Risk Informing Regulatory Oversight of Nuclear Facilities in Finland

Teemu Soukki[a*], Ari Julin[a]
[a]STUK, Vantaa, Finland

Abstract: In Finland, probabilistic risk assessment (PRA) is an official licensing document. A full scope, plant specific, PRA is required in all licensing phases of an NPP including construction license, operating license, and decommissioning license. The Radiation and Nuclear Safety Authority (STUK) has actively promoted the use of PRA especially in the safety management during the whole life cycle of a nuclear facility. In recent years, significant steps and progress has been established in the increasing use of risk insights to support the decision making and planning of regulatory oversight, as well.

Combining deterministic and probabilistic insights to support regulatory decision making has been ongoing for decades. However, there has been, and still is, a need for more systematic, practical, and documented approaches including proper tools to support risk informing and grading of various regulatory activities.

The paper highlights the benefits and challenges in utilization of risk informed graded approach and use of PRA applications to support regulatory oversight. Examples of recent development are presented, including risk informed grading of SSCs and their oversight during their whole life cycle, a tool to communicate risk information for regulatory staff, methodology to assess review classes for regulatory tasks, and targeting of regulatory inspections. Semi-quantitative methods have also been explored to introduce risk insights into areas involving more complex cause and effect relationships.

Risk informed approach, and especially PRA, has proven its strength in enhancing regulatory staff risk awareness, more holistic assessment of various safety issues, and especially in grading of regulatory activities and resource allocations related to reviews and inspections of safety significant SSCs. Further development of more concrete and systematic approaches and tools for different technical disciplines are under development at STUK.

Keywords: Risk Informed Regulation, PRA, Graded Approach, Applications

1. INTRODUCTION

The objective of this paper is to highlight and provide insights on the benefits and challenges in utilization of risk informed graded approach and use of PRA applications to support regulatory oversight as well as to present the state of risk informed regulatory oversight in Finland. Example tools for risk informed grading are also covered.

Finland currently has five operating NPP units, and there are no ongoing new NPP build projects after the completion of Olkiluoto 3 (OL3) and the termination of the Hanhikivi 1 project. These five units produced more than 40% of total electricity in Finland in 2023 [1].

Currently the political climate in Finland is favorable to the continued use of nuclear power [2]. In 2023 the Loviisa NPP was granted a continued operating license until the end of 2050 [3]. Owner of Olkiluoto NPP, TVO, is also looking into uprating the power of the plant units' OL1 and OL2, by 80 MWe, as well as extending their service life [4]. Furthermore, there is an interest in the increased use of nuclear energy, especially in the form of SMRs.

For a while now, there has been an aim to develop regulation into a more risk informed direction and apply graded approach in the safety management of NPPs and lately, especially in regulatory oversight. The ambition comes from both the nuclear energy act, as well as from the strategy of STUK. In the nuclear energy act, it is stated "The safety requirements and measures for ensuring safety shall be graded and targeted so as to be commensurate with the risks in the use of nuclear energy" while STUK's strategy emphasizes risk informed steering of oversight, as well as goal oriented, risk informed and enabling regulations. It's important to note that risk informed regulation in Finland combines both probabilistic and deterministic insights.

With risk informed graded approach, inspection resources can be better targeted, increasing efficiency and effectiveness. Nuclear safety is increased, as less effective work is reduced, and the effort is redirected to areas more important to safety. This means, that more attention can be allocated to safety significant areas without increasing the costs of oversight. However, the tendency has so far been to make decisions for increased oversight (resources, new items), while decreasing the oversight, has been difficult.

2. DEVELOPMENT OF PRA AND PRA REQUIREMENTS

When the first Finnish nuclear reactors began operating, PRA wasn't obligatory. However, in 1984, this changed as level 1 and level 2 PRAs became mandatory, while level 3 remains optional. The first PRAs were conducted in-house, by the licensees, to improve the personnels understanding of the plant specific risks and to facilitate the use of PRA in decision making. External consultants were only used for special topics. For new NPP projects the PRA has been developed by the vendor, but licensees have still been involved in the development from a very early point.

Since 1988, PRA has been an official licensing document in Finland, and it is required in all licensing phases including construction license, operating license, and decommissioning. The general requirement on the use of PRA is set forth in the Nuclear Energy Decree. PRA requirements have been gradually extended and implemented in legislation and in the regulatory YVL guides issued by STUK. The current structure of Finnish nuclear safety legislative framework is outlined in figure 1.

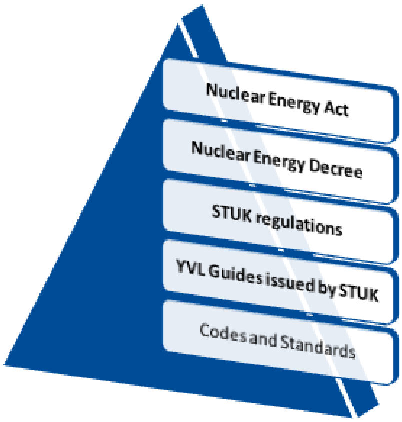

Figure 1. The current structure of nuclear safety legislative framework in Finland.

The PRA computer model, together with its documentation is also required to be delivered to STUK. The model provides a common communication platform between STUK and the licensees and is used in risk-informed regulation. In addition, for the purpose of construction and operating licence reviews, an independent external peer review of the PRA shall be submitted to STUK. This peer review should cover e.g. the used reliability data and other input data, modelling methods and their application in practice. Since STUK is dependent on the model submitted by the licensee, a detailed regulatory review is carried out.

According to the current regulatory guides, PRA shall:

- be applied all through the plant lifetime
- be plant specific, full scope level 1 and 2 PRA
- include all operating modes
- be up to date (annual updates)
- demonstrate the fulfilment of acceptance criteria: CDF < 1E-5/year and LRF < 5E-7/year. [5]

The quantitative acceptance criteria are strict for new NPP builds, but for units that were completed before the current regulatory guides were implemented, they act as target values to be reached by continuous safety improvements. In addition to the criteria mentioned above, several PRA applications are required as a condition for licensing and operation.

The first internal event PRAs for Loviisa unit 1 (LO1) and Olkiluoto unit 1 (OL1) were submitted in 1989. Since then, the licensees have gradually extended the, now unit specific, models to cover internal events, internal, hazards and external hazards for power operation and shutdown states. Figure 2 showcases how evolving regulatory requirements, have driven the licensees to develop and use PRA, which has further guided plant modifications and continuous improvement of safety.

Currently all Finnish NPPs have a full scope unit specific level 1 and level 2 PRAs covering all potential internal events, as well as internal and external hazards in all operating states. Separate PRAs have been completed for the spent fuel interim storage facilities and the spent fuel encapsulation plant operated by Posiva.

Recently Loviisa NPP completed new seismic hazard and fragility estimates for both units and the PRA will be updated when ongoing seismic studies are finalized. At OL1 and OL2 recent plant modifications have decreased the CDF and LRF. Some examples of these include an alternative coolant injection system and recirculation lines to auxiliary feed water system to remove dependency from sea water cooling. Due to continuous plant improvements, all operating NPP units have been able to reduce their CDF to under the 1E-5/year limit. However, when comparing long-term PRA results, it is important to note that the results are influenced not only by plant changes but also by the evolution of the model. At OL3, the updated PRA, performed by the vendor is currently under review. It includes several changes to model and documentation, but no significant change in CDF or LRF. The licensee (TVO) will continue the work to develop the OL3 PRA further. Ongoing tasks include a more detailed modelling of fire risks, reducing of calculation time, transferring the level 2 model on to the same software as level 1, as well as several other model and documentation updates.

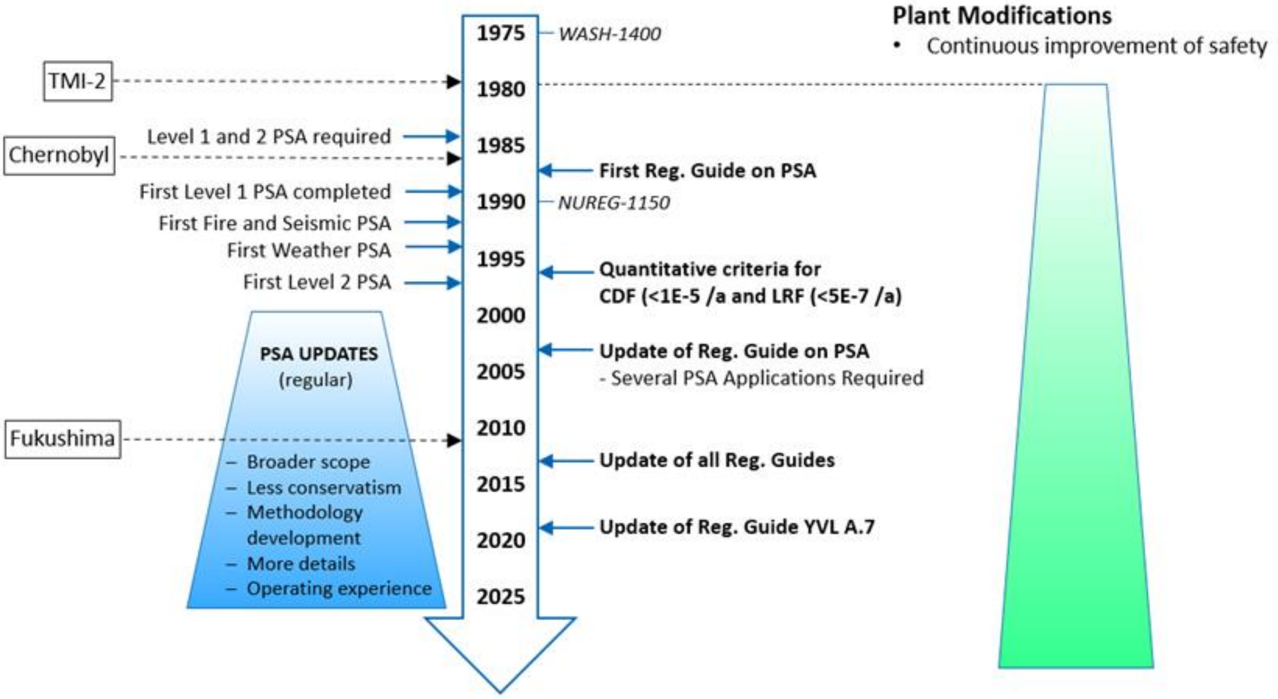

Figure 2. Timeline of PRA development in Finland.

STUK has actively promoted the use of PRA in risk informed safety management, for more than 30 years. Several PRA applications have been required in the YVL regulatory guides as a condition for construction and operating licenses. Based on development efforts and experience, more requirements have been set forth to extend the use of PRA to various risk informed applications, many of which have been examined through STUK initiated pilot studies.

The PRA applications currently required in the regulatory guides are set out in table 1. The requirements have been focused on the risk informed safety management of NPP units, but they are applied to other nuclear facilities when relevant.

Table 1. The PRA applications currently required by the regulatory guides. [5]

PRA Application
Plant modifications (identification of need and risk impact)
Risk Informed Pre- and In-Service Inspections (RI-PSI/ISI)
Risk Informed In-Service (periodic) Testing (RI-IST/RI-PT)
Risk Informed Operational Limits and Conditions (RI-OLC)
Risk Informed On-line Preventive Maintenance (RI-PM)
Training of operator (and other staff)
Procedures development
Risk Informed Safety classification of SSCs (RI-SC)
Outage specific risk assessment for outage planning
Assessment of the coverage and balance of the commissioning test programs and reduction of commissioning risks
“Security” PRA (vital area identification)

Every two years, STUK conducts a regulatory inspection related to the utilization of PRA by the licensees in the NPP safety management.

3. REGULATORY USE OF PRA

It has been recognized that a risk informed approach allows for a regulatory body to increase effectiveness and efficiency. When correctly handled, a PRA forms a common communication platform between the regulatory body and the licensees and increases the risk awareness of the staff at both. It allows for transparent and well justified insights to support decision making, which in turn creates more consistent regulatory decisions and more effective allocation of resources.

At STUK, risk-informed regulation has been practiced, even before it was explicitly defined, on a case-by-case basis. In practice, this has meant considering both deterministic and probabilistic perspectives in the decision-making process. The proportion of these approaches has varied, ranging from almost fully deterministic to an equal emphasis on both, depending on the specific situation and the decision makers involved.

The licensees have well adopted the risk informed safety management practices in accordance with regulatory YVL guides. In recent years STUK has also put more effort on developing risk informed applications for regulatory use. Some PRA applications in use at STUK are set out in table 2. In addition to these applications STUK has developed a powerful and versatile PRA code (FinPSA) for model development, calculations and especially for review purposes. The development of FinPSA started in 1988 and it is now maintained by VTT Technical Research Centre of Finland.

Table 2. PRA applications in use at STUK

PRA Application
Evaluation of outage risks
Verification- and sensitivity analysis
PRA information system (PRAIS)
Evaluation of the acceptability of exemptions from TechSpecs LCO (limiting conditions for operation) requirements
Risk informed targeting of regulatory inspections & reviews
Use of PRA in emergency preparedness situations
A more formal use of PRA and risk information in the consideration of safety significance

3.1. Development of Risk Informed Graded Approach

After the explicit amendment of a graded approach principle in the Finnish Nuclear Energy Act in 2013, it was also gradually introduced into STUK's Management System with the aim to cover all regulatory activities to target and allocate the regulatory resources. The oversight should be focused on issues based on their safety significance. In the past, the regulatory review and assessment process was mainly based on deterministic criteria and on the application of safety classification of systems structures and components (SSCs) of a nuclear facility with limited use of probabilistic insights. In other words, the SSCs with the highest safety class received most regulatory attention also in the review and assessment process. Probabilistic insights were utilized on a case-by-case basis.

STUK initiated a graded approach development project in 2014, based on which the principles and application of graded approach were described in internal procedures and utilized formally since the beginning of 2016. Although the approach was fairly easy to apply to grading of documentation reviews related to SSCs, it soon became evident that more detailed review guidance and support was needed in some cases for the determination of the scope and depth of the regulatory reviews, and for its application to other regulatory oversights activities. Thus, the development of graded approach was continued in a project called RIGA (Risk Informed Graded Approach) with the aim to develop practical guidance and tools on how to use risk information to support the implementation of graded approach to a broad scope of regulatory oversight activities. The development was strongly supported by STUK's management since one of the key areas in the STUK's strategy plan for 2018-2022, was the development of a more systematic, practical, and documented approaches and tools for risk-informed graded oversight.

3.1.1. RIGA-tool

RIGA tool is one of the outputs of the RIGA project. RIGA tool provides the risk importance classification of systems and equipment, which can be used to support the determination of regulatory review classes. There are four review classes in use at STUK. Review class 1 represents a full scope review, while class 4 means that the item does not need regulatory handling at all.

RIGA tool covers all Finnish NPP units, and it utilizes the risk information that can be obtained from the plant specific PRA models. RIGA tool has especially been designed to support the inspection work carried out by the section for mechanical engineering and the section for operational safety.

Risk informed grading of oversight activities related to mechanical equipment covers the whole life cycle of the equipment (including the design phase). RIGA tool provides equipment location specific quantitative risk metrics, which considers both the risk of loss of integrity and loss of function (also potential common cause failures). Qualitative increase factors are applied e.g., pressure equipment safety (personnel), first of a kind (FOAK), difficulty of detection.

Another example of the use of RIGA tool is the assessment of system and component unavailabilities. It is used to assess the safety significance of equipment failures reported in licensee event reports (including daily reports) in a timely manner in order to be able to request for additional information from the licensees in due time.

The work to develop dedicated versions of RIGA tool to needs of other sections at the nuclear reactor regulation department is under way.

3.1.2. PRA Information System (PRAIS)

It has already been established, that a PRA model, contains useful risk information, that can be used in risk informed regulation of NPPs. However, useful data can be hard to extract from the model itself, and it doesn't necessarily reach the right people. To solve this, STUK has developed a system, that makes PRA data more accessible, and understandable, without the need for extensive PRA training.

The PRA information system, or PRAIS is a PRA application aimed at enhancing STUKs inspectors' comprehension of the risks associated with Finnish NPPs. PRAIS is a passive tool for risk informed regulation in the sense, that it is not actively used in direct decision making, instead it offers the user a heightened perception of risks associated with a specific NPP, and how this information is used, is left to the individual inspector.

PRAIS gets its initial data from the PRA model, which is then refined to offer a graphical interpretation. In addition, PRAIS also offers information in text form, about PRA in general and some unit specific points of interest. PRAIS in whole, text-based information included, is maintained by the section of risk assessment. The application covers all Finnish NPP units and includes PRA results from level 1 and 2.

The system is built on a common platform with other STUK's database applications, including the overall safety assessment model, periodic inspection program, handling of open issues as well as gathering and handling of all regulatory findings, to name a few. To have the system in a common platform means that its familiar to users, linking between projects is possible and sharing of confidential information is already authorized, some restrictions excluded. However, the platform choice has not been without issue, as the development has been harder than expected, as PRAIS is fundamentally different from other applications in the platform and has therefore demanded a different set of skills.

The graphs generated by PRAIS are dynamic, in the sense, that the user can change parameters and explore the data. Some graphs are also interactive and allow actions, such as drilling into data categories, or screening some elements from the graph. The graphs are also easy to export, using a built-in export feature, so that they can be more easily used in presentations and training sessions, further increasing the staff risk awareness. Two such exports can be seen in Figures 3 and 4, where in figure 3 is the yearly evolution of the CDF of Loviisa units 1 and 2, and in figure 4 are the level 1 results of the year 2023 for unit 1, broken down into categories.

One of the guiding principles in PRAIS development was that it should be easy to update. This was tackled by using standardised PRA model data printouts and processing them on purpose-built MS Excel sheets before exporting the data to the host platform. The data is turned into visualizations in the host platform, by automated scripts, that need only to be verified by the user. The largest time investment is in verifying, and correcting possible mistakes of the process, especially in the excel sheets. Text based information that is harder to update, is mostly limited to themes that won't need yearly changes. These themes include general knowledge about PRA, initiating event descriptions, and interpretations about historic changes in the main results.

PRAIS is a living project, meaning that further development is ongoing. This development includes expanding text-based data to give rationale to the plant specific risk profiles e.g., why some initiators are more dominant in specific plants or how and why certain modelling assumptions affect the results. To keep the updating workload minimal, the focus will be on data that is mostly static. Better interface with other wiki-style platforms already at use in STUK is also explored, to ensure a consistent approach between applications.

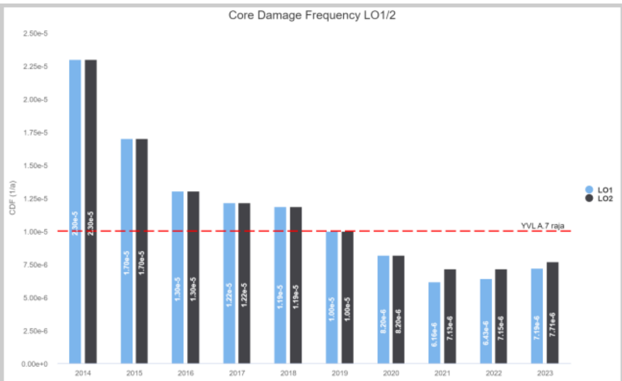

Figure 3. Bar chart export from PRAIS.

Figure 4. Sunburst chart export from PRAIS

3.2. Challenging Areas of Graded Approach

While applying graded approach to SSC inspections and documentation reviews is relatively straight forward, specific areas where graded approach is harder to apply, have been identified. These areas include but are not limited to radiation safety, security, and organizational aspects.

On topics such as the above mentioned, a more qualitative method might be more suitable. One such method is the traffic light system, which is in use at STUK for the overall safety assessment model for NPPs. Every four months, there is a management meeting, within the Department of Nuclear Reactor Regulation, where the overall picture is discussed for different areas and decisions are made for focusing of regulatory oversight. Traffic light status is then defined, based on the outcome of various oversight activities and common assessment.

In addition, other semi-quantitative methods have also been explored to introduce risk insights into areas involving more complex cause and effect relationships such as the assessment of organizational performance and capability. STUK has developed a tool with qualitative indicators structured around three thematic areas: commitment to safety, improvement of safety, and resources and organizational structures. Quantitative scoring (0-5) is given to each indicator area based on review findings and assessment carried out every four months. The tool is used for grading and targeting of regulatory oversight activities.

Another risk matrix-based tool is used in the significance determination of regulatory inspection and review findings. This tool queries the user on the severity and the probability of the finding. The query gives a binary value on each point, and places the finding on a risk matrix, based on the number of points on both categories, severity, and probability.

4. FUTURE PERSPECTIVES

While no new NPP build projects are currently ongoing, interest, as well as public opinion, on nuclear technologies has been on the rise in Finland [2]. SMRs for heat production have been a special interest for a country with a dependence on district heating, and an industry with a need for low-carbon heat sources.

Sustaining necessary knowledge and competent personnel is a challenge for each stakeholder in Finland including licensees, regulators, and suppliers. Since Finnish nuclear sector consists of multiple plant designs, as well as a nuclear waste disposal plant, the required expertise is very broad. With new reactor types being discussed for use in district heating and other applications, this need for expertise is only assumed to get broader.

Risk informed regulation and graded approach has a key role in ensuring, that new challenges, can be tackled effectively with the limited available resources. This is also one of the main objectives in the ongoing renewal of legislation and requirements.

4.1. Renewal of Nuclear Safety Regulations

Based on earlier preparatory work a total revisal of nuclear safety legislation and requirements was started at STUK in 2022. The basic principles have been to highlight the licensee responsibility, to set requirements correctly in respect to safety relevance and to enable efficient allocation of inspection resources based on risk significance. A clearer distinction will be made between the mandatory requirements and the indicative content, such as recommendations and guidance. The premise is, that safety level and top-level principles will remain as they have been. Safety requirements are intended to be written in a way that is as technology neutral as possible and less detailed, to enable a variety of design concepts, SMRs included.

Graded approach will be incorporated more consistently into the new regulations enabling e.g. licensing process more commensurate with the potential risks. For example, SMR designs typically utilize inherent safety features such as use of passive safety systems, large water inventories, accident tolerant fuel and increased grace periods, which are beneficial to safety and reliability, and which are essential in the demonstration of the safety case and fulfillment of required safety level.

The work is expected to be done by 2027, with the aim of preparing a first draft by the end of 2024. For the renewal to proceed smoothly and on schedule, substantive issues need to be discussed with key stakeholders in a pro-active manner.

4.2. Role of SMRs

Finland, being a Nordic country with a long winter, needs heating for most of the year. District heating has historically been an efficient way to offer affordable heating for cities, but it has also been based on combustion-based technology. With the rising need to replace these with a more environmentally conscious solution, the idea of using SMRs for district heating has risen to public debate.

Unlike with electricity, which can be produced far away from the consumer, district heating must be local, to combat the heat losses. With SMRs intended for district heating coming closer to population than traditional reactors, the question of emergency planning zones had to be solved. Previously a so-called precautionary action zone (PAZ) and emergency planning zone (EPZ) in Finland were fixed to 5 km (PAZ) and 20 km (EPZ) limits, but since February of 2024, STUKs regulation has allowed the zone limits to be defined on a case-by-case basis. Zone planning shall be based on analyses of the time-behaviour progress of accident scenarios resulting in a potential release. Generic analyses may be used when defining the PAZ and the EPZ if it can be demonstrated that they cover differences between plants and sites. Sufficiently conservative analyses can help to reduce duplication of work if similar power plants or locations are under consideration Although level 3 PRA is not required in Finland, this might cause the need to develop capabilities for environmental consequence analyses that can be linked to level 2 PRA in a proper manner.

Related to the renewal of nuclear legislation, STUK is currently familiarizing itself with different types of SMRs and their specific characteristics and is participating in international cooperation. This cooperation includes bilateral and multilateral cooperation with nuclear safety authorities in other countries, as well as discussions with designers and other actors in the field. One example of this, is the assessment of selected features of the EDF Nuward reactor, together with French and Czech nuclear safety authorities [5].

5. CONCLUSION

Probabilistic risk assessment was first required forty years ago and has since proven its worth in terms of design changes, plant modifications, risk reductions as well as PRA applications. From a regulatory perspective PRA is a valuable tool for overall safety management of NPPs, other nuclear facilities, such as the encapsulation facility, and for risk informed regulation.

STUK has in use multiple PRA applications, which help to implement risk informed graded approach in oversight activities. PRAIS and the RIGA tool are examples of such applications. These tools are especially useful for risk classification of SSCs. However, some challenging areas of graded approach remain, including radiation safety, security, and organizational aspects, and thus the further development of tools to support the grading is ongoing.

Renewal of legislation and requirements is underway, just as public opinion and interest on nuclear technologies, including SMRs is on the rise in Finland. The renewed legislation aims to enable a variety of design concepts, which might further diversify the already broad nuclear field in Finland. These changes will require extensive expertise from STUK, and the work to acquire more knowledge on different reactor types has already begun. Together with broad expertise, new and systematic ways for risk informed regulation and graded approach are needed, to guarantee the efficient and effective allocation of inspection and review resources.

References

[1] Official Statistics of Finland (OSF). (2024, April 17). *Energy supply and consumption 2023* [Online]. Available: https://stat.fi/en/publication/cln2zc9wg8fgb0cut7vm9hil8

[2] Nurmela S. *Mielipiteet ydinvoimasta*, Energiateollisuus, Helsinki, C451000968, 2024.

[3] Ministry of Economic Affairs and Employment. (2023, Feb. 16) *Fortum granted licence to operate Loviisa power plant units until end of 2050* [Online].
Available: https://valtioneuvosto.fi/-/1410877/fortumille-lupa-kayttaa-loviisan-voimalaitosyksikoita-vuoden-2050-loppuun?languageId=en_US

[4] Teollisuuden Voima Oyj (TVO). (2023, Oct. 10) *TVO is analysing the possibility of extending the service life of two plant units at Olkiluoto* [Online].
Available:
https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2023/tvoisanalysingthepossibilityofextendingtheservicelifeoftwoplantunitsatolkiluoto.html

[5] Radiation and Nuclear Safety Authority (STUK), *Probabilistic risk assessment and risk management of a nuclear power plant*, YVL Guide A.7, Helsinki, 2019.

[6] Radiation and Nuclear Safety Authority (STUK). (2023, Sept. 26). *STUK assesses the safety of small nuclear power plants together with the French and Czech authorities* [Online].
Available: https://stuk.fi/en/-/stuk-assesses-the-safety-of-small-nuclear-power-plants-together-with-the-french-and-czech-authorities