. “Questioning Attitude”—whether individuals avoid complacency and continuously reconsider existing conditions and activities in order to identify discrepancies;
10. “Decision making”—whether decisions that support or affect nuclear safety are systematic, rigorous and thorough.

The importance of NSC can be demonstrated by the example of the following event: in 2015, a leak from a welded joint of the emergency water supply pipeline of the steam generator was identified at EDU Unit 4. The unit was shut down and the cause was investigated. The welded joint was inspected in 2014 and no damage was found, which did not correspond to the mechanism of the failure, which had to have developed for a longer time. During the investigation of the event, it was found that inconclusive inspections of welded joints on non-essential pipelines of smaller diameters had been carried out for some time. A subcontractor performed inspections of welded joints and the license

holder's control of the result was insufficient [50]. The causes of the event identified by the regulatory body include, in particular:

- Satisfaction with the favorable assessment for both NPPs, even on an international basis, e.g., in the framework of a number of reports and conclusions from missions carried out by IAEA or WANO;
- Prevailing emphasis placed on technical aspects of the operation, at the expense of the interest of the personnel leading and the management and cooperation between particular organizational units, with little emphasis placed by top management on enforcement of appropriate behavior;
- non-conceptual efforts to reduce costs also had an influence [51].

Thus, these are typical signs of a weakened safety culture. The event led to a six-month shutdown of Units 2 and 3, with the extension of the planned outages of other Units lasting several months. The license holder calculated the total financial loss at EUR 100 million [48], even if the event was rated as an INES 0 [50].

3. Nuclear Safety Culture in Fusion

3.1. ITER Project in the French Nuclear Context

France is characterized by a large number of nuclear fission power plants and of nuclear facilities located in the whole country. France also hosts the largest fusion experiment for peaceful purposes in the world, named ITER. ITER is an acronym for International Thermonuclear Experimental Reactor and is built in the framework of a wide international collaboration in the Provence region in southern France, next to the French Alternative Energies and Atomic Energy Commission CEA Cadarache facility in Saint-Paul-lès-Durance. Another much smaller fusion tokamak device, named Tore Supra, has been working since 1988 in the CEA Cadarache laboratories in the framework of a collaboration between CEA and Euratom (European Atomic Energy Community).

ITER is the largest among more than one hundred fusion research facilities built worldwide since the 1950s, and is a major step to demonstrate the scientific and technological feasibility of fusion for possible future energy production. The project is funded and run by the following seven members that represent the 35 countries directly or indirectly participating in the project: Euratom (representing the European Union), the US, Russia, China, India, South Korea and Japan.

ITER will not produce electricity but it will pave the way for its successor, the DEMO fusion reactor meant for electric energy production in an experimental environment. Future commercial reactors are envisaged only when full-scale electricity-producing fusion power stations are built after DEMO [9,10].

Nuclear safety is always a priority in activities with ionizing radiation, and France demonstrates outstanding records with important and wide experience in mastering nuclear science and technologies in all their numerous aspects, applying it also in the field of fusion energy.

The practical implementations of nuclear safety concepts in fusion and fission reactors present some fundamental differences due to the physical and technological characteristics of each. However, the main concepts of NSC that are adopted in fusion reactors are also based on those of other types of installations with radioactive materials, especially from nuclear fission power plants.

The fusion process is considered inherently safe and fission-type meltdown is not possible. The fusion reaction relies on a continuous input of a limited amount of fuel while any perturbation in the fusion reaction process will stop it immediately. The amounts of tritium fuel radioelement considered for some fusion facilities are of the order of only a few grams during plasma pulse, and its confinement measures are one of the most important safety objectives.

Even in case of total loss of cooling, the confinement barriers conceived for fusion facilities would not be affected, keeping their safety function without reaching the melting temperatures of the materials.

A system of multiple independent and redundant layers or barriers is designed also for fusion reactors to protect against any possible radioactive releases into the environment. This is the basis of the so-called Defense in Depth (DiD) concept that is adopted for both fission and fusion applications, with the same objective of protecting the health and safety of the public, workers and environment. The purpose of multiple barriers is to compensate for any possible potential mechanical or human failures so that no single layer, no matter how robust, is exclusively relied upon. In fusion reactors, the Vacuum Vessel (VV) represents the first confinement barrier while the buildings are the second level barrier. Where tritium is handled, there is also the need for an advanced detritiation system for the recovery of tritium from gas and liquids and to inhibit the outward diffusion of tritium; therefore, an efficient second dynamic confinement barrier with air pressure cascading in the buildings is conceived.

3.2. NSC in Fusion: The ITER Implementation

The ITER Organization (IO) is the nuclear operator of the ITER facility and the overall integrator of the project with cooperation among its members. The IO strictly observes the French nuclear safety regulations, since ITER is classified as a basic nuclear installation or INB (Installation Nucléaire de Base in French) similarly to all the nuclear fission power plants and other nuclear facilities. ITER is identified by the number “INB no. 174” in France. For this reason, ITER receives controls and inspections from the country’s regulatory body, Autorité de Sûreté Nucléaire (ASN), and its technical support organization, the Institute of Nuclear Safety and Radioprotection (IRSN), like any nuclear installation in France.

ITER is the first fusion device that has passed the full nuclear licensing process and that is considered as a basic nuclear installation in France. ITER safety studies started in the mid-1990s and were later adapted to the present location in Cadarache (France) [9,10].

The objective of ITER is to demonstrate the scientific and technical feasibility of fusion energy for peaceful purposes, an essential feature of which is the achievement of sustained fusion power generation. Nevertheless, the IO’s first priority, over and above its progress in research activities during ITER operations, is to protect the public, workers and environment by preventing accidents and by limiting their consequences related to nuclear safety. The IO had to define safety objectives and functions together with the correct identification of risks and means to mitigate and minimize them.

The main French regulations applicable to ITER are briefly summarized in Figure 4. At the top of the regulatory pyramid there is the French Environmental Code.

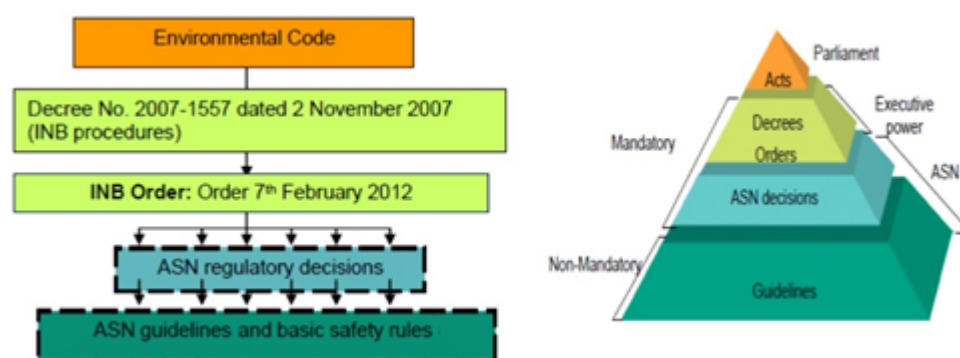


Figure 4. Main French regulations applicable to ITER.

The main INB regulation, carefully observed by the IO, is the French Order of 7th February 2012 that lays down general requirements applicable to basic nuclear installations (INB) or “Arrêté du 7 février 2012 fixant les règles générales relatives aux Installations Nucléaires de Base” [52]. This INB order, 2012, harmonizes the practices of three previous INB orders: the order of the 10th of August 1984 (quality order), the order of the 26th

of November 1999 (discharges procedures) and the order of the 31st of December 1999 (general regulation of INB risk prevention and limitation).

With Decree No. 2012-1248 dated 9 November 2012, the IO was authorized to create a basic nuclear facility INB No. 174, called “ITER”.

With ASN Decision 2013-DC-0379 dated 12 November 2013, ITER prescriptions for the ITER design and construction were established.

With ASN Decision 2015-DC-0529 dated 22 October 2015, ITER requirements were amended.

With ASN Decision 2017-DC-0601 dated 24 August 2017, ITER prescriptions were amended.

The authorization of the creation of ITER was issued only when the IO operator was demonstrated to have all the needed technical and organizational measures capable of preventing or sufficiently limiting the risks and inconveniences according to Article L593-7 of the French Environmental Code. The analysis of the risks of incidents or accidents with or without radiological impact is presented in the ITER Preliminary Safety Report (PSR, or in French, RPrS, Rapport Préliminaire de Sécurité). The PSR demonstrated that, during normal operation, the radiological impact of ITER on the population is negligible and even the most exposed members of the public will receive a dose that is one thousand times less than natural background radiation. The PSR also indicated that the evacuation of the population next to the ITER site would never be necessary, even in the case of the worst accidents, such as a fire in the tritium plant.

The French nuclear safety and regulatory authority, ASN, requested particular attention also to toxic materials, such as beryllium, in order to protect the workers, the public and the environment from their potential risks. Beryllium is used mainly in the ITER blanket and as an armor material for the components of the ITER VV that will directly face the plasma, due to its compatibility, thermal and mechanical properties. Nevertheless, beryllium is classified as a potential carcinogen, especially if inhaled as dust. In ITER it will be used as beryllium blocks and measures are being taken to reduce the risks of producing microscopic particles released into the air during transport, handling and other activities. Specific control measures are being taken to limit the airborne concentration.

The IO and all its contractors and subcontractors shall ensure that the first priority is given to nuclear safety, with the objective to prevent accidents and limit their consequences and protect the workers, the public and the environment in all situations by:

- Implementing a robust Nuclear Safety Culture (NSC) through staff and organizations involved in the life cycle of the ITER project;
- Implementing safety requirements on Protection Important Components (PICs);
- Identifying the Protection Important Activities (PIAs) related to PICs defined in the contract requirements;
- Implementing a robust surveillance/Technical Control (TC) of PIAs and Protection Important Systems, Structures and Components.

According to the INB order 7 February 2012 [40], in every contract involving PICs and PIAs, disregarding the level in the supply chain of the contracting parties, it must be clearly stated that Defined Requirements (DR) on PICs and PIAs have to be fulfilled. Defined Safety Requirements (DRs) are defined in Article 1.3 of the INB order as “requirement assigned to a protection important component so that it fulfils—with the expected characteristics—the function provided for in the demonstration mentioned in the second paragraph of Article L. 593-7 of the Environmental Code, or to a protection important activity so that it fulfils its objectives as regards this demonstration”. It means that specific requirements have been assigned to a Protection Important Component or a Protection Important Activity so that they may perform the function provided for in the safety demonstration.

4. Discussion

The results of this study, in accordance with some of the main theoretical approaches of the high-risk industry, contribute to characterize the safety culture traits of European countries, and the implementation of the NSC methodologies in fission and fusion installations, where the Czech Republic and ITER are used as examples. This study is mainly

a descriptive study: it is not focused on a theoretical point of view, but on describing some NSC traits within the EU nuclear context. In this frame it is important to recall that a European Commission (EC) nuclear safety directive in 2009 [53] emphasized the fundamental principle of national responsibility for nuclear safety. An amendment to the safety directive approved by the EU in July 2014 [54] introduces a high-level EU-wide nuclear safety objective that aims to limit the consequences of a potential nuclear accident as well as address the safety of the entire lifecycle of nuclear installations (siting, design, construction, commissioning, operation and decommissioning of nuclear plants), including on-site emergency preparedness and response. It also introduces a set of rules to support the independence of national nuclear safety regulators, with a new peer review system.

It is important to underline that the favorable public opinion, the political opinion and the scientific community's respect play a fundamental role in the possibility to build new nuclear units in the Czech Republic, although, despite this favorable situation in the Czech Republic, construction of new units is still a long process due to the system based on opening tenders used until recently, and other political and economic issues. Such a favorable environment, uncommon in the EU, could lead to the development of the existing technology along with the implementation of new technologies, such as Small Modular Reactors (SMR) and nuclear fusion installations. In this sense, this stimulates the improvement of the legislation through continuous updates and harmonizations which, beyond the present legal obligations of the Czech Republic, implement the most advanced NSC principles and, more generally, safety and radiation protections according to the international community (IAEA, WENRA, EC, OECD, etc.) best practices. Indeed, the Czech situation pointed out some important upgrades from the previous legislation to the actual one, where such topics are more addressed, also based on WENRA recommendations. As a consequence of this continuous strengthening of NSC importance, some non-compliances found during some inspections have evidenced the role of the NSC in the whole process.

The safety culture is contained in the Czech legislation and assured by several methods. One of the most commonly used is the "10 Traits" methodology. This (or a similar) methodology, at least in principle, can be used to improve the overall implementation of the safety principles in fusion reactors. In fact, such a methodology has been already used in other nuclear facilities, which are different from the "classical" nuclear power plant, such as in the case of Czech research reactors or other nuclear installations.

In the frame of fusion installations, although the consequences of a possible accident are well researched, the associated probability of occurrence is still a matter under investigation, due to their complexity and the relatively low experience gained in the maintenance and operation of existing facilities (such as Joint European Torus (JET) [55], Axially Symmetric Divertor Experiment (ASDEX) [56] and COMPASS [26]). Nevertheless, the total risk (expectation value of an appropriate measure of a specified (usually unwelcome) consequence $\sum = p_i \cdot C_i$, where p_i is the probability of occurrence of scenario or event sequence i and C_i is a measure of the consequence of that scenario or event sequence [15]), although not easily quantifiable, should probably not be considered low or negligible. As an example, a fusion reactor with a beryllium first wall can lead to a significant production of dust [57] and, therefore, to some specific types of accidents connected with radiological and chemical hazards. For this reason, the implementation of conservative approaches and principles (e.g., high safety margins, multiple levels of Defense in Depth, strict functional diversity, segregation, separation, etc.) for risk assessment and reduction seems to be justified and appropriate. Many of these principles and approaches have been developed since the early times of nuclear installation operations, also in the case of limited experience with these installations, and they are commonly known, well-researched and developed. On the contrary, an excessively high level of conservatism can bring oversized and unacceptable measures that hinder the achievement of fusion facility's goals and require unfounded resource requests in terms of time, money and effort.

5. Conclusions

In this paper, two different approaches are presented in order to take into account that the population and the environment have to be protected against the risks resulting from the operation of different nuclear facilities. In both cases, NSC is used as an additional tool to prevent serious consequences. Firstly, an overview of the Czech (fission and fusion) nuclear facilities is given, along with a description of the NSC principles implemented in the Czech Republic legislation. Then, a comprehensive picture of the NS procedures adopted in ITER are presented, focusing on some aspects which can be compared with the Czech experience.

Based on the experience gained over several years of reactor operation, the paper also introduces a point of view which can help fusion technologies to update safety culture implementation as an investment in terms of reduction in chemical hazards and improvement of radioprotection. In fact, using a focused risk approach is beneficial also for fusion installations in order to better assess the radiological hazards and other risks associated with normal operation and possible accidents involving facilities and activities. Finally, the implementation of NSC principles, due to their soft and non-technical nature, should not significantly increase the costs (in comparison with the implementation of other conservative approaches or with the overall fusion installation's capital costs) and the benefit of the approach will be to lead the technology toward a robustness even higher than that of nuclear fission power plants.

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Abbreviations

ASDEX	Axially Symmetric Divertor Experiment
ASN	Autorité de Sûreté Nucléaire (in French) or Nuclear Safety Authority
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (in French) or French Alternative Energies and Atomic Energy Commission
DiD	Defense in Depth
EC	European Commission
EU	European Union
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICF	Inertial Confinement Fusion
INB	Installation Nucléaire de Base (in French) or basic nuclear installation
IO	ITER Organization
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
LLW	Low-Level Waste
MCF	Magnetic Confinement Fusion
MLW	Medium-Level Waste
NPPs	Nuclear Power Plants
NS	Nuclear Safety
NSC	Nuclear Safety Culture

PIA	Protection Important Activity
PIC	Protection Important Component
PSR	Preliminary Safety Report (or in French, RPrS, Rapport Préliminaire de Sûreté)
SMR	Small Modular Reactors
TC	Technical Check
UN	United Nations
US	United States
VLLW	Very Low-Level Waste
VV	Vacuum Vessel

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