Developing nuclear security related legislative guarantees in licensing mobile Small Modular Reactors

Master thesis

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Summary

Goal of the thesis is to research enhancement of the legislative robustness and its possibilities regarding nuclear security of mobile Small Modular Reactors (SMRs) in The Netherlands to improve the licensing process. SMRs are small Nuclear Power Plants (NPPs) with an electrical power output lower than 300 MW_e with specific attributes like modularity and mobility, which is beneficial in serial manufacturing, like simplified design features, so fewer components allows for a higher reliability, like passive safety features, which connotes the behavior of components according to known laws of physics, for instance gravity, and like inherent safety features which are defined by reactor characteristics.

Chapter 2 reviews the inherent safety and security features of SMRs and its implications on nuclear safety and nuclear security. Chapter 3 deals with the international nuclear regulatory framework and its applicability towards licensing SMRs. Some IAEA Member States have revisioned their legal structure to optimize an SMR licensing process by applying a graded approach towards nuclear security and safety requirements. In Chapter 4 the Dutch nuclear regulatory framework and its impact on SMR developments related to nuclear safety and security are discussed. Suggestions and recommendations for possible legal adjustments are made. Chapter 5 approaches the harmonization of licensing requirements by proposing a more efficient alternative to the Dutch licensing process for all types of NPPs, including SMRs, as presented in international recommendations. Chapter 6 considers the need for SMRs and an alternative approach to the stakeholder involvement in the Dutch NPP licensing process.

Generally nuclear regulatory frameworks mainly focus on licensing conventional NPPs and the corresponding nuclear safety and security requirements and therefore prescribing overshooting regulations. Legal options to gradually approach safety and security requirements are deeply embedded in the Dutch Nuclear Energy Act and corresponding legislation. Combined with legal adjustments as denoted in the conclusions and recommendations, the adjustment are not only permittable and justifiable but also legally possible. Therefore, the licensing process of SMRs can be streamlined, establishing a harmonized and robust nuclear regulatory framework creating great opportunities for enriching the energy mix in The Netherlands with SMRs.
Introduction

Land based civilian nuclear energy production is tightly connected to major infrastructural investments and long-term planning. Since the beginning of nuclear energy producing plants, the idea of constructing small nuclear core producing heat which is directly transferred to mechanical or electrical power, has set foot amongst manufacturers. Recent technological advances in materials, inherent safe nuclear core designs\(^1\) and the need for sustainable energy sources has reawakened this ambition and has been picked up by many different companies and organizations researching and prototyping over 50 Small Modular Reactor (SMR) designs.

As with any development, licensing and procurement of nuclear related technology and therefore also with an SMR, is the issue of its nuclear security. Nuclear security of nuclear reactors is a major concern to the public so stakeholder involvement is a necessity. Furthermore, the nuclear regulatory body of any IAEA Member State should be prepared for procurement of SMRs by national companies or organizations.

The subject of this Master Thesis will be the nuclear security in licensing mobile Small Modular Reactors. More specifically, the nuclear security related legislation issues when licensing mobile SMRs in The Netherlands. The technical scope will relate to the working principles of SMRs and their security features. The legal scope will focus on the different legal perspectives in recent national and international legislation towards nuclear security at stationary and mobile NPP sites.

Harmonization of nuclear security related international legislation bound SMR building requirements will be reviewed to propose a universal and a national building set of requirements to pave the way for a successful international implementation of SMRs and to prevent possibly contradicting building requirements.

Goal of the research is to find out how to enhance the legislative robustness and its possibilities regarding to nuclear security of mobile SMRs in The Netherlands to improve the licensing process.

What are the basic nuclear security needs and principles for nuclear legislation in The Netherlands to provide a solid base for licensing mobile SMRs and how would an appropriate licensing process look like? What are legislative and regulatory basic needs and principles regarding nuclear security in countries developing or acquiring mobile SMRs? What would a graded approach in nuclear security in licensing mobile SMRs look like when comparing SMRs and regular NPPs? What are the basic nuclear security related guarantees required for a regulatory body to license a mobile SMR? The answers on these questions are helpful in creating oversight and clarifying issues.

Any literature or other materials bound to national or organizational classification grades will be taken into consideration but will not be part of the master thesis nor be referred to.

\(^1\) aris.iaea.org
1 Methodology

For the qualitative research method, I will use the literature desk research methods. For my desk research I will use topic specific literature, legal and international cases.

For academic journal literature, academic books and access to academic literature, the search engines of the Dutch Defense Academy (NLDA) library will be used. Already used literature sources are: researchgate.net, academia.edu, Google Scholar, OCLC, JSTOR and other open source literature websites.

Keywords used for literature search are: nuclear security, SMR, IAEA, nuclear safety, ANVS, nuclear regulatory framework, military, ground based operations, fuel supply.

Also interviews with nuclear security experts from Dutch government departments, like the nuclear regulatory body, the Authority for Nuclear Safety and Radiation Protection (ANVS), will be scheduled to form a background.

The Institute for Security and Safety (ISS) at the Brandenburg University of Applied Sciences together with international and national governmental nuclear regulatory bodies and The Netherlands Ministry of Defense can be interested in or benefit from the conclusions of the work.

The advisory panel consists of the Thesis Supervisor from ISS, an External Thesis Supervisor with an associate professorship at the Leiden University and a Thesis Reader from the National Institute for Public Health and the Environment (RIVM).

The scope of this thesis is security matters related to the design, commissioning and operation of SMRs and include:

- SMR technologies and their impact on security
- Security by design; Nuclear Safety/Safeguards/Security interfaces
- Impact of SMRs on the regulatory framework, including challenges and opportunities
- Engagement with key stakeholders on SMR security

Cybersecurity and the impact of SMRs on the security of the fuel cycles facilities are beyond the scope of this thesis.
2 Small Modular Reactors and Safety & Security

Small Modular Reactors (SMRs) are small Nuclear Power Plants (NPPs) producing electrical power or heat with specific attributes like modularity, which is beneficial in serial manufacturing, simplified design features, so fewer components allows for a higher reliability, passive safety features, which connotes the behavior of components according to known laws of physics, like gravity, and inherent safety features which are defined by reactor characteristics.

2.1 Small Modular Reactors

The IAEA defines an SMR as a nuclear power production plant around 300 MWₑ or less. A very Small Modular Reactor (vSMR) is defined as a nuclear power production plant with an output lower than 15 MWₑ.

The ‘modular’ term refers to the one or several submodules creating the unit assembly of the nuclear steam supply system (NSSS). The construction of SMRs by assembling factory-built elements or modules is an integral part of the construction strategy envisioned for all SMRs but is not unique applied to SMRs.

On 19 December 2019 Rosatom, the Russian state corporation specialized in nuclear energy, connected for the first time the ‘Akademik Lomonosov’ to the grid, the world’s first mobile SMR housing two KLT-40S PWR reactors producing 35 MWₑ gross capacity each.

![Rosatom's floating SMR named 'Akademik Lomonosov'](image)

Prototypes of SMRs, both mobile and stationary, are reaching their final production phase within years and SMRs will reach the global energy market.

Another example is the commercial U-Battery consortium. The U-Battery consortium has successfully completed Phase 1 of the two-stage evaluation process in July 2019 and has launched Phase 2 in June 2020. The Canadian Nuclear Laboratories’ (CNL) has invited U-Battery to site a first-of–a-kind SMR at the Atomic Energy of Canada Limited’s (AECL) Chalk River Laboratories campus in Chalk River, Ontario.

[Wilton, 2012], [Carelli & Ingersoll, 2015], [Söderholm, 2013] and [International Atomic Energy Agency (IAEA), 2017] all provide an oversight of available nuclear reactor techniques applicable into SMR designs. Overall, the reactor techniques suitable for SMRs can be divided into different categories according to their core design:
- High Temperature Gas Cooled Reactors (HTR)
- Fast Neutron Reactors (FNR)
- Light Water Reactors (LWR)
- Molten Salt Reactors (MSR)

The extensive oversight developed by the ARIS [IAEA Department of Nuclear Energy, 2016] shows the current status of IAEA Member States SMR development.

2.2 Nuclear Safety of SMRs

Safety-by-design: conscious design and engineering choices may lead to elimination of initiators for certain accidents or classes of accidents. Key factors in the safety evaluation (Safety-by-Design) are [Carelli & Ingersoll, 2015]:

- bounding the potential energy release
- mitigation of release of fission products by scrubbing in primary coolants
- response to the loss of coolant accident (LOCA) and provision for ultimate removal of decay heat.

2.2.1 Bounding potential energy release and scrubbing

To set boundaries to the potential energy release of SMRs, a coolant disperses the energy released by the core. As in large NPPs, coolants in SMRs can be light water, gas or liquid metal. The use of light water in pressurized and boiling water reactors can be readily replicated for SMR application. The liquid metal coolants of SMR choice are...
sodium, lead, and lead-bismuth. As a gas coolant, helium seems most effective because:

- the high temperature coolant outlet at 750°C, providing process heat for various industrial processes like hydrogen production by thermochemical cycles. In case of an accident and the temperature rises, solely air reactions can occur and no other explosive byproducts are generated
- helium is an inert gas and poses the least corrosion potential of all coolants
- the radiological implications. Neutron activation of helium is minimal so minimal production of radioactive byproducts
- no biological or chemical toxicological hazards, apart from asphyxiation hazard
- no fission products in the helium coolant by scrubbing

Water coolant based SMRs (PWR, BWR) can create steam expansion, hydrogen production and therefore mechanical damage by explosion which creates the necessity to replenish core coolant by, for example, passive, gravity-driven core reflood systems.

Liquid metal based SMRs (SFR, LFR) prevent the threat of exposure of fuel and cladding by containing the coolant in the guard vessel in case the reactor vessel has lost its integrity. Decay heat is removed by an in-vessel natural circulation loop and/or radial heat flow through the guard vessel.

2.2.2 Loss Of Coolant Accidents and decay heat dissipation

When comparing SMR reactors on Loss of Coolant Accidents (LOCAs) and decay heat removal, the gas coolant reactors (HTGR) seems most effective in using passive safety. The moderate dimensions of the SMR gas cooled reactor core and the radial conduction path to the ex-vessel heat sink of the high-conductive graphite core both provide passive heat removal capabilities.

Helium-cooled reactors of the pebble type have the unique feature of low power density coupled with a high heat capacity core and reflector that yields a design such that the reactor, upon an increase in temperature, neutronically reduces the power to a very low level because of the negative nuclear Doppler feedback i.e. an increase of the fuel temperature leads to more neutron capture of $^{238}$U and to a declining fission chain reaction.

2.3 Nuclear Security of SMRs

Since nuclear safety and nuclear security are deeply intertwined, as shown in 4.4 Safety and security synergies, passive or inherent safety features enhance nuclear security.

The World Institute of Nuclear Security (WINS) concludes that to ensure regulatory efficiency and nuclear security of SMRs, a graded approach based on risk-informed criteria needs to be adopted, and security by design and cybersecurity need to be carefully considered. Furthermore, the security implications associated with these new reactors need to be identified and addressed as early as possible. The objective should be to reduce the cost of security without compromising safety or security. It is also important to begin engaging with industry, the public and indigenous representatives
early in the design and development process because their support and acceptance of this new technology will be crucial for its successful implementation.

According to [World Nuclear Association (WNA), 2020], SMRs are designed for a high level of passive or inherent safety in the event of malfunction. Also, many are designed to be emplaced below ground level, giving a high resistance to terrorist threats.

[Wilton, 2012] has made a comparison between several SMR designs, analyzing their passive safety, its proliferation resistance (PR) and economic potential. In assessing nuclear security of SMRs, passive safety and proliferation resistance are key issues.

Proliferation resistance

As noted by [Close, et al., 1995] the major components affecting the PR are (1) the material form, (2) the physical access, (3) the safeguards and security and (4) the conflicts that arise when trying to achieve the aforementioned points.

SMRs using TRISO fuel as its material form, make use of High-Assay Low Enriched Uranium (HALEU) in TRISO coated particles (5% < $^{235}$U < 19.75%).

[Wilton, 2012] states that fissile contents of TRISO fuel pebbles should not be considered irretrievable although reprocessing and physical barriers are costly and sophisticated.

According to [Lee & Woo, 2018] conceptual designs for SMRs show a much more compact size of reactor buildings, facilities, and total area needed than a conventional NPP. Because of the compact sizing for an SMR, the vital area is expected to be smaller, therefore the concept of physical protection for SMRs requires a new method and evaluation. [Lee & Woo, 2018] propose a new strategy of physical protection for SMRs. The characteristics for SMR design could include:

- downgraded or partially embedded nuclear islands
- a spent fuel storage in the nuclear islands
- a passive heat removal system
- a malicious action resistant control system.

With these measures in mind, the adversarial threat can be narrowed down to radiological sabotage, which is sabotage with the intent to release radiological material on site.

Fissile weapon materials from spent fuel either stolen or diverted would not be a credible scenario, given the material's high radiation level and low fissile material concentration. In case of U-Battery’s reactor core design the TRISO coated fuel ($^{235}$U) enrichment is below 20% U-235 (LEU), typically <9% U-235. In case of the Project Pele, HALEU is considered as fuel. The need for a nuclear fuel reprocessing plant, capable of handling TRISO coated fuel, and an enrichment facility, necessary to convert the reactor core uranium to weapons grade HEU (>20%-85% U-235) or weapons grade plutonium (>93% Pu-239) from the neutron irradiated U-238, makes it
an implausible scenario. Other ways to manufacture weapons grade uranium are much more appealing to a state actor hosting these types of plants.

Lastly, impact from an airborne source, such as from a commercial airliner, is taken into account in the structural design. Protection against these threats has been greatly simplified by the smaller size and buried below ground level or partially embedded reactor building.

Therefore, [Lee & Woo, 2018] state that limited security concerns and reduced credible threats present favorable conditions for SMR security. Under this reduced security requirement, it is possible to change the physical protection strategy for the SMR plant without compromising the current paradigm of repelling an adversary in a protected area. The current paradigm being: [deter], detect, delay and deny an adversary access to a vital area.

Five types of threats remain from the only credible adversarial threat, radiological sabotage:\(^2\): (1) a violent external assault, (2) an attack by stealth and (3) a land or waterborne vehicle bomb assault. The insider threat (4) and cyberattack (5) were not part if this study.

In [Lee & Woo, 2018], new protection strategies are suggested, and models are provided, to evaluate risk for an SMR plant with respect to attack by stealth threat scenarios and an attack by a violent assault or a vehicle assault. Recommended improvements and supplements are:

- security system design and evaluation model development for protection against non-physical threats (i.e., cyber-attack and internal threats) and beyond design basis threats (i.e., air assault and underground infiltration)
- enhancement of suggested models by improving the consequence factor and response time equations
- development of a data acquisition model for security measures’ non-detection probability and delay time with a probabilistic approach
- implementation of suggested models into SMR designs.

[Cipiti, Wyss, Durán, & Lewis, 2013] touch on the subject of physical security design and staffing requirements for SMRs. If these would be the same as for large LWRs, the costs would be much larger (proportionally) for SMRs that produce less electricity. Also, smaller source terms and use of new technology may provide opportunities for limiting security staffing, which is one of the major cost items. New analyses are required to determine if these costs can be minimized while still achieving adequate physical protection. [Cipiti, Wyss, Durán, & Lewis, 2013] proposes a novel physical security analysis methodology (RIMES\(^3\)) that uses levels of difficulty an adversary would encounter instead of a probabilistic risk assessment to inform a vulnerability assessment. The RIMES methodology found that rather simple structural design changes are able to address the attack scenarios that had slightly lower difficulty ratings than others of similar consequence.

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\(^2\) Nuclear Regulatory Commission (NRC) regulations 10 CFR Part 73 Physical Protection of Plants and Materials

\(^3\) Risk Informed Management of Enterprise Security

Security-by-Design is defined by accidents that cannot occur in the first place cannot be malevolently initiated either. Key factors in security evaluation are:

- proliferation resistance (PR)
- physical protection (PP)
- inherent safety features

The synergy between nuclear safety and nuclear security is prominent in the inherent safety features since eliminated initiators for accidents cannot be malevolently initiated either. For example, placing an SMR below ground level, whether full or partial underground placement of at least the SMR reactor and used fuel vessels, enhances the level of security by [Carelli & Ingersoll, 2015]:

- protection from airborne threats
- unauthorized access and intrusion protection by limiting the number of access or intrusion points
- more difficult access to safety-relevant equipment
- inherent increased resilience of passive safety systems to sabotage or intentional maloperation
- inherent safety features

### 2.4 Implications of Nuclear Safety and Security of SMRs

Safety and security of SMRs reactor core types are evaluated and judged in the way they cope with accident scenarios or respectively DBTs.

Safety design features of SMRs, specifically vSMRs or ‘nuclear batteries’ like the Aurora power plant developed by Oklo Power, are sometimes referred to as ‘too safe to regulate’ since the vendors claim inherent safety features. Regulatory frameworks and crisis response organization must be prepared to deal with smaller NPPs and the absence of post-accidental off-site radiological consequences after careful consideration.

Security design features of SMRs like proliferation resistance and physical protection have implications on the exposed vital areas, overall footprint of the site, reduction of size and amount of restricted access zones, remote control of I&C and security forces needed to protect the site. Maintaining high levels of security, regulatory frameworks should validate novel physical security analysis methodologies of SMR security designs. By using the graded approach towards Defence-in-Depth (D-i-D) analysis, DBT scenarios and towards Emergency Planning Zones (EPZs) in crisis response plans and operations, regional siting’s might be an option.

[Cipiți, Wyss, Durán, & Lewis, 2013], [Lee & Woo, 2018], [Carelli & Ingersoll, 2015], shows a graded approach towards nuclear security requirements of SMRs is justified, as it is in nuclear safety.

### 2.5 Subconclusions

SMR security features benefit from safety requirements mainly because of the compact design and its inherent safety features. The regulatory framework should facilitate a graded approach towards Defence-in-Depth (D-i-D) analysis, DBT scenarios and
towards Emergency Planning Zones (EPZs) in crisis response plans and operations. Regulatory frameworks and crisis response organization must be prepared to deal with smaller NPPs and the absence of post-accidental off-site radiological consequences after careful consideration.
3  SMRs and international nuclear regulatory frameworks

Upon examination of the various technologies utilized in the design of SMRs, it is evident that there is a substantial difference between these new designs and existing Light Water Reactor (LWR) technology sufficient to justify a "bottom-up" assessment of security and safety. Regarding regulations on SMRs in the European Union (EU), [Improved safety features of LW-SMR, 2020] presents an overview of the safety directives and good practices of institutes towards SMRs, specifically LW-SMRs:

- European safety directives show an integrated graded approach towards the SMR licensing process, for instance the promotion of “an effective nuclear safety culture” in Art. §8a to Art. §8c of the Council Directive 2014/87/Euratom
- IAEA has no safety guidance specifically for SMRs
- WENRA formulated its Safety Objectives (7) in a qualitative way resulting in, for instance, “optimization of protection” (improvement as far as reasonably achievable)
- the European Nuclear Safety Regulators Group (ENSREG) had no SMR specific statements and/or special requirements in their documents

Several EU countries have been reviewed regarding their regulatory framework towards SMRs:

- FRANCE: regulatory context is fully applicable to SMRs
- GERMANY: Considering the German phase-out for nuclear power for the production of electrical power, new-build projects of (most) SMRs in Germany are forbidden by law. Though SMRs are developed as multi-unit plants and many designs use passive safety systems, for which the German regulatory framework is well equipped
- LITHUANIA: primary legal basis and provisions are in line with international approved regulatory frameworks. Some specific exceptions were made regarding SMRs: (BSR-2.1.6-2018) “These Requirements [Intentional crash of a commercial aircraft, red.] do not apply to the design of nuclear power plants with integrated pressurized-water reactors and small modular reactors”
- CANADA: The Canadian regulatory framework allows for a graded and alternative approaches towards safety requirements
- UNITED STATES: Since regulations may not be fully adapted to SMRs, the Licensing Modernization Project (LMP) has the goal to develop a new framework for regulatory processes for advanced reactors
- UNITED KINGDOM: The risk-informed framework with mostly non-prescriptive high-level goals, is technology-neutral and does not need to be changed in order to regulate SMRs
- RUSSIAN FEDERATION: The Russian Federation legal and regulatory framework allows for the use of a graded approach for SMRs, making it broadly applicable

ELSMOR (towards European Licensing of Small Modular Reactors), aims to create methods and tools for the European stakeholders to assess and verify the safety of light water small modular reactors (LW-SMR) that would be deployed in Europe.
In [Improved safety features of LW-SMR, 2020] the WENRA’s Safety Objectives were directly translated into Objective 5 (O5 Safety and security interfaces) which states “Ensuring that safety measures and security measures are designed and implemented in an integrated manner. Synergies between safety and security enhancements should be sought.” So the integration of security and safety is expected by the EU in the early design phase of SMRs.

3.1 Revisioning the nuclear regulatory framework

According to the findings of the Regulatory Readiness Working Group [Canadian Small Modular Reactor Roadmap Steering Committee, November 2018], the current regulations would require SMRs to incorporate security infrastructure comparable to the full scale nuclear power plants that are operating today. Industry stakeholders and the CNSC are already engaged in discussions about potential changes to these regulations by implementing a graded approach, commensurate with size and risk, while continuing to ensure appropriate security coverage is maintained.

According to [World Nuclear Association (WNA), 2020], licensing is potentially a challenge for SMRs, since design certification, construction and operation license costs are not necessarily less than for large reactors. Several developers have engaged with the Canadian Nuclear Safety Commission’s (CNSC’s) pre-licensing vendor design review process, which identifies fundamental barriers to licensing a new design in Canada and assures that a resolution path exists. The pre-licensing review is essentially a technical discussion, Phase 1 of which involves about 5000 hours of staff time, during which the conceptual design is considered and the costs are charged to the developer\(^4\). Phase 2 requires twice that effort, and addresses system-level design.

In November 2018, the Canadian government released its SMR Roadmap, a 10-month nationwide study of SMR technology. The report concludes that Generation IV SMR development is a response to market forces for "smaller, simpler and cheaper" nuclear energy, and the large global market for this technology will be "driven not just by climate change and clean energy policies, but also by the imperatives of energy security and access."

The Steering Committee concluded in short in their Roadmap 2018 [Canadian Small Modular Reactor Roadmap Steering Committee, November 2018] that their existing regulatory and legislative processes are solid and ready for SMR deployment in Canada.

To further increase efficiency in SMR regulation, the CNSC should consider regulatory refinements in existing regulatory documents (REGDOCS) based on a graded approach using risk-informed criteria. A typical example of such a refinement would be a revision of REGDOC 2.10.1 to eliminate the 10 MW thermal lower limit for application of the full suite of requirements. The need to apply the full suite of requirements should be based on risk-informed criteria, the current low limit on reactor thermal power seems chosen arbitrarily.

\(^4\) In July 2019 the U-Battery consortium (www.u-battery.com) had completed Phase 1.
[Söderholm, 2013] presents a recommendation for a new, optimized licensing process for SMRs in Finland. The most important SMR-specific feature, in terms of licensing, is the modularity of the design. Here the modularity indicates multi-module SMR designs, which creates new challenges in the licensing process. Since [Söderholm, 2013] focuses on Finland, the main features of the new licensing process are adapted to the current Finnish licensing process, aiming to achieve the main benefits with minimal modifications to the current process.

3.2 Graded approach in nuclear security in international regulatory frameworks

According to IAEA INFCIRC/225/Rev. 5, graded approach is a Fundamental Principle (H). Physical protection requirements should be based on a graded approach, taking into account the current evaluation of the threat, the relative attractiveness, the nature of the nuclear material and potential consequences associated with the unauthorized removal of nuclear material and with the sabotage against nuclear material or nuclear facilities. A graded approach is used to provide higher levels of protection against events that could result in higher consequences.

According to [World Nuclear Association (WNA), 2020], the nuclear security related features of an SMR are:

- Low power and compact architecture and usually (at least for the nuclear steam supply system and associated safety systems) employment of passive concepts. Therefore, there is less reliance on active safety systems and additional pumps, as well as AC power for accident mitigation
- The compact architecture enables modularity of fabrication (in-factory), which can also facilitate implementation of higher quality standards
- Lower power leading to reduction of the source term as well as smaller radioactive inventory in a reactor (smaller reactors)
- Potential for sub-grade (underground or underwater) location of the reactor unit providing more protection from natural (e.g. seismic or tsunami according to the location) or man-made (e.g. aircraft impact) hazards
- The modular design and small size lends itself to having multiple units on the same site
- Lower requirement for access to cooling water – therefore suitable for remote regions and for specific applications such as mining or desalination
- Ability to remove reactor module or in-situ decommissioning at the end of the lifetime

One of the Priority Recommendations of the CNSC Roadmap 2018 is that it should engage with industry, public, and Indigenous representatives on amendments to the Nuclear Security Regulations to ensure a graded approach based on risk-informed criteria. This recognizes that, while the policy, legislative, and regulatory framework in Canada is sound and ready for the safe deployment of SMRs, there are efficiencies that could be pursued to provide further flexibility and clarity in SMR licensing and regulation.

In the report [A Call to Action: A Canadian Roadmap for Small Modular Reactors, November 2018], a recommendation concerning nuclear security has been given to the
CNSC: it should revise its *Nuclear Security Regulations* to cover high-level principles similar to other regulations and remove prescriptive requirements. A CNSC regulatory document (REGDOC) should then be produced providing necessary details and including the concept of a graded approach. The expected results would be more liberal towards SMRs:

- Revised *Nuclear Security Regulations* only cover high-level principles similar to other regulations and prescriptive requirements are removed.
- New CNSC REGDOC produced providing necessary details and including the concept of a graded approach.

The recommendations from [World Nuclear Association (WNA), 2020] and [Canadian Small Modular Reactor Roadmap Steering Committee, November 2018], combined with results from [Cipiti, Wyss, Durán, & Lewis, 2013] and [Lee & Woo, 2018] show that a graded approach towards nuclear security of SMRs, or other reactor designs than conventional NPPs for that matter, is not only a long standing desire but is also justifiable.

### 3.3 Optimizing SMR licensing process

[CORDEL Group, 2010] proposes a stepwise integration approach to which an approval issued for a certain reactor design can achieve multinational recognition, paralleled with alignment of licensing processes and harmonized national safety requirements:

- Phase 1: Share design assessment.
- Phase 2: Validate and accept design approval.
- Phase 3: Issue international design certification.

In Phase 1, countries must be willing to accept foreign or internationally agreed upon (IAEA) codes and standards of reactor designs.

Two examples of the validation process in Phase two are:

- the aviation sector and the licensing of commercial aircrafts;
- the licensing of radioactive material transportation casks (“packages”)

According to [CORDEL Group, 2010], governments and legislators would need to take a number of steps, both concerning national legislation and international agreements. National Nuclear Energy Acts in some countries might require some modification to allow for an adjustment of licensing processes and for a facilitated acceptance of foreign design approvals and foreign design standards. Newcomer countries could draft their new nuclear policy acts giving consideration to the mutual recognition of foreign practices from the start. A good example for a legal provision paving the way for an acceptance is Italy’s Act on Energy Companies as cited in Phase 2 (section 6). Any national provision for such mutual recognition of foreign practices would have to be backed by international or bilateral agreements. First, there could be a set of agreements between states to allow for a facilitated takeover of a design approval.

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issued in another state, as described in Phase 2 (section 6). At a later stage, international agreements could establish joint design approvals with applicability in all participating states, as envisaged in Phase 3. On an international level, there would also be a need for internationally agreed high-level safety goals. The willingness and ability to achieve the creation of such an international nuclear safety framework is in the hands of national governments.

An effective international certification scheme should allow for newcomer countries to take effective steps towards building regulatory competence and capacity whilst allowing mature countries to improve their regulatory effectiveness [Cooperation in Reactor Design Evaluation and Licensing (CORDEL), August 2015].

3.4 Subconclusions

As international regulatory frameworks show revisions to implement SMR requirements, and the Dutch regulatory framework shares the same legal basis, implementations might be on their way.

A recommendation could be to implement the acceptance of foreign or internationally agreed upon (IAEA) codes and standards of reactor designs and its reactor design certification system into the Nuclear Energy Act or into Regulations of The Netherlands nuclear regulatory framework.
4 SMRs and nuclear regulatory framework in The Netherlands

In The Netherlands the Ministry of Infrastructure and Water Management (IenW) is responsible for nuclear safety and security. Since 2017 the Authority for Nuclear Safety and Radiation Protection (ANVS) is the Dutch nuclear regulatory body. The ANVS is an independent administrative authority (zbo) which enables decisions to be made independently. The ANVS is answerable to the Minister of IenW.

The [Guide for Readers - National Policy for nuclear safety and radiation protection] published by the Dutch nuclear regulatory body, the ANVS, provides an overview of the regulatory framework in The Netherlands. In Appendix 13.1 Dutch nuclear legal framework all six levels of the Dutch nuclear regulatory framework are explained.

![Figure 3 Schematic pyramid overview of the structure of the Dutch statutory framework.](image)

In the Netherlands, the construction and operation of nuclear installations are governed by the Nuclear Energy Act, whose basic provisions are further elaborated in the Nuclear Installations, Fissionable Materials and Ores Decree\(^6\) (the Installations Decree).


The design of SMRs must be based on these basic requirements specified in these Safety Guidelines and at the same time must meet the requirements of nuclear security laid down in the nuclear security related regulations like the Nuclear Facilities and Fissionable Materials (Security) Regulation\(^7\) (Rbnis) and the Regulation nuclear safety of nuclear installations\(^8\).

\(^6\) Besluit kemininstallaties splijtstoffen en erts (BKSE)  
\(^7\) Regeling beveiliging nucleaire inrichtingen en splijtstoffen (Rbnis)  
\(^8\) IENM/BSK-2017/128532 Regeling nucleaire veiligheid kemininstallaties
4.1 Licensing process of nuclear power plants

In accordance with Chapter II of the Installations Decree, the licensing procedure for any power plant involves at least four principal stages:

- filing of the application
- consultation of the parties concerned
- draft construction license (including EIA\(^9\))
- local licenses concerning environment (marine, land, road, water, buildings)
- granting of the construction license
- granting of the operating license

In compliance with the Environmental Protection Act (EPA) and the Environmental Impact Assessment Decree (EIAD), an Environmental Impact Assessment (EIA) is always required for the construction of a nuclear power plant.

The applicant for a new nuclear reactor, like an SMR, has to fulfill requirements for nuclear power plants described in the Safety Guidelines [Authority for Nuclear Safety and Radiation Protection, 2015]:

- Technical requirements for a new nuclear reactor (defence-in-depth concept, the barrier concept, radiological objectives)
- Annex 1 Acceptance targets and criteria and a generic list of postulated initiating events to withstand
- Annex 2 Specific requirements regarding protection against internal and external hazards.
- Annex 3 Specific requirements regarding application of the single-failure criterion and maintenance.
- Annex 4 Safety demonstration for a license applicant.
- Annex 5 List of definitions.
- Annex 6 Application of grading in relation to research reactors and contains further specific requirements for research reactors.

4.2 Nuclear security

The most relevant Ministerial Regulations for nuclear security are:

- the Nuclear Safety Regulation for Nuclear Facilities
- the Nuclear Facilities and Fissionable Materials (Security) Regulation, in which the Convention on the Physical Protection of Nuclear Material (CPPNM/a) has been implemented.

The Minister of IenW can, if required, identify specific Design Basis Threats (DBTs).

These reference scenarios define the most severe and conceivable threats. These DBTs apply both to physical security infrastructure and to cybersecurity. They define the scenarios against which nuclear facilities must protect themselves. The licensees of nuclear facilities then select the most effective and efficient security measures for their

\(^9\) Milieu Effect Rapportage (MER)
own organization. They submit the proposed measures as the security package to the ANVS for approval.

4.3 Nuclear safety

An applicant has to be able to match the requirements for power reactors with the design and use of the research reactor in question. An applicant seeking a license for a research reactor shall be able to demonstrate how the specific requirements for power reactors will be met while also complying with the principles and general requirements set out in Annex 6 to the Safety Guidelines [Authority for Nuclear Safety and Radiation Protection, 2015].

The ANVS proposes a three-staged structured method: (1) categorization of the research reactor, (2) analysis of specific factors not covered and (3) the applicability of power reactor requirements to particular research reactors. A recommendation could be to apply the same three-staged structured method is on SMRs.

4.3.1 Stage 1 Categorization

When these stages are applied to an SMR, the first step is that the SMR needs to be categorized. The SMR shall be assigned to:

- a risk category (takes the radiological impact into account and represents the fundamental safety function “confinement of the radioactive materials”)
- a cooling category (considers the necessary measures for residual heat removal and represents the fundamental safety function “fuel cooling”)

The risk- and cooling categories both delineate low to high risks (1 to 3).
Taking into perspective a standard SMR, for example U-Battery\textsuperscript{10}, HolosGen\textsuperscript{11} or the Project Pele\textsuperscript{12}, the matching risk category could be one (1) because of the use of high integrity TRISO\textsuperscript{13} fuel and the attached low risk of radiological impact, for its impact is meant to remain in restricted to supervised or controlled areas. In the worst-case accident scenario no off-site radiological impact and no radiological impact on-site is expected from HTGR-based SMRs since the expected inherent safety designs of mHTGRs. The IAEA is establishing Safety Design Criteria for mHTGRs in the IAEA Coordinated Research Project (CRP) I1026 on Modular High Temperature Gas cooled Reactor Safety Design\textsuperscript{14}.

The matching cooling category would be one (1) because no reactor coolant is necessary to dissipate residual heat from the reactor core to an ultimate heat sink. In the worst case scenario no cladding failure or melting of fuel element is expected to occur since the negative nuclear Doppler feedback prevents the reactor core from overheating.

Although TRISO fuel used in Pebblebed Modular Reactors (PBMR) has a long record of being safe, [Moormann, 2008] pointed out that the TRISO fuel technology used in the German AVR\textsuperscript{15}, essentially a High Temperature Reactor (HTR) lead to heavy contamination of the primary circuit with metallic fission products (Sr-90, Cs-137), which created problems in current dismantling. A major fraction of this contamination is bound to graphitic dust and thus partly mobile in depressurization accidents, which has to be considered in safety analyses of future reactors. [Moormann, 2008] concluded that the AVR contamination was mainly caused by inadmissible high core temperatures.

\textsuperscript{10} www.u-battery.com
\textsuperscript{11} http://www.holosgen.com/
\textsuperscript{12} https://nic.nrc.gov/docs/abstracts/waksmanj-th34-hv.pdf
\textsuperscript{13} TRIstructural-ISOtropic
\textsuperscript{14} https://nucleus.iaea.org/sites/htgr-kb/gif-iaea/Shared%20Documents/1st%20GIF-IAEA-mHTGR/A7_Reitsma_IAEA_GIF_Safety_mHTGR-Dec2019.pdf
\textsuperscript{15} Arbeitsgemeinschaft Versuchsreaktor near Jülich Research Center in Germany
during operational hours and accidents, increasing fission product release rates, and not – as presumed in the past - by inadequate fuel quality only.

4.3.2 Stage 2 Analysis of specific factors not covered

The following specific factors need to be analyzed to identify specific risk potentials of SMRs, which could contradict an appropriate application or waiving of requirements proposed for a certain risk category or cooling category:

- The reactor power
- The source term
- The amount and enrichment of fissile and fissionable material
- Spent fuel elements, high pressure systems, heating systems and the storage of flammables, which may affect the safety of the reactor
- The type of fuel elements
- The type and the mass of moderator, reflector and coolant
- The amount of reactivity that can be introduced and its rate of introduction, reactivity control, and inherent and additional safety features
- The quality of the containment structure or other means of confinement
- The utilization of the reactor (experimental devices, tests and reactor physics experiments)
- Siting
- Proximity to population groups

In case of a standard SMR, some of the factors abovementioned are not applicable but the majority of the factors needs to be analyzed.

The graded approach, i.e. grading or waiving safety requirements from the “Safety requirements for NPP”, needs to be justified and traceably documented while evaluating its applicability to:

- the Technical safety concepts
- the Technical requirements
- the Postulated operating conditions and events
- the Requirements for the safety demonstration
- the Requirements for the operating rules
- the Requirements for the documentation.

For a standard SMR, some safety requirements are generally applicable both for the risk and cooling category irrespectively of its category level (1 to 3), for instance while applying ‘Internal and external hazards requirements’.

Other safety requirements are less applicable and therefore graded, for instance while applying the ‘Concept of the multi-level confinement of the radioactive inventory (barrier concept)’. In case of risk category level 1, “At least two barriers shall be included in the design. No containment is required.”.

4.3.3 Stage 3 The applicability of nuclear power reactor safety requirements to SMRs

A specific transcription for research reactors has been added in an Annex (Annex 6) to match the nuclear power reactor safety requirements to research reactor safety requirements. Topics covered are:

- General safety requirements
- Reactor core and fuel design
- Reactor coolant system and related systems
- Confinement of radioactive materials
- Commissioning and operation
- Human factors and ergonomic considerations
- Radiation protection
- Extended shutdown
- Advisory groups / safety committees

The topic on Utilization and modification of research reactors can be waived when applying for an SMR. The List of postulated initiating events will still be necessary to apply.

4.4 Safety and security synergies

Compared to currently operating nuclear power plants, the Western European Nuclear Regulatory Association (WENRA) expects to ensure that safety measures and security measures are designed and implemented in an integrated manner. Synergies between safety and security measures should be sought [WENRA, 2010].

In [Interfaces between Nuclear Safety and Nuclear Security, 2019] the WENRA created a Task Force that should bring together nuclear safety and nuclear security experts and identify existing interfaces between nuclear safety and nuclear security for NPPs in operation as well as potential issues of a safety-security-interface.

Common ground was found on:

- Independent Assurance and Oversight Functions
- Integrated Management System
- Staff Qualification and Training
- Requirements for IT-Systems related to Nuclear Safety and Nuclear Security (safety and security both benefit from cybersecurity)
- Systems, Structures and Components
- Feedback from Operating Experience and Plant Modification (Operating Experience & Plant Modification)
- Regulatory Framework
SMR security features benefit from safety requirements mainly because of the compact design and its inherent safety features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Safety impact</th>
<th>Security impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integral vessel</td>
<td>No external primary pipes, elimination of large break LOCA</td>
<td>Compact design, feasible partial or full underground siting with enhanced physical protection</td>
</tr>
<tr>
<td>Compact containment</td>
<td>High design pressure; coupled vessel-containment performance in some designs limits coolant inventory loss</td>
<td>Compact design, feasible partial or full underground siting with enhanced physical protection</td>
</tr>
<tr>
<td>Inherent safety features, passive safety, safety-by-design</td>
<td>Eliminates/reduces possibility of nonintentional initiation of certain accidents</td>
<td>Eliminates/reduces possibility of malevolent initiation of certain accidents</td>
</tr>
<tr>
<td>Compact reactor building</td>
<td>Seismic isolation feasible</td>
<td>Compact design, feasible partial or full underground siting with enhanced physical protection</td>
</tr>
</tbody>
</table>

Table 1 Synergy of safety and security features [Carelli & Ingersoll, 2015]

4.5 Safety and security issues

Any applicant must comply with both safety and security legislation. The safety and security laws and regulations are equivalent and in case of conflicting interests, the applicant has to make a choice:

- prioritize the safety measures and compensate with security measures
- prioritize the security measures and compensate with safety measures

In either way the applicant must motivate its decision towards the nuclear regulator who will decide if applicable law and regulations have been met.

In [Interfaces between Nuclear Safety and Nuclear Security, 2019] interfaces between nuclear safety and nuclear security were identified as issues:

- Communication, Transparency and Confidentiality
- Organizational Culture (differences in regards of focus, approaches and language used due to technical training and professional experiences that exists amongst the experts in the two disciplines)
- Site Area (trade-off between nuclear security and emergency arrangements)
- Requirements for Safety and Security Measures (accessibility for operative personnel during a safety-related event versus diminishing insider threat)
- On-site Emergency Response (for instance, consider nuclear events’ cause agnostic until the initiator is confirmed)
- Zones, Access and Escape Routes (fire safety measures aim at rapid evacuations, PP measures aim at controlling access)

4.6 Graded approach

As a graded approach is an IAEA Fundamental Principle, the Dutch government has implemented the application of a graded approach towards nuclear security in the Dutch nuclear regulatory framework.

4.6.1 Graded approach in nuclear security

In Art. §3.1 and Art. §3.3 of the Nuclear Facilities and Fissionable Materials (Security) Regulation, a graded approach to nuclear security seems legally possible.

Art. §3.1 The licensee shall take the security measures that are reasonably necessary to protect the facility or the Category I, II or III material against the threats set out in the reference threat, taking into consideration the security package defined and approved in accordance with Articles 4 and 5.

Art. §3.3 The licensee shall gear the combination and level of security measures to the nature of the material and the facility, and the extent of the potential effects due to exposure to radiation of humans, animals, plants and property in the event of theft or sabotage of Category I, II or III material or sabotage of facilities.

In case reference threat scenarios do not apply to the SMR design, either in part or in total, only security measures need to be taken that are reasonably necessary (Art. §3.1 Nuclear Facilities and Fissionable Materials (Security) Regulation).

The combination and level of security measures needs to be proportional to:

- the nature of the reactor core material used
- the extent of the potential human and environmental effects due to radiation exposure
- the sabotage of the facility

4.6.1.1 Reference threats and security package

The scenarios in the reference threat package (DBTs\(^\text{16}\)) and changes therein are defined by the Minister of IenW. The applicant must take security measures that are reasonably necessary to protect the nuclear facility against the threats set out in the reference threat, described in the regulatory body approved security package.

The security measures taken must be proportional to the category I, II or III material on-site. This means that a risk-adjusted level of security measures must be applied from different angles. It is about taking those security measures that are proportionally geared to the manageability level of incidents (or the threat thereof) and the possible

\(^{16}\) Design Basis Threats
consequences. For instance, a nuclear facility that is in a safe containment phase is subject to different security measures than a nuclear facility that is in a full operational phase which results in the presence of an IBO\textsuperscript{17} but an absence of an EBO\textsuperscript{18} for the shutdown NPP Dodewaard.

The security package must contain at least:

- designation of a security expert and deputy security expert who are responsible for the implementation and observation of the security measures and who meet the educational requirements
- designation of positions of trust (appropriate screening level)
- an internal security organization plan
- a description of the security measures taken and to be taken
- designation of a Central Alarm Station (CAS)
- designation of a licensed\textsuperscript{19} security service company
- an evaluation program comprising tests, checks, audits and exercises to enable the effectiveness of the security measures to be assessed

4.6.1.2 Reference Threats and Intelligence

The Minister of the Interior and Kingdom Relations is responsible for the General Intelligence and Security Service (AIVD). The Minister of Defence is responsible for the Military Intelligence and Security Service (MIVD). The Minister of Justice and Security is responsible for the main Dutch counter-terrorism unit, the National Coordinator for Security and Counterterrorism (NCTV). The NCTV is responsible for:

- analyzing and reducing identified threats
- providing surveillance and protection for persons, property, services and events, as well as for vital sectors
- expanding and strengthening cyber security
- making property, persons, structures and networks more resistant to threats
- ensuring effective crisis management and crisis communication.

The Netherlands makes use of a system of threat levels indicating the chance of a terrorist attack in or against the Netherlands. Quarterly the NCTV publishes the Terrorist Threat Assessment Netherlands (DTN). Various factors are taken into account in the threat level assessment. In balancing all these factors, a conclusion can be drawn: the current threat level, which is an estimate of an attack in or against The Netherlands, runs from 1 (minimal) to 5 (critical).

The DTN is a general assessment of radicalization, extremism and of the national and international terrorist threat to the Netherlands and Dutch interests abroad. The assessment is a trend report in which the main threat developments are outlined. The DTN is primarily drawn up for the benefit of the administrative and political leadership and policy makers, for instance the Ministry of IenW in developing the reference threat package.

\textsuperscript{17} Interne Beveiligingsorganisatie
\textsuperscript{18} Externe Beveiligingsorganisatie
\textsuperscript{19} Private Security Organisations and Detective Agencies Act
The *reference threat*[^ref] containing the DBT scenario package, was defined in the predecessor of the Rbnis (-2018), as:

| Art. §1 reference threat: long-term analysis of threats of theft of Category I, II or III material or of sabotage of that material or of facilities |

The current version (2018-) of the Rbnis doesn’t seem to have a legal definition of the *reference threat* anymore.

The INFCIRC/225/Rev.5 has been implemented in 2016 in the Rbnis. Therefore, as stated in §3.39 of the INFCIRC/225/Rev. 5: the State should continuously review the threat and evaluate the implications of any changes in the threat assessment or design basis threat. Therefore, a *reference threat* should be regularly coordinated with information based upon threat level analyses from the national intelligence services.

For the long-term analysis of threats, the reference threat has been drawn up in collaboration with the National Police, the AIVD, the NCTV and the plant security managers of the nuclear installations in The Netherlands. The reference threat contains a long-term analysis of real conceivable threats of:

- theft of category I, II or III nuclear material
- sabotage of category I, II or III nuclear material
- nuclear facilities.

Since 2010 and its revision in 2015, the physical reference threat covers a period of about 5 to 10 years. The cyber reference threat is in place since 2014 and is evaluated every two years.

In case of a broad and heavy DBT scenarios package, not all scenarios might apply to SMRs at the same level, therefore some threat scenarios could most likely be waived. A recommendation could be to apply the graded approach to the DBT scenarios package, since some scenarios are overkill for certain SMR reactor designs.

[^ref]: referentiedreiging
Novel DBTs might be needed to be set up in case of a mobile SMR, for instance theft of an entire mobile facility must be taken into account as a novel reference DBT scenario.

The licensee shall take physical and electronic security measures that at least delay the threats in the reference threat and cover at least roofs, ceilings, walls, floors, windows, doors, door and window furniture, safes and fences.

Categorization of nuclear materials (Category I, II, and III) in Annex II of the Amendment to the Convention on the Physical Protection of Nuclear Material\textsuperscript{21}, indicates levels of physical protection for nuclear material and therefore is the basis for graded approach, see Appendix 13.2.

For instance, the use of proliferation sensitive HEU (Category I) in the reactor core of the HFR in Petten, North-Holland, was one of the main reasons for the HEU-LEU-conversion of the reactor core in 2006. The same international political pressure instigated the replacement of LEU-targets instead of HEU-targets for medical isotope production ($^{99}$Mo).

When taking the security measures, the licensee has to divide the site on which the facility and its buildings are located, insofar as applicable, into:

- a limited access area, being an area between the boundary of the site on which a facility is located and the boundary of a protected area
- a protected area, being an area within a limited access area where Category III material may be held, and
- a vital area, being an area within a protected area where Category I or II material may be held or where facilities are located or where materials may be present that could cause direct or indirect harm in the event of sabotage

In case of SMRs, not all security measures might be applicable due to its reduced sizes of the limited access area, protected area and vital areas.

The licensee has to take security measures that cover at least:

\textsuperscript{21} CPPNM/a or INFCIRC/274/Rev.1/Mod.1 9th May 2016
- shielding and illumination of the areas and the buildings in those areas
- surveillance of the areas and the buildings in those areas
- limiting access and, if necessary, escorting persons and vehicles in the areas and the buildings in those areas, and
- supervision of that access.

The Nuclear Energy Act (Confidentiality) Decree applies to the reference threat and the security package and is therefore classified information.

4.6.2 Graded approach in nuclear safety

Since The Netherlands hosts not only a power reactor but also two research reactors, which pose smaller radiological risks, a certain degree of grading of safety measures is allowed by the Safety Guidelines (Authority for Nuclear Safety and Radiation Protection 2015).

The graded approach allows for deviation from the requirements for power reactors by matching the requirements with the design and use of the research reactor in question, without compromising the fundamental safety objectives.

Special attention goes to Annex 6 (specific requirements and the graded approach for research reactors) since proportional application of certain requirements are dependent on the potential risk to the environment.

The radiological risk to the public associated with research reactors is generally less than that associated with power reactors. Therefore, the same comparison might apply for an SMR since:

- the SMR source term is considerably smaller than a source term of a conventional NPP
- (hence) the SMR reactor power is considerably smaller than the reactor power of a conventional NPP
- (hence) the amount and enrichment of fissile and fissionable material in an SMR is considerably smaller than the amount in a conventional NPP

The graded approach might also be applicable to the EIA. The obligatory international consultation for an EIA of an SMR might, under the treaties of AARHUS and ESPOO, not be necessary, since the transboundary effects of an accident with an SMR are absent.

The Nuclear Facilities and Fissionable Materials (Security) Regulation22 (Rbnis) includes the Dutch implementation of the amended Convention on the Physical Protection of Nuclear Material (CPPNM/a) and sets the security policy framework for the Netherlands.

4.7 Subconclusions

Since the graded approach proposed in [Safety Guidelines; Guidelines on the Safe Design and Operation of Nuclear Reactors, 2015] of safety requirements towards

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22 Regeling beveiliging nucleaire inrichtingen en splijtstoffen (Rbnis)
research reactors with their unique reactor designs, the same approach could also apply for SMRs, as they could be categorized as a small nuclear power reactor, provided that nuclear power safety requirements are matched and compliance with principles and general safety requirements in [Safety Guidelines; Guidelines on the Safe Design and Operation of Nuclear Reactors, 2015] are met.

Adding an extra chapter concerning SMRs to the VOBK an extra chapter concerning SMRs might be an option, but revision of the VOBK and Nuclear Energy Act by legally implementing acceptance of future Reactor Design Certifications could be a general enhancement in the application process.

If one does not take into account the core design and size of an SMR, its nuclear security level must equal that of a conventional NPP. The abovementioned graded approach in nuclear security regulations ensures that security requirements are appropriate for the postulated threats.

Siting of a new NPP in The Netherlands has been restricted to three locations (Borssele, Maasvlakte, Eemshaven), as ordered by the Dutch government. Whether SMRs apply to this statement remains to be seen because the standard NPP infrastructure might not be necessary for an SMR. An SMR has no need for:

- excessive amounts of cooling water since it produces less heat
- massive power grid connections since it produces less power
- large emergency preparedness zones because of on-site accident impacts

These argument are possible reasons to reconsider the designated NPP locations in The Netherlands and allow for more liberal choices like regional locations for SMRs. Local authorities, like municipalities, might be given the responsibility to choose for a nuclear powered grid.

The recommendations from (World Nuclear Association (WNA) 2020) and the liberal approach towards licensing SMR designs by CNSC (Canadian Small Modular Reactor Roadmap Steering Committee November 2018), combined with results from (Cipiti, et al. 2013) and (Lee and Woo 2018) show that a graded approach towards nuclear security of SMRs, or other reactor designs than conventional NPPs for that matter, is not only a long standing desire and justifiable, but also legally possible.

In nuclear security legislation in The Netherlands, such an approach already seems permittable and therefore revisions of legislation do not seem imminent. But publishing a nuclear security guide from the ANVS, explaining the possibilities for an applicant, would be recommendable.

Overall, the Dutch nuclear regulatory framework is well-positioned to respond to the SMR paradigm shift, but some modernization will be necessary to reflect the implications of the smaller size and power of an SMR.
5 Harmonization of licensing requirements

Every EU and IAEA Member State has its own and independent nuclear regulatory body, imposing their own set of rules on the design of new NPPs. Building a NPP on a site from the ground up, makes building more expensive than installing a standardized module, because the design must fit, possibly contradicting requirements and national safety and security requirements. Unraveling the elements (modules) in the application process and standardizing the application process when applicable, will harmonize and create successful implementations of SMRs.

A World Nuclear Association 2015 report [Cooperation in Reactor Design Evaluation and Licensing (CORDEL), August 2015] on SMR standardization of licensing and harmonization of regulatory requirements said that the enormous potential of SMRs rests on a number of factors:

- Because of their small size and modularity, SMRs could almost be completely built in a controlled factory setting and installed module by module, improving the level of construction quality and efficiency.
- Their small size and passive safety features make them an option for countries with smaller grids and less experience in nuclear power.
- Size, construction efficiency and passive safety systems (requiring less redundancy) can lead to easier financing compared to that for larger plants.
- Moreover, achieving ‘economies of series production’ for a specific SMR design will reduce costs further.

The various national systems today follow similar paths in approving nuclear power plant construction and operation. The process generally includes the following elements:

- Taking the decision to build and operate a nuclear power plant
- Selecting and approving a site
- Certifying a reactor design
- Assessing and approving a construction license and an operating license

![Figure 6 Major Licensing Steps for Nuclear Power Plants](image)
The Dutch nuclear regulatory framework is similar, as is shown in Chapter 4 SMRs and nuclear regulatory framework in The Netherlands, as is in most European countries.

The WNA proposes in [Cooperation in Reactor Design Evaluation and Licensing (CORDEL), August 2015] an optimization for the SMR licensing process which constitutes out of SMR specific elements:

- **Decision in Principle.** This decision is a governmental ruling which, in effect, allows work (non-safety related) to be started. It is seen as very beneficial, especially in that it serves to reduce political risk during the later stages of a project.
- **Site Approval.** Similar to the site approval for NPPs. More specific to the SMR case would be the need to consider how (or if) the unique features of an SMR would impact the site selection.
- **Module Design Certification (MDC).** Certification of the detailed design of the SMR reactor module, including the primary safety systems, preferably transferrable to other countries.
- **Master Facility License.** A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity. In this case facility refers to any number of combined small modular reactors.

![Diagram of Modular Licensing Process for SMRs](image)

*Figure 7 Possible Elements of a Modular Licensing Process for SMRs [Söderholm, 2013]*

However, it would still be necessary to assess other requirements such as multiple operation of reactors using common facilities, common cause failure modes, emergency preparedness and security.
Very similar to [Söderholm, 2013], the proposed approach in [CORDEL Group, 2010] would minimize the licensing risk and allow SMRs to be licensed as standard designs in many countries.

![Diagram of Design Approval as part of a comprehensive national regulatory process](image)

Figure 8 Design Approval as part of a comprehensive national regulatory process

The proposed approach is centered on limiting the scope of the design certification, and separating it from site-specific approvals and operational requirements, thereby allowing for a feasible reduction in the existing differences between countries’ licensing practices.

5.1 Module Design Certifications

Module Design Certification (MDC) would be a huge facilitator for the international acceptance of SMRs. It is a cost-effective approach separating reactor certification from the Site Approval.

As [CORDEL Group, 2010] states already in 2010, a Design Certificate for an SMR would be the certification of the detailed design of the SMR reactor module, including the primary safety systems, independent from other parts of the plant. Once certified, the module’s design, including the primary safety systems, would not need to be reviewed again as a single module during any specific NPP licensing process.

Design certifications do not exist yet although in 2020 NuScale entered Phase 4 of the Design Certification Application process of the Nuclear Regulations Committee (NRC) in the US. In September 2020 the NRC is on track to complete the design review though international acceptance of the NRC certificate is not implemented yet in regulatory frameworks.

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23 www.nuscalepower.com
5.2 Mobile and stationary SMRs

Mobility of an SMR applies to all phases, i.e. construction, storage, transportation, operational or decommissioning phase. Aircraft carriers, the ice breaker fleet of Rosatom and nuclear submarines are proof of its mobile possibilities in challenging situations and climates.

Studying reactor designs of mobile and stationary SMRs, the general impression is that mobile SMRs are applied in remote areas in challenging climates or serve military purposes. The impact of replacing fossil fuel powered civil or military power generators is high in these areas in terms of life’s gained, maintenance costs, reliability and reduction of emissions.

Mobile SMRs incorporate passive safety and security features to withstand extreme environments and operational situations but also to reduce costs of active systems and security personnel.

Gas-cooled reactors are the most researched choice for mobile SMRs since their passive safety is a convincing inherent property. Other reactor types need active safety systems like backup systems or water supplies to uphold a high safety level.

Higher SMR power output reduces its mobility because power output is correlated with the reactor core size, and the higher level of safety and security requirements with a larger reactor core. These requirements immobilize

5.3 Subconclusions

In case of a mobile SMR the three steps in the licensing process, Decision in Principle, the certification (MDC) and the Master Facility License can be prepared in advance. The location of a mobile SMR is changeable so the Site Approval should set boundaries in an abstract manner or should point out specific site locations.

Recommendation: Prepare The Netherlands Nuclear Energy Act for acceptance of MDCs.
6 Stakeholder involvement

The Netherlands have had a democratic culture with participation procedures for decades. During several phases of a licensing procedure, stakeholders can make their voices heard. Since the opportunities for stakeholders, either democratic or judicial, are widespread in several stages of different license procedures, broad political support will be ensured, when a license is granted. But this process also leads to reluctant investors because every necessary license has a participation procedure.

In the case of nuclear reactors support is needed to take the risk of investment. Suggestions have been made to prepare a Decision in principle together with all the stakeholders, as a government decision to reduce the political risk of delay, pause or cancellation during subsequent phases of the project.

6.1 The need for SMRs

Major incentives for SMR deployment are [Carelli & Ingersoll, 2015] a reduction of initial investment and associated financial risk and an improved match to smaller electric power grids. Other desirable factors deriving from the SMR characteristics are:

- effective protection of plant investment from the potential to achieve a reactor design with enhanced safety and security characteristics
- possible reduction of the emergency planning zone by virtue of the smaller core inventory and potential for added safety and security design features
- reduction of transmission requirements and a more robust, more reliable grid
- suitability for city heating, hydrogen production and desalination.

Challenges in SMR deployment are:

- sufficient reduction of financial risk
- achievement of a competitive SMR’s Levelized Unit Electricity Costs (LUEC24)
- fuel cycle compatibility with existing facilities and strategies

The military [Study on the use of mobile nuclear power plants for ground operations, 2018] has shown that SMRs, or Micro-Nuclear Power Plants (MNPP), are a viable option, because: “energy is, and will remain, a critical enabling component of military operations with demand continuing to increase over time” [Defense Science Board (DSB), 2016]. Employment of mobile nuclear power is consistent with the new geopolitical landscape, logistics and storage of fossil fuel curtails Combatant Commander (CCDT) options, increases complexity, and/or imposes substantial economic challenges.

Other arguments mentioned are: infrastructure requiring large-scale power (e.g., ports, airfields, rail, other transportation supporting infrastructure, industry etc.), mission assurance is required or where “islanding” is desirable (providing continuous power to a location even though energy from an electrical grid/external power source is no longer present), energy intensive systems (e.g., forward radar site operations) require significant power, power is desired to support Defense Support to Civil Authorities

24 US$/kWh
(DSCA) and/or access to an established or stable electrical grid is unavailable or where the electrical grid requires reinforcement or reconstitution to support intermediate staging bases, logistics staging areas, and/or medium to large base camps.

[Hokenson] points out that SMRs installed at military bases would help address several major challenges facing the military and the commercial nuclear industry, for instance, the U.S. military would be able to reduce its dependence on fossil fuels, long energy supply lines, and vulnerable civilian energy grids, while commercial industry would be able to take advantage of an innovative new technology without having to shoulder all of the risks and startup expenses that otherwise might prevent it from doing so. A faster and more widespread adoption of SMRs would serve multiple purposes, according to [Hokenson, 2016]: alleviating the reliability impact of increasingly expensive coal plants being closed down, replacing aging nuclear power plants nearing decommissioning, adding critical base load to an increasing mix of renewable sources, making nuclear power an option in regions previously too small to support a traditional reactor, and displacing more carbon intensive coal and natural gas production in line with environmental goals.

The arguments abovementioned are both valid for military and civil objectives to be met, like regional scalable energy production, contribution to a CO$_2$-neutral energy mix and increasing electrical power consumption.

SMRs are in the perspective of [Kernenergie is nodig om de klimaatdoelen te halen, 2020] a scalable option in delivering industrial process heat and production of hydrogen gas, which makes the use of SMRs more realistic.

One of the key findings of the [Canadian Small Modular Reactor Roadmap Steering Committee, November 2018] was the importance of early onset of and continuous engagement of members of the public. Some key points were identified:

- The rebuild of trust in nuclear power after several international accidents needs much work.
- Authentic engagement can provide opportunities to strengthen mutually beneficial and respectful relationships with members of the public by ensuring communities have democratic power to make decisions about their energy futures.
- Areas in close proximity of nuclear related industries have the highest support for nuclear power in contrast to areas further away.
- People are most likely to be concerned about nuclear safety, waste and used fuel management, as well as perceived environmental risks. Nuclear energy is also perceived as an expensive form of power generation.
- Individuals with higher levels of formal education are more likely than others to support nuclear power.
- Men, particularly those with higher levels of income and formal education, are more likely than women to view nuclear power favorably.
- Known positive aspects of nuclear power are CO2-neutral electrical energy and nuclear medicines.
- Many people feel that the negative aspects outweigh the positive aspects, for example radiation exposure, long-term nuclear waste and used fuel management.
- Confusion between nuclear power and nuclear weapons.

Some Steering Committee recommendations: The CNSC should continue public and community engagement in meaningful dialogues on a range of issues, such as the licensing process and waste. The CNSC should continue to deliver on its mandate of disseminating objective scientific, technical, and regulatory information to the public. These recommendations should apply to every nuclear regulatory body.

The proposed Decision in Principle by the WNA is a decision, a governmental ruling, which, in effect, allows work (non-safety related) to be started. It is seen as very beneficial especially in that it serves to reduce political risk during the later stages of a project.

6.2 Stakeholder involvement in nuclear regulatory framework in The Netherlands

The stakeholder involvement in the Dutch nuclear regulatory framework is spread in the application process. It involves participation procedures in several licenses and in case of the EIA, international participation procedures. Other ways to prevent the regulatory body to grant a license, is to file legal objections which leads to a legal process and a decision by the Council of State25.

A simplified visual representation of the license application process in The Netherlands shows its participation options.

![Figure 9 Current licensing process for a NPP in The Netherlands](image)

Implementing the recommendations done by [Söderholm, 2013] and [CORDEL Group, 2010], the license application process could be more efficient, take less time and reduce political risk during the later stages of a project. A simplified visual representation of these recommendations implemented, shows a parallel licensing
process for a NPP, more in particular an SMR, an implementation of MDCs in legislation and stakeholder involvement and a nuclear policy decision on beforehand.

Figure 10 Recommended licensing process for a NPP (or SMR) in The Netherlands

Stakeholder involvement in The Netherlands can be categorized as:

- International stakeholders like WENRA, WANO, ENSREG, IAEA, surrounding countries (EIA)
- National stakeholders like Externe Reactor BedrijfswaarschuwingsCommissie (ERBVC), Vereniging Nuclear Nederland, Greenpeace, Wise and Laka
- Private stakeholders: investors
- Public stakeholders: members of the public, the involved municipalities and the security regions

6.3 Stakeholder involvement and SMRs

Anti-nuclear movements state that “SMRs would inevitably increase nuclear insecurity, as their proliferation in numbers would be accompanied by a massive proliferation in nuclear sites and nuclear materials transports, both in the form of fresh unirradiated nuclear fuel and irradiated (spent) nuclear fuel (SNF). Both of these give greater new opportunities for malevolent actors (eg terrorists) to intervene with potentially catastrophic consequences.”

These kinds of media statements fool fast readers with highly improbable, worst-case scenarios with exaggerated consequences without references. All arguments in these kinds of statements can be put by with the information from the chapters above, except for the DBT scenarios where terrorist actions are involved because they contain classified information but rest assured, these are included in the DBT scenarios.

Countering arguments with interest groups is no guarantee for removal of unrest among the public because the discussions are on different playing fields, rationality and

emotions. Interest groups represent emotions and need to be addressed in an early stage (*Decision in Principle*). Communication efforts must be aimed at the majority, the public, to claim maximum effect and trust.

6.4 Subconclusions

Stakeholder feedback from diverse groups need to be considered in revisions on the nuclear regulatory framework to implement recommendations like graded approach in nuclear safety and security, acceptance of MDCs and a political decision towards nuclear policy cast in a governmental ruling, to ensure public engagement and secure broad support before the application process.

Implementing the recommendations done by [Söderholm, 2013] and [CORDEL Group, 2010], the license application process could be more efficient, take less time and reduce political risk during the later stages of a project.
7 Conclusions

The design of SMRs must be based on the basic requirements specified in the Safety Guidelines and at the same time must meet the requirements of nuclear security laid down in the nuclear security related regulations like the Nuclear Facilities and Fissionable Materials (Security) Regulation\(^\text{27}\) (Rbnis) and the Regulation nuclear safety of nuclear installations\(^\text{28}\).

An appropriate licensing process for novel reactor types, like SMRs, would be inspired by the recommendations done by the CORDEL workgroup.

Legislative and regulatory basic needs and principles regarding nuclear security in countries developing or acquiring mobile SMRs, are identification of safety and security synergies and conflicts, implementation of graded approach to safety and security requirements, harmonization of licensing requirements and early phase stakeholder involvement.

Since the graded approach of safety requirements towards research reactors in The Netherlands is specifically mentioned in legislation, the same approach could also apply for safety requirements of novel reactor types, like used in SMRs. And because SMR security features benefit from safety requirements, mainly because of the compact design and its inherent safety features, the same applies to SMR nuclear security requirements. The graded approach might also apply to the defence-in-depth and emergency planning zones.

The Dutch nuclear regulatory body, the ANVS, proposes a three-staged structured method: (1) categorization of the research reactor, (2) analysis of specific factors not covered and (3) the applicability of power reactor requirements to particular research reactors. The same three-staged structured method is applicable for SMRs.

Adding an extra chapter concerning SMRs to the Dutch Safety Guidelines guidance, the VOBK, might be an option, but revision of the VOBK and Nuclear Energy Act by legally implementing acceptance of future Module Design Certifications (MDCs) could be a general enhancement in the application process. Although the US NRC is on track to complete the design review of NuScale\(^\text{29}\) though international acceptance of MDCs like the NRC certificate (or from any other IAEA Member State) is not implemented yet in regulatory frameworks, although the Italian nuclear legislation adjustments sets a good example.

The recommendations from (World Nuclear Association (WNA) 2020) and the liberal approach towards licensing SMR designs by CNSC (Canadian Small Modular Reactor Roadmap Steering Committee November 2018), combined with results from (Cipiti, et al. 2013) and (Lee and Woo 2018) show that a graded approach towards nuclear security of SMRs, or other novel reactor designs than conventional NPPs for that matter, is not only a long standing desire and justifiable, but also legally possible. If one does not take into account the core design and size of an SMR, its nuclear security

\(\text{27} \) Regeling beveiliging nucleaire inrichtingen en splijtstoffen (Rbnis)
\(\text{28} \) IENM/BSK-2017/128532 Regeling nucleaire veiligheid kerninstallaties
\(\text{29} \) www.nuscalepower.com
level must equal that of a conventional NPP. The graded approach in the Dutch nuclear security regulations ensures that security requirements are appropriate for the postulated threats.

In nuclear security legislation in The Netherlands, such an approach already seems permissible and therefore revisions of legislation do not seem imminent. But publishing a nuclear security guide from the ANVS, explaining the possibilities for an applicant, would be recommendable.

Studying reactor designs of mobile and stationary SMRs, the general impression is that:

- mobile SMRs are mostly applied in remote areas in challenging climates or serve military purposes
- mobile SMRs incorporate passive safety and security features
- gas-cooled reactors are the most researched choice for mobile SMRs
- a higher power output reduces mobility

Regulatory frameworks and crisis response organization must be prepared to deal with smaller NPPs and the absence of post-accident, off-site radiological consequences, only after careful consideration.

Maintaining high levels of security, regulatory frameworks should validate novel physical security analysis methodologies of SMR security designs. By using the graded approach in D-i-D analysis, DBTs and towards EPZs in crisis response plans and operations, regional siting might be an option.

These argument are plausible reasons to reconsider the designated NPP locations in The Netherlands and allow for more liberal choices like regional locations for SMRs. Local authorities, like municipalities, might be given the responsibility to choose for a nuclear powered grid.

Overall, the Dutch nuclear regulatory framework is well-positioned to respond to the SMR paradigm shift, but some modernization will be necessary to reflect the implications of the smaller size and power of an SMR.
Recommendations

1. Module Design Certification (MDC) would be a huge facilitator for the international acceptance of SMRs. It is a cost-effective approach separating reactor certification from the Site Approval. Provide and educate experts taking part in reactor validation processes.

2. Implement the acceptance of foreign or internationally agreed upon (IAEA) codes and standards of reactor designs and its reactor design certification system into the Nuclear Energy Act or into Regulations of The Netherlands nuclear regulatory framework. Prepare The Netherlands Nuclear Energy Act for acceptance of MDCs.

3. In case of a broad and heavy DBT scenarios package, not all scenarios might apply to SMRs at the same level, therefore some threat scenarios could most likely be waived. A recommendation could be to apply the graded approach to the DBT scenarios package, since some scenarios are overkill for certain SMR reactor designs. Novel DBTs might be needed to be set up in case of a mobile SMR, for instance theft of an entire mobile facility must be taken into account as a novel reference DBT scenario. Implement a graded approach towards nuclear security of SMRs in the Dutch nuclear regulatory framework.

4. Implementing the recommendations done by [Söderholm, 2013] and [CORDEL Group, 2010], the license application process could be more efficient, take less time and reduce political risk during the later stages of a project.

5. Stakeholder feedback from diverse groups need to be considered in revisions on the nuclear regulatory framework to implement recommendations like graded approach in nuclear safety and security, acceptance of MDCs and a political decision towards nuclear policy cast in a governmental ruling, to ensure public engagement and secure broad support before the application process.

6. In case of a standard mobile SMR the three steps in the licensing process, Decision in Principle, the certification (MDC) and the Master Facility License can be prepared in advance.

7. The location of a mobile SMR is variable so the Site Approval should set boundaries in an abstract manner or should point out specific regional site locations or should include non-operation during specific phases.

8. The graded approach might also be applicable to the EIA. The obligatory international consultation for an EIA of an SMR might, under the treaties of AARHUS and ESPOO, not be necessary, since the transboundary effects of an accident with an SMR are absent.
8 Outlook

As performed by the CNSC, a Regulatory Readiness Working Group (RRWG) might consider the full range of existing regulatory and legislative processes, carrying out line-by-line analyses and tabletop emergency exercises to evaluate how they might apply to SMR deployment in The Netherlands.

The Dutch military might be interested in applying SMRs for energy production during or between military operations. For instance, researching electrical propulsion by SMRs for large container ships, naval vessels or submarines can be subject of study.

In contrast with Canada, The Netherlands doesn’t have a full spectrum nuclear fuel cycle industry, starting from uranium mining’s to nuclear fuel waste storage sites. The focus of a Dutch approach, inspired by the RRG W, should therefore be on specific topics like stakeholder involvement or SMR design research, nuclear fuel production and transport and nuclear fuel waste storage sites to ensure commercial availability for SMRs.

Since the only NPP in The Netherlands is scheduled to close in 2033, the feasibility of regionally installing SMRs in The Netherlands might be subject of study. The result of this study would be a case study of detailed recommendations to the Dutch regulatory framework for licensing SMRs. An example of such a study might be the UK’s Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project. In 2018, UK’s Department for Business, Energy & Industrial Strategy has launched its Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project.
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<th>Acronym</th>
<th>Description</th>
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</thead>
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<tr>
<td>ANVS</td>
<td>Authority for Nuclear Safety and Radiation Protection (Dutch: Autoriteit voor Nucleaire Veiligheid en Stralingsbescherming)</td>
</tr>
<tr>
<td>AIVD</td>
<td>General Intelligence and Security Service (Dutch: Algemene Inlichtingen en VeiligheidsDienst)</td>
</tr>
<tr>
<td>Bbs</td>
<td>Decree on Basic Safety Standards for Radiation Protection (Dutch: Besluit basisveiligheidsnormen stralingsbescherming)</td>
</tr>
<tr>
<td>BWR</td>
<td>Boiling Water Reactor</td>
</tr>
<tr>
<td>CCDT</td>
<td>Combatant Commander</td>
</tr>
<tr>
<td>CNSC</td>
<td>Canadian Nuclear Safety Commission</td>
</tr>
<tr>
<td>CPPNM/a</td>
<td>Amendment to the Convention on the Physical Protection of Nuclear Material IAEA INFCIRC/274/Rev.1/Mod.1 9th May 2016</td>
</tr>
<tr>
<td>DBT</td>
<td>Design Basis Threat</td>
</tr>
<tr>
<td>D-i-D</td>
<td>Defence-in-Depth</td>
</tr>
<tr>
<td>DSB</td>
<td>Defense Science Board (USA)</td>
</tr>
<tr>
<td>DSCA</td>
<td>Defense Support to Civil Authorities (USA)</td>
</tr>
<tr>
<td>DTN</td>
<td>Terrorist Threat Assessment Netherlands (Dutch: Dreigingsbeeld Terrorisme Nederland)</td>
</tr>
<tr>
<td>ENSRA</td>
<td>European Nuclear Security Regulators Association</td>
</tr>
<tr>
<td>ENSREG</td>
<td>European Nuclear Safety Regulators Group</td>
</tr>
<tr>
<td>EPZ</td>
<td>Emergency Planning Zone</td>
</tr>
<tr>
<td>HALEU</td>
<td>High-Assay Low Enriched Uranium</td>
</tr>
<tr>
<td>HEU</td>
<td>Highly Enriched Uranium</td>
</tr>
<tr>
<td>HFR</td>
<td>High Flux Reactor</td>
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<tr>
<td>HTGR</td>
<td>High-Temperature Gas Reactor</td>
</tr>
<tr>
<td>ISS</td>
<td>Institute for Security and Safety</td>
</tr>
<tr>
<td>IenW</td>
<td>Ministry of Infrastructure and Water Management (NLD) (Dutch: Ministerie van Infrastructuur en Waterstaat)</td>
</tr>
<tr>
<td>KeW</td>
<td>Nuclear Energy Act (Dutch: Kernenergiewet)</td>
</tr>
<tr>
<td>KLPD</td>
<td>National Police Services Agency (Dutch: Korps Landelijke Politiediensten)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>LEU</td>
<td>Low Enriched Uranium</td>
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<tr>
<td>LFR</td>
<td>Lead Fast Reactor</td>
</tr>
<tr>
<td>LOCA</td>
<td>Loss Of Coolant Accident</td>
</tr>
<tr>
<td>LWR</td>
<td>Light Water Reactor</td>
</tr>
<tr>
<td>MDC</td>
<td>Module Design Certification</td>
</tr>
<tr>
<td>MIVD</td>
<td>Military Intelligence Security Service</td>
</tr>
<tr>
<td></td>
<td>(Dutch: Militaire Inlichtingen en VeiligheidsDienst)</td>
</tr>
<tr>
<td>MNPP</td>
<td>Micro Nuclear Power Plant</td>
</tr>
<tr>
<td>NCTV</td>
<td>National Coordinator for Security and Counterterrorism</td>
</tr>
<tr>
<td>NLDA</td>
<td>Dutch Defense Academy (NLD)</td>
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<tr>
<td>NPP</td>
<td>Nuclear Power Plant</td>
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<tr>
<td>NSSS</td>
<td>Nuclear Steam Supply System</td>
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<tr>
<td>PP</td>
<td>Physical Protection</td>
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<tr>
<td>PR</td>
<td>Proliferation Resistance</td>
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<tr>
<td>PWR</td>
<td>Pressurized Water Reactor</td>
</tr>
<tr>
<td>Rbnis</td>
<td>Nuclear Facilities and Fissionable Materials (Security) Regulation</td>
</tr>
<tr>
<td></td>
<td>(Dutch: Regeling beveiliging nucleaire inrichtingen en splijtstoffen)</td>
</tr>
<tr>
<td>RIVM</td>
<td>National Institute for Public Health and the Environment (NLD)</td>
</tr>
<tr>
<td>SFR</td>
<td>Sodium Fast Reactor</td>
</tr>
<tr>
<td>SMR</td>
<td>Small Modular Reactor</td>
</tr>
<tr>
<td>TRISO</td>
<td>TRistructural ISOtropic-type</td>
</tr>
<tr>
<td>vSMR</td>
<td>very Small Modular Reactor</td>
</tr>
<tr>
<td>VOBK</td>
<td>Guidance to the Safe Design and Operation of Nuclear Reactors</td>
</tr>
<tr>
<td></td>
<td>(Dutch: Handreiking voor een Veilig Ontwerp en het veilig Bedrijven van Kernreactoren)</td>
</tr>
<tr>
<td>WENRA</td>
<td>Western Europe Nuclear Regulatory Association</td>
</tr>
<tr>
<td>WNA</td>
<td>World Nuclear Association</td>
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<tr>
<td>zbo</td>
<td>independent administrative authority</td>
</tr>
<tr>
<td></td>
<td>(Dutch: zelfstandig bestuursorgaan)</td>
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</tbody>
</table>
12 Bibliography


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13 Appendices

13.1 Dutch nuclear legal framework

13.1.1 Nuclear Energy Act

The Nuclear Energy Act (NEA) is a framework act comprising of approximately 80 sections. A remarkable feature of the Nuclear Energy Act is its comprehensive character: all uses of ionizing radiation and all of the requirements to protect against it are regulated exclusively by this Act and by legislation based on it.

An extensive body of legislation is based on the Nuclear Energy Act. This includes administrative orders, ministerial regulations, the regulations issued by the ANVS, and a number of general operating decisions. These include:

**Nuclear Facilities, Fissionable Materials and Ores Decree (BKSE):** the licensing system for practices with fissionable materials and ores has been elaborated in the Nuclear Facilities, Fissionable Materials and Ores Decree.

**Fissionable Materials, Ores and Radioactive Materials Transport Decree (BVSER):** The licensing system for the shipment of these materials has been elaborated in the Fissionable Materials, Ores and Radioactive Substances (Transport) Decree. There are four categories of transport licenses: fissionable materials, fissionable materials with depleted uranium shielding, import or export of medicines or consumer items, and shipment in accordance with a special regulation.

**Decree on Basic Safety Standards for Radiation Protection (Bbs):** the Decree on Basic Safety Standards for Radiation Protection has been in force since 6 February 2018. The goal of this Decree is to protect the public, the environment, employees and patients against the adverse effects of ionizing radiation. It replaces the Radiation Protection Decree. This complies with the 2013/59/Euratom directive – the Basic Safety Standards or BSS –, which in turn is an elaboration of the recommendations of the International Commission on Radiological Protection. The requirements set out in the Decree have been further elaborated, in the form of the associated regulations.

**Regulation on Radiation Protection for Occupational Exposure:** Responsibility for the protection of employees from occupational exposure to radiation rests with the Ministry of Social Affairs and Employment. Specific topics have been further elaborated in the

**Regulation on Radiation Protection for Occupational Exposure 2018.** These include additions to risk assessment & evaluation, cooperation with radiation practitioners/occupational health service, criteria for the registration (or re-registration) of radiation practitioners, warning signals, National Dose Registration and Information System, requirements concerning dosimetric services, and radon in the workplace.

**Regulation on Radiation Protection for Medical Exposure:** In the field of medicine, important technological and scientific developments have generally
led to a marked increase in patients’ exposure. The BSS emphasize that justification of medical exposure is required (in individual cases). These standards also impose strict requirements on information provided to patients, on the registration and reporting of doses used in medical procedures, on the use of diagnostic reference levels, and on the availability of instruments for measuring doses. This is laid down and regulated in the Decree on Basic Safety Standards for Radiation Protection (Chapter 8) and in the Regulation on Radiation Protection for Medical Exposure.

**Regulations on Basic Safety Standards for Radiation Protection:** The Regulation on Basic Safety Standards for Radiation Protection contains provisions for the elaboration of the Decree on Basic Safety Standards for Radiation Protection. These Regulations contain rules and appendices with technical and other requirements for implementation, such as administrative requirements, values for exemption and release from regulatory control, core competences and other qualifications for experts and the corresponding educational requirements, generic justification for practices and measures.

**Nuclear Safety Regulation for Nuclear Facilities:** The regulations extend to implementation of the Euratom Directive for the nuclear safety of nuclear facilities (Directive 2009/71/EURATOM, as amended by Directive 2014/87/EURATOM). The regulations provide the necessary Community framework for maintaining the nuclear safety of nuclear facilities and for promoting continuous improvement.

**Nuclear Facilities and Fissionable Materials (Security) Regulation:** This regulation includes the Dutch implementation of the amended Convention on the Physical Protection of Nuclear Material (CPPNM/a).

### 13.1.2 ANVS Regulations

The ANVS Regulation on Basic Safety Standards for Radiation Protection has been in force since 6 February 2018. These regulations contain further rules to protect people against the hazards of exposure to ionizing radiation. The ANVS-Regulation on Nuclear Safety and Security will enter into force in the spring of 2019.

### 13.1.3 Nuclear Safety Guidelines

The licenses for nuclear facilities make use of the Nuclear Safety Guidelines (NVR’s). These are IAEA Safety Requirements and Safety Guides that have been adapted to the Dutch situation. They are linked to a license, depending on the nuclear facility in question. Through its affiliation with the Western European Nuclear Regulators Association (WENRA), the ANVS has committed itself to implement the reference levels. These are important for various reasons, such as promoting the national and international harmonization of legislation.

### 13.1.4 Guidances

Guidances are informative documents that indicate how specific topics in the legislation should be interpreted. Guidances are not binding. The Netherlands has a number of guidances in the field of nuclear safety and radiation protection. These include the
Guidance to the Safe Design and Operation of Nuclear Reactors and Guidance to license applications for fissionable materials, radioactive materials and devices. Other ministries also issue guidances that are relevant to radiation protection, such as the Ministry of Social Affairs and Employment’s Guidance to risk analysis for radiation applications.
13.2 Categorization of Nuclear material (INFCIRC/274/Rev.1/Mod.1)

**ANNEX II**

**TABLE: CATEGORIZATION OF NUCLEAR MATERIAL**

<table>
<thead>
<tr>
<th>Material</th>
<th>Form</th>
<th>Category I</th>
<th>Category II</th>
<th>Category III$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plutonium$^d$</td>
<td>Unirradiated$^b$</td>
<td>2 kg or more</td>
<td>Less than 2 kg but more than 500 g</td>
<td>500 g or less but more than 15 g</td>
</tr>
<tr>
<td>2. Uranium-235</td>
<td>Unirradiated$^b$</td>
<td>5 kg or more</td>
<td>Less than 5 kg but more than 1 kg</td>
<td>1 kg or less but more than 15 g</td>
</tr>
<tr>
<td></td>
<td>- uranium enriched to 20%$^{235}$U or more</td>
<td>10 kg or more</td>
<td>Less than 10 kg but more than 1 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- uranium enriched to 10%$^{235}$U but less than 20%</td>
<td>10 kg or more</td>
<td>Less than 10 kg but more than 1 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- uranium enriched above natural, but less than 10%$^{235}$U</td>
<td>10 kg or more</td>
<td>Less than 10 kg but more than 1 kg</td>
<td></td>
</tr>
<tr>
<td>3. Uranium-233</td>
<td>Unirradiated$^b$</td>
<td>2 kg or more</td>
<td>Less than 2 kg but more than 500 g</td>
<td>500 g or less but more than 15 g</td>
</tr>
<tr>
<td>4. Irradiated fuel</td>
<td></td>
<td></td>
<td>Depleted or natural uranium, thorium or low-enriched fuel (less than 10% fissile content)$^{b\text{iv}}$</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ All plutonium except that with isotopic concentration exceeding 80% in plutonium-238.

$^b$ Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 1 gray/hour (100 rads/hour) at one metre unshielded.

$^c$ Quantities not falling in Category III and natural uranium should be protected in accordance with prudent management practice.

$^d$ Although this level of protection is recommended, it would be open to States, upon evaluation of the specific circumstances, to assign a different category of physical protection.

$^{b\text{iv}}$ Other fuel which by virtue of its original fissile material content is classified as Category I and II before irradiation may be reduced one category level while the radiation level from the fuel exceeds 1 gray/hour (100 rads/hour) at one metre unshielded.

*Figure 11 Categorization of Nuclear material in Annex II of IAEA INFCIRC/274*
14 Declaration of honor

I hereby confirm that I have written this thesis independently and have not used any sources or resources other than those specified and that the work in the same or similar form has not yet been submitted to any other examination authority.

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Place: Escharen, The Netherlands
Date: 10th of August, 2020

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