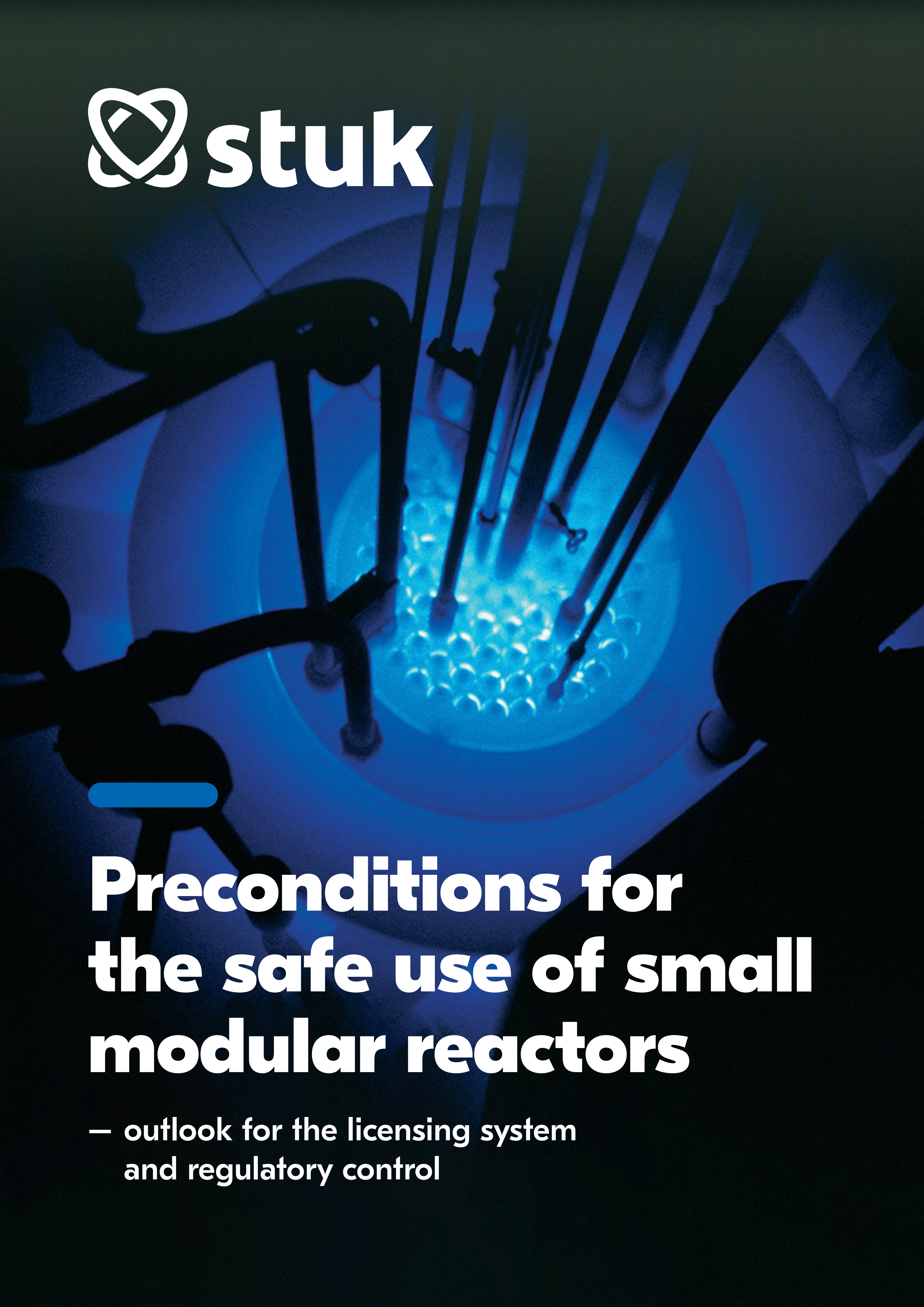

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Preconditions for the safe use of small modular reactors

– outlook for the licensing system
and regulatory control

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Cover: VTT. FiR 1 research reactor core.

Preconditions for the safe use of small modular reactors

– outlook for the licensing system and regulatory control

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1. Finns' radiation safety must be ensured

A small modular reactor is a nuclear power plant, and it must be safe.

In discussions about future energy range, one option presented has been the utilization of small and medium-sized modular nuclear reactors (Small Modular Reactors, SMR) in the production of electricity and district heating. Generally, small modular reactors refer to nuclear power plants in which electrical power is less than 300 MW [1] (megawatts) [2]. Modularity has no established definition, but generally it means that a reactor and its parts can be serially produced in a factory, transferred on site in large pieces (modules) or several reactors can be placed adjacent to each other. In this report, the term "reactor" refers either to the reactor itself or the reactor-containing nuclear power plant in its entirety.

Significant investments are being made in the world in the development of small modular reactors, and the first pilot facilities are expected to be in operation already at the beginning of 2020s [3]. This report does not assess the future of the energy system or small modular reactor technologies. However, the great attention gained by the subject has led the authorities to consider their preparedness for licensing small modular reactors and performing their safety assessment and supervision. Discussions and considerations nationally and internationally are called for, because technology and expectations progress currently faster than the regulation. The Finnish Radiation and Nuclear Safety Authority (STUK) must be prepared for possible upcoming applications, because the authority must also have preparedness to assess safety of new facility types. However, developing regulations and regulatory control as well as increasing safety competence require time. An important part in the preparedness is participating in international discussions on the safety and licence practices of small modular reactors.

1 For the sake of comparison, the electrical power of current Finnish plants is 500-1600 MW.

2 IAEA Advances in Small Modular Reactor Technology Developments (2018) and OECD NEA Small Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment (2016).

3 Closest to commissioning are the Chinese HTR-PM, the Russian KLT-40S and the Argentinian CAREM. Development work is also carried out, for example, in the United States and in Canada. Small modular reactors are already in wide use, for example, in warships and submarines. In addition, there is a floating nuclear power plant Akademik Lomonosov in Russia.

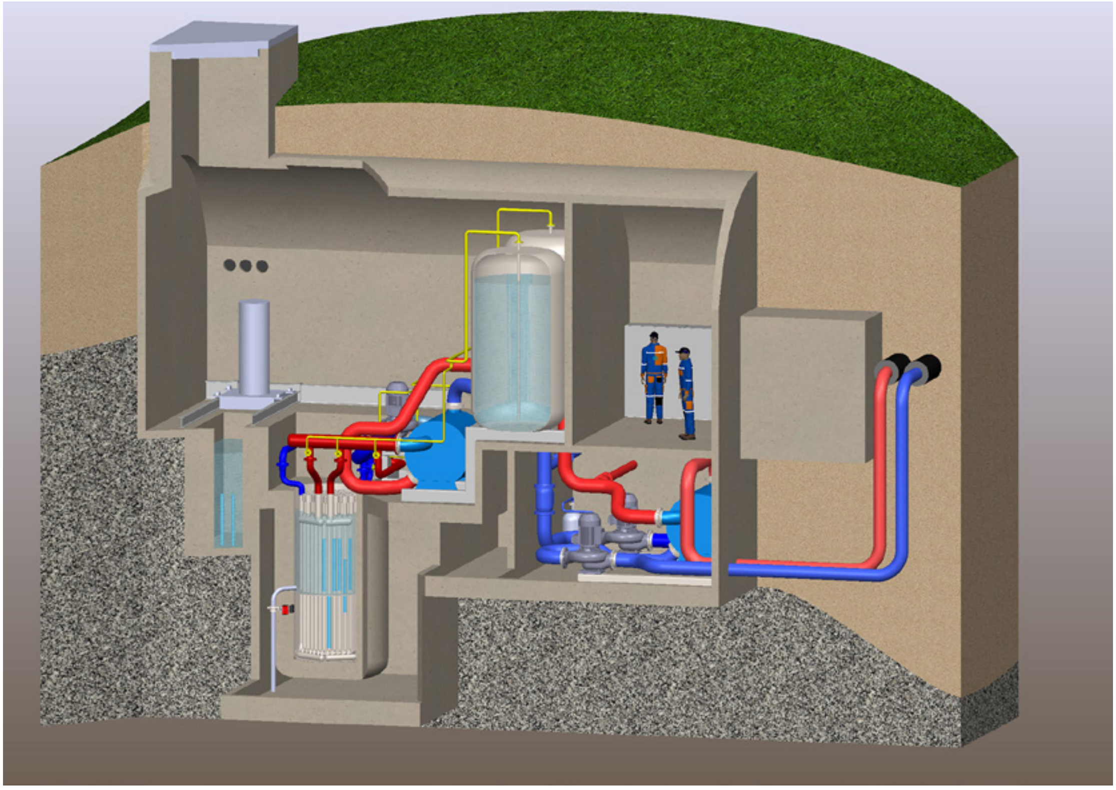


FIGURE 1: The vision of the Lappeenranta University of Technology on a small modular reactor for the district heating production placed underground. Figure: LUT Nuclear Engineering.

The basic precondition for the use of nuclear energy will continue to be safety, for which the licensee of a nuclear facility is responsible. Irrespective of the technology used in the facility, the safety of people and the environment must be ensured and the safety must be demonstrated to be at least at the same level as at the currently operating nuclear power plants. However, there may be differences in the suitability and application of technical requirements between small modular reactors and current large nuclear power plants.

This report provides an overview of small modular technologies and certain related safety issues. It should be noted that this report considers the matter at a general level, because knowledge and experiences gained are still limited. On the other hand, the aim has been to write the report so that it provides useful information especially to those decision-makers, reporters and citizens who wish to understand what kinds of questions are involved in the development of nuclear safety, especially from the point of view of small modular reactors.

The first chapter of the report is the introductory chapter. The second chapter discusses the licensing of nuclear power plants. The third chapter tells about small modular reactor technologies and considers their siting. Certain special safety issues of small modular reactors are reviewed in the fourth chapter. The fifth chapter considers the liabilities of a small modular reactor licensee. Conclusions are presented in the final chapter six.

2. The use of nuclear energy requires a licence – also applies to small modular reactors

The current licence procedure is not necessarily applicable to small modular reactors. The development of the licence procedure is carried out by the Ministry of Economic Affairs and Employment of Finland. The Ministry started the Nuclear Energy Act development project in autumn 2019[4]*. The licence procedures and safety requirements of small modular reactors are also considered in international cooperation where STUK is involved.*

A nuclear reactor, also a small modular reactor, contains radioactive substances, which in rare severe accidents could cause significant harm to people and the environment as well as property if released to the environment. In Finland, the Government's authorization is required for the construction, commissioning and decommissioning of a nuclear reactor. This licence procedure is determined in the Nuclear Energy Act, the development of which is carried out by the Ministry of Economic Affairs and Employment. The ultimate purpose of the required licences is to protect people, the environment and future generations from harmful effects of radiation and to assess the benefits and detriments of a proposed nuclear power plant project from the point of view of the overall good for society.

The first licence phase is a decision-in-principle on whether constructing and using a nuclear power plant is according to the overall good for society. After the decision-in-principle, the next licence phase is the construction licence, which is required before starting the construction. After the construction, an operating licence is required for the commissioning and eventually, after the use of the facility has ended, a decommissioning licence is required for the dismantling of the facility. The licences are granted by the Government, and the Parliament accepts or rejects a decision-in-principle. STUK will assess safety in each licence phase, in other words, whether the proposed nuclear power plant fulfils the requirements set for the safety of the nuclear energy use. The Government for its part has to take STUK's proposals on safety into account in each licence phase. In addition, it must be noted that the commissioning and also later the decommissioning of a facility requires STUK's approval.

4 The development needs of the nuclear energy legislation are investigated in the legislative project TEM080:00/2019 of the Ministry of Economic Affairs and Employment.

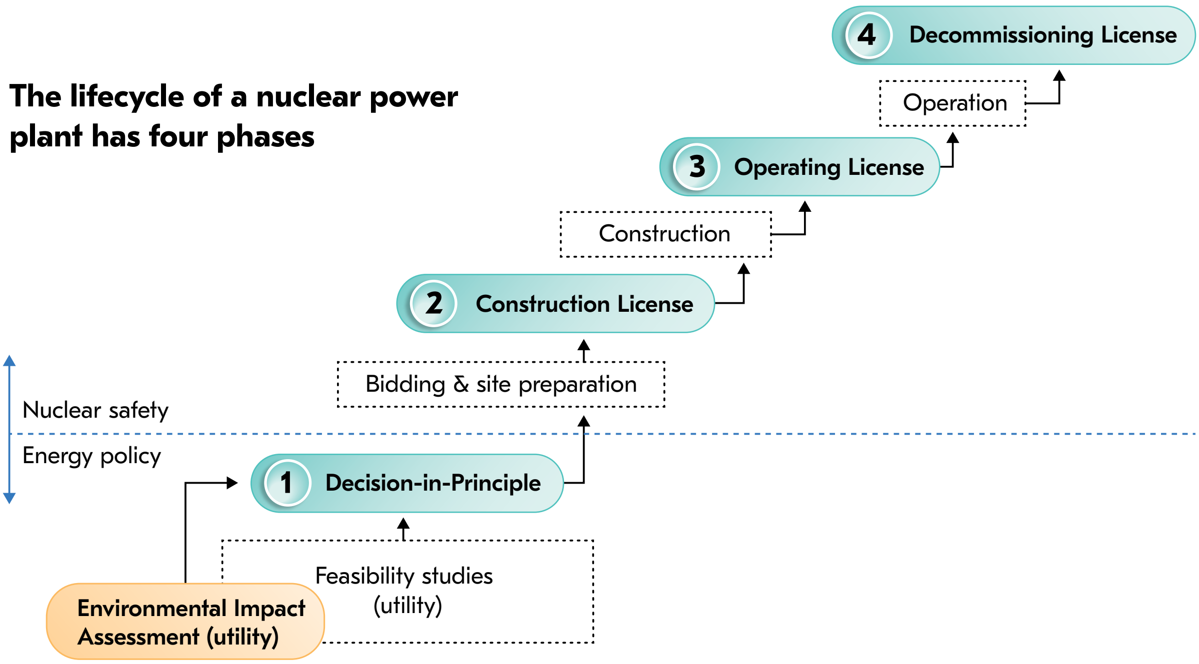


FIGURE 2: Licensing phases of a nuclear power plant. STUK assesses safety at every licensing phase.

The legislation does not separate reactors of different sizes. The same licence procedure applies to all reactors[5]. However, the licence procedure was at one time prepared for large reactors and it is not necessarily appropriate for the licensing of small modular reactors, because a small modular reactor project may deviate from the traditional nuclear power construction project in many ways:

- A facility may comprise several reactors that are constructed at different times. Similar facilities may be constructed in several different places.
- The construction may be timed so that the first reactors are already in use when the next ones are still under construction.
- There is not necessarily a traditional nuclear power company focusing on power generation behind the project, but new operating models and objects of use may arrive in the field.
- The construction time of small modular reactors must be significantly shorter than what has been used to in large nuclear power plant projects. In a small modular reactor project, the licence phases may comprise a significant part of the entire construction project duration.

5 However, very small reactors having thermal input less than 50 MW do not need a decision-in-principle according to section 11 of the Nuclear Energy Act (990/1987).

The current legislation does not preclude applying for a decision-in-principle for several reactors or facility sites, but the established practice gives a licence to only one reactor at a time. In addition, a condition for a decision-in-principle might be to submit a construction licence application within a certain period of time and the construction licence may require the commencement of the construction in a given period of time. Unlike in some other countries, there is no licensing phase for the approval of a facility site in Finland for the approval of a facility site in Finland. According to the current practice, a facility site will be licensed in connection with the construction licence.

Thus, according to the current legislation, licensing small modular reactors is possible, but it requires changing the established practices and way of thinking. It would also be good to consider the suitability of licensing procedure for different situations in the construction and use of small modular reactors, because, for example, the following situations would deviate from the construction of large reactors:

- An energy company would like to add one reactor to the already existing power plant entity. The new reactor would join the already existing units on the facility site and use the same infrastructure. The increase in electrical power of the power plant would be approximately 10 percent. Is a decision-in-principle required for the addition? The power output of Loviisa and Olkiluoto facilities has been increased by more than 10% from the original, but because the increases were made by modernizing the existing plant units, no decision-in-principle was required (the renewal of the operating licence was sufficient).

- An industrial plant wants to construct for its own need one smallish small modular reactor (but exceeding 50 MWt) on its existing industrial site. Is a decision-in-principle required?

- A local energy company is seeking a long-term solution to generate power and heat. The repayment period of the small modular reactor plant proposed as a solution is predicted to be 25 years while the plant's operating life is 60 years, but the plant would be granted operating licence only for 20 years. As set out in the Nuclear Energy Act, the overall safety of the plant and its use are assessed at least in 10-year intervals in addition to continuous regulatory control. Are there other grounds for the fixed-term nature of the operating licence than safety?

In autumn 2019, the Ministry of Economic Affairs and Employment initiated a project to develop the Nuclear Energy Act with regard to the licensing phases of the lifecycle of nuclear facilities, and in connection to that the law is also being reviewed with regard to the licensing procedure of small modular reactors.

Solutions from international cooperation

From the viewpoint of the nuclear power industry, the profitability of small modular reactors would increase if the reactor were acceptable as such in most countries. Manufacturers aim for serial production instead of tailoring reactors and manufacturing them per project or country. A challenge is that safety requirements in different countries vary somewhat from each other. National requirements are affected by a country's other legislation, required safety level and site-specific conditions which vary significantly. For these reasons, national differences in the legislation covering the use of nuclear energy will probably always exist.

The harmonization of safety requirements would benefit the industry, but also the licence and safety authorities and through that also the safety of the licensed facilities. A common requirement basis would enable, for example, a safety assessment prepared in cooperation between countries interested in the same reactor type. A common safety assessment would reduce the need for and the scope of national assessments, and further the approval of a reactor without significant tailoring in the countries participating in the assessment.

Even though safety requirements are always likely to have specific national features, it is possible to unify the requirements in many respects. Important organizations and cooperative bodies involved in the harmonization of requirements are the International Atomic Energy Agency (IAEA) and WENRA (Western European Nuclear Regulators Association). In collaboration with its member states, the IAEA prepares safety standards which are basically made for large light water reactors. WENRA has prepared Safety Objectives for new nuclear power plants and Safety Reference Levels for plants already in operation. The objectives concerning new plants were made before the interest in small modular reactors arose, and the objectives, similarly to the IAEA, were prepared with large new light water reactors in mind. In 2019, WENRA started to review how the safety requirements could be applicable to small modular reactors. STUK is actively involved in that work.

The licence procedures of small modular reactors are also considered in other international forums. STUK is also involved in the regulators' forum concerning small modular reactors (SMR Regulators' Forum). The forum does not aim for harmonizing requirements but identifying challenges relating to the licence procedures and safety demonstrations of small modular reactors and trying to find common solutions for them.

Even though creating a transnational licensing procedure or a perfect harmonization of requirements are not probable in the near future, the authorities of different countries are cooperating so that a functioning licensing of small modular reactors would also be possible.

Safety requirements

- Safety requirements apply to nuclear power plants, plant sites, organizations utilizing a nuclear power plant and various functions (such as security and emergency response arrangements, nuclear waste management, safeguards of nuclear materials and environmental radiation control).
- An example of a technical requirement concerning a nuclear power plant: "A concrete containment shall be lined with leaktight steel cladding."
- An example of a requirement concerning the plant site: "In the nuclear power plant's vicinity, no activities shall be engaged in that could pose an external hazard to the plant."
- An example of a plant site requirement concerning the design of the nuclear facility: "In the design of the nuclear facility, natural phenomena assessed as possible at the facility site are to be taken into account."
- For example, a requirement concerns an organization utilizing a nuclear power plant: "Significant functions with respect to safety shall be designated. The competence of the persons performing in these functions shall be verified."
- Safety requirements are provided in STUK's regulations and nuclear safety guides (YVL)[6].

6 The nuclear safety regulations are available at www.stuklex.fi/en

3. Small modular reactor technologies

Safety of new reactor types must be demonstrated reliably. There are different kinds of small modular reactors, and some of them have a different operating principle than the light water reactors in use, for which the current safety-related requirements have been developed. The size of the precautionary action zone encompassing the facilities must be considered according to need.

A few dozen different small modular reactors are under development around the world. All nuclear reactors, irrespective of size or type, have in common the need to control the fission chain reaction of neutrons and the fact that even if the chain reaction was stopped, the reactor continues to generate heat. The dispersion of radioactive substances formed in fissions must be restricted to protect people, the environment and property. Different reactor technologies require and enable different solutions for achieving these objectives. The special features of technologies also make different purposes of use possible.

Traditionally, nuclear facilities equipped with nuclear reactors have mainly been used for the electricity generation. Reactors have also been in ships and submarines as well as in the use of research and the pharmaceutical industry. However, small modular reactors have been seen as an opportunity to utilize nuclear energy more flexibly also in heat production, for example, in the production of process steam needed by district heating or the industry. Some reactor technologies are suitable for producing higher temperatures better than at present, so they can also be utilized in the hydrogen production requiring high temperature.

Small modular reactors can be roughly divided into five types according to the reactor technology. Of them, the water cooled reactors located both on land and at sea are discussed jointly in this report[7]. The safety advantages or possible challenges of reactor technologies have not been analyzed in depth in this review; instead the purpose is to give a general overview of the technologies' basic differences and preparedness levels.

7 Reactor concepts have been introduced in the IAEA publication Advances in Small Modular Reactor Technology Developments, 2018: https://aris.iaea.org/Publications/SMR-Book_2018.pdf

Small modular reactor types

Water cooled reactors

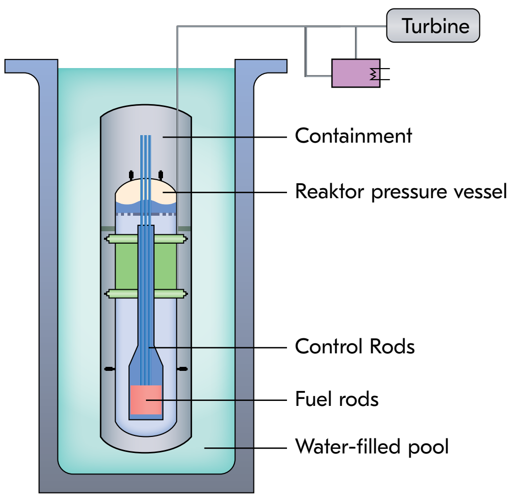
The majority of operational nuclear power plants are water cooled, and therefore most research and operating experience data concern that technology. In the design of water cooled small modular reactors, experiences gained from them and reactors formed based on different design objectives, such as ship reactors, have been utilized.

In addition to pressure water and boiling water technologies, for example, the pool reactor is being developed for district heating production, where the cooling circuit of the reactor has not been pressurized. Pool reactors have so far typically been in use in research, such as FiR 1 located in Otaniemi, Espoo, Finland.

Some of these reactor types are meant to be located on the coast or at sea to enable electricity and heat production in places especially hard to reach. One example of such a facility is the Russian floating nuclear power plant equipped with KLT-40S reactor (transferred to Pevek, Russia in autumn 2019, where it started electricity generation in January 2020). ■

WATER COOLED REAKTOR

Most ofthe nuclear reactors in the world are water cooled. Due to the mature technology, the first commercial small modular reactors can also be expected to be water cooled.



Gas cooled reactors

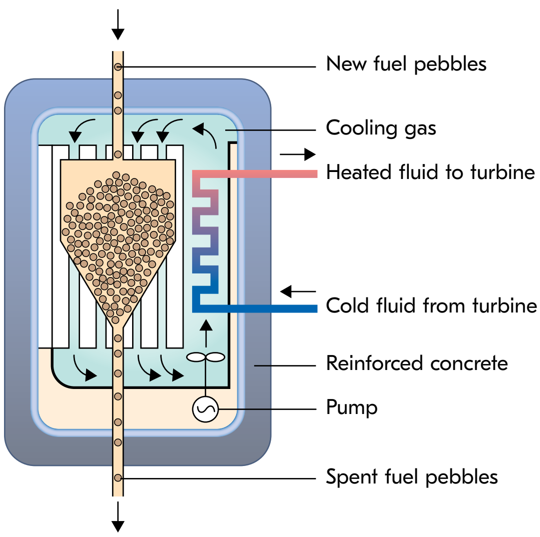
In gas cooled reactors, the reactor core is cooled by gas instead of water, and graphite is used to moderate neutrons emitted from splitting of atom nuclei, i.e. fissions. Large gas cooled reactors in power plant operation are, among other places, in Great Britain.

In gas cooled small modular reactors, helium is typically used as the coolant and graphite as the moderator, but along with the development of reactor technology, the reactor core solutions may deviate from previous ones. The gas cooled reactor technology enables a very high temperature, and therefore a connection to a more effective power plant process.

There is currently a so-called pebble bed reactor HTR-PM in construction in China, which represents one type of gas cooled reactor. ■

GAS COOLED REAKTOR

In gas cooled reactors, fuel consists of microscopic pebbles, which can be made into larger pebbles, for example.



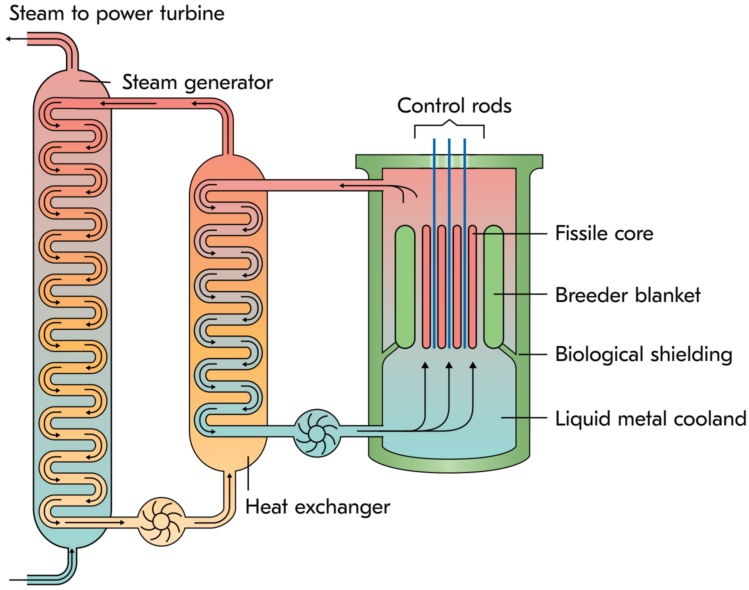
Fast reactors

Fast reactors generally mean such reactor types where neutrons emitted from fissions are not slowed down. In fast reactors, the coolant used may be molten natrium or lead, for example. Of the fast small modular reactors under development, most are lead cooled. Fast reactors can use thorium or such uranium atoms as fuel, which cannot be used in light water reactors or in other neutron-moderating reactor types. Such a reactor may also produce additional fuel, in other words, act as a so-called breeder reactor.

In the beginning of the utilization of nuclear energy, fact reactors were developed actively. Fast reactors have been and still are in use as research reactors and also somewhat in electricity generation. Currently, both large and small facilities of small reactors are under development or construction. ■

FAST REACTOR

Fast reactors may produce more fuel – even more than they consume.



Molten salt reactors

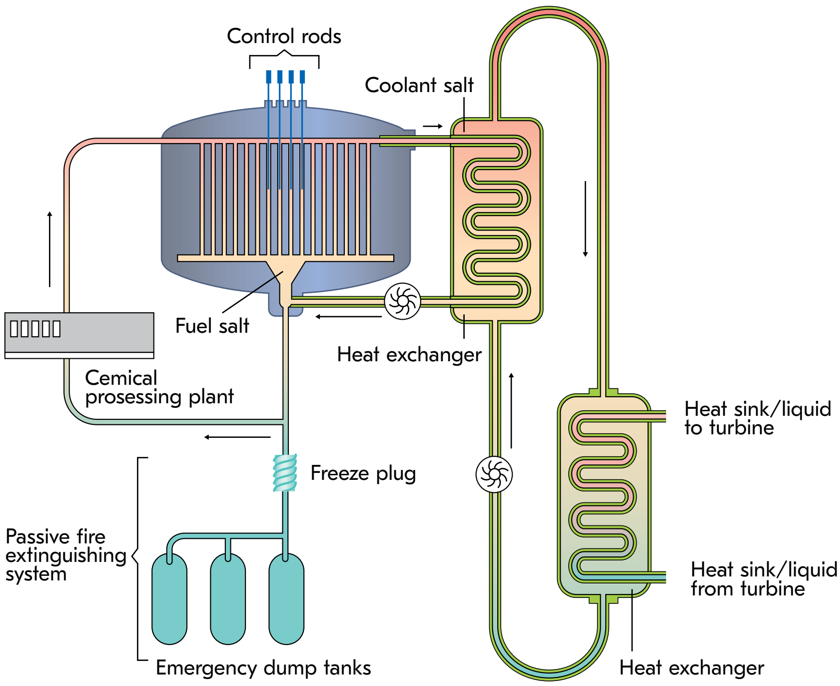
The molten salt reactor concept was originally developed in the 1940s–1950s, when the aim was to have an aircraft reactor that fits in a very small space. The project was dicontinued, but the development of the technology for civil use was continued. However, the reactor type did not end up in actual use, so experiences of it are limited to research reactors.

In a molten salt reactor, the coolant is some molten salt mixture. In most small modular reactors based on salt technology, the fuel is also in molten form and graphite is used as the moderator. Some of the reactors are also above-described fast reactors.

Among other things, the high process temperature in low pressure, the possibility for reusing nuclear waste as fuel and the functioning as a breeder reactor are seen as benefits of the molten salt technology. ■

MOLTEN SALT REACTOR

Experiences of molten salt reactors are limited to research use. In molten salt reactors, besides the coolant, the fuel may also be molten.



Safety of new reactor types must be demonstrated reliably

Safety of both large and small nuclear power plants is based on the functional and structural defence-in-depth. The dispersion of radioactive substances into the environment is restricted by means of successive barriers (structural defence-in-depth), the integrity of which is secured by multiple safety functions independent of each other.

In many small modular reactors, safety is sought through safety functions which do not require control by people or automation or electrical equipment; in other words, by so-called passive means. Some designers of facilities are suggesting that due to the high reliability of design solutions and the nature of the basic physics of the facilities, for example, a containment building restricting the dispersion of radioactive substances is not needed at all. Due to a potentially lower risk level of the facility (e.g. passive safety, lower amount of radioactive substances), locating small modular reactors close to settlements is deemed possible.

The improvement of safety of small modular reactors has also been sought by the reduction of that which could cause disruptions in the facility. Such improvements can be, among other things, reducing the number of places leading to leaks (e.g. pipes) or, especially in molten salt or gas cooled reactors, the possibility to add fuel more flexibly during the use. However, new kinds of solutions may also lead to new kinds of disruptions or cause challenges to different areas of nuclear safety, such as the nuclear materials control measures.

Arguments for the efficiency and sufficiency of defence-in-depth require experimental testing, calculations and other such estimates on design solutions. The procedures used in the arguments must also be valid, i.e. they must also be based on research and experimental demonstrations. Assessments require information about the physics and technology of the object, because various characteristics and risks relate to different materials, for instance. Demonstrating the safety of small modular reactors may require new kinds of procedures and methods with regard to experimental testing, calculation methods and measurement and inspection techniques, for example.

The safety of a facility using a nuclear reactor also involves the safety demonstration of other related processes and measures. The manufacturing, handlign and transportation of fuel, the handling of process materials and the handling of fuel and process waste must be done safely. Ensuring the safety of the facility requires that the facility can be manufactured and constructed to be safe and its operating condition can be monitored during the entire lifecycle of the facility. All these require design solutions and infrastructure, the preparedness level of which may depend on applicable technological solutions. For example, new kinds of material needs or fuel may require new kinds of production plants, which require further design and know-how. Preparing and assessing design solutions require a tremendous amount of underlying data that is based on research and experience.

In Finland, requirements relating to safety and its demonstration have been developed with large water cooled reactors in mind. Therefore, it is necessary to review and possibly redefine safety requirements to take into account both the size of the reactors and the reactor technology in use. The more materials and technological solutions deviate from the currently widely used ones, the less basic data on them is available and the more other infrastructure relating to the facility also requires development. For that reason, it is easier to demonstrate safety for reactors resembling current ones – in other words, water cooled small modular reactors can be presumed to be closer than others to commercial production and use in Finland.

The purpose of precautionary action zones and emergency planning zones is to protect people: the size of the zones is to be considered according to need

Currently in Finland, a precautionary action zone of approximately five kilometres is required around nuclear facilities, where land use restrictions are in force[8]. The location of a nuclear power plant must be chosen so that, for example, no hospitals, schools or significant industrial facilities, the safe evacuation or maintenance of which in the event of an accident is not possible, are located inside the precautionary action zone.

In addition, a nuclear power plant, as any other industrial facility possibly causing danger, must prepare a rescue plan for the environment to mitigate the consequences of an accident. In case of nuclear power plants, this so-called emergency planning zone is expected to cover approximately the 20-kilometre radius from the plant.

The size of the precautionary action zone and the emergency planning zone are determined based on the consequences of possible accidents in currently operating, large nuclear power plants. Therefore, it is necessary to assess the size of the precautionary action zone and the emergency planning zone with regard to the consequences of possible accidents in small modular reactors. Precautionary action zones and emergency planning zones are a key issue, especially in the utilization of small modular reactors in district heating production where district heating plants must be located relatively close to the object of use.

It is often brought up in connection with small modular reactors that they could be placed close to habitation because their safety has been ensured by passive means, for example. It is surely easier to implement important safety-related functions for small modular reactors without external electricity or measures requiring immediate action by people. An individual small modular reactor has naturally also less radioactive material than a large reactor. On the other hand, one facility site may have several small modular reactors, and the impact of a simultaneous accident of several reactors would not necessarily differ from the impacts of an accident of one large reactor.

The safety of small modular reactors must thus be assessed as a whole, ensuring that the safety characteristics and locations of facilities form together a safe entity for people, the environment and property.

8 The precautionary action zone is defined in STUK Regulation Y/2/2018.

4. Special issues

The requirements and obligations of nuclear waste management, safeguards of nuclear materials, security arrangements and emergency response arrangements as well as nuclear liability relating to the use of nuclear energy must be adhered to in the planning, construction, commissioning, operation and decommissioning of small modular reactors.

The safety requirements and operating methods of the currently operating nuclear power plants are in many parts also suitable for water cooled small modular reactors, which use the same type of fuel as in the Finnish nuclear power plants. But there are also differences. In the following, the feasibility of nuclear waste management, safeguards of nuclear materials and the security arrangements has been reviewed from the point of view of water cooled small modular reactors.

Nuclear waste management

The operation of small modular reactors generates spent nuclear fuel as well as low- and intermediate-level nuclear waste similarly as that of the current nuclear power plants. The decommissioning, i.e. demolition, of small modular reactors also generates nuclear waste. Waste generated by light water cooled small modular reactors can be treated and disposed of by similar technical solutions that are already in use or planned in Finland. The current safety requirements can be followed in nuclear waste management.

The basic idea of Finnish nuclear waste management is each licensee's responsibility for processing the nuclear waste generated by them. Behind this principle included in the Nuclear Energy Act is the idea that large nuclear power plant licensees can be expected to have the capability to take care of nuclear waste. The premises required for waste treatment and final disposal of low- and intermediate-[9]level waste of the current nuclear power plants are located in each plant site. A separate final disposal facility for the final disposal of spent nuclear fuel is under construction.

9 Low- and intermediate-level nuclear waste is, for example, generated in connection with cleaning and maintenance actions of nuclear power plants (the so-called maintenance waste) as well as later on with the decommissioning of nuclear power plants.

New operating models for the arrangement of small modular reactors' nuclear waste management should be investigated if facilities are to be located apart or licensees are smaller than the current nuclear power companies or, for example, municipal operators. Each facility site or a smaller operator cannot realistically be expected to have their own nuclear waste management arrangements or facilities. It would be more practical to implement waste management through centralized solutions. For example, alternatives could be arranging nuclear waste management in cooperation with current nuclear power companies and Posiva, waste management arranged in cooperation with the licensees of small modular reactors or a national nuclear waste company that would take care of nuclear waste treatment and final disposal. Small modular reactor licensees would in any case be liable for the costs of the nuclear waste management as set out in the Nuclear Energy Act.

In some small modular reactor concepts, the reactor module is delivered to the facility site complete, including also fuel, in which case no fuel processing or storage is needed at the site. With regard to such facilities, a separate module processing plant would be needed in Finland, or alternatively modules should be transported to a processing plant located abroad. The Nuclear Energy Act prohibits the transport and the final disposal of nuclear waste outside Finland.

Transports and the handling of spent fuel in Finland can be implemented according to the current safety regulations and technical solutions.

Safeguards of nuclear materials and security arrangements

The objective of the safeguards of nuclear materials is to ensure that nuclear materials remain in their peaceful and reported purpose of use and, for example, nuclear fuel is not used for manufacturing nuclear weapons and the use of nuclear energy does not otherwise promote the spreading or development of nuclear weapons. The purpose of security arrangements is to prevent unlawful or other deliberate action endangering nuclear or radiation safety as well as actions aimed at harming the nuclear facility. The security arrangements also, for their part, ensure the achievement of the objectives of the safeguards.

In the safeguards in water cooled small modular reactors, the same principles and technical solutions can be used as in the (Finnish) nuclear power plants. For example, camera surveillance and seals would be used for small modular reactors to make sure that no fuel is taken out from a facility unannounced. In Finland, a licensee would be required to have responsible persons and instructed procedures accepted by the Radiation and Nuclear Safety Authority, with which the liabilities of the safeguards of nuclear materials are managed. Corresponding obligations are also in use in Finland with regard to smaller nuclear materials holders, such as research institutions.

Small modular reactors would be subject to the safeguards of the International Atomic Energy Agency (IAEA), and thereby possible unannounced inspections. Reactor modules with fuel included would change the current practices somewhat, because the fuel could not be verified at the facility during the use, but there are international practices for such an operation.

Security arrangements will be dimensioned, planned and implemented according to the planning criteria threat resulting from the facility type and risk. Required security arrangements and security organization depend, for example, on what kinds of systems are needed for maintaining safety of the facility, whether systems can be damaged, what the location of the facility is and what kind of threat a damage to the facility causes to the inhabitants in the area. Many of the matters relating to the sizing of security arrangements are common with issues relating to the safety and security arrangements of small modular reactors. Special features of small modular reactors could be their siting in several different locations and the resulting increase in the fuel transports, where security arrangements must also be taken into account.

Many small modular reactors are designed so that they require only a few operating personnel. Also, fully unmanned small modular reactors are being planned. Unmanned reactors would be controlled and monitored from a central control room located further away, which could be common for several reactors. The remote use would bring up new issues for consideration, especially in the security arrangements of the facility site (detection, delay and response time) and in the data security of the remote use as well as in the arrangement and implementation of safeguards of nuclear materials. In addition to security arrangements, the replacement of maintenance performed by the operating personnel should also be reconsidered in remote use. New methods, such as robotics and the utilization of virtual reality, might also be developed for maintenance. There is only minimal, if any, experience of their use in nuclear power plants.

Nuclear liability

Nuclear facilities and the transports of nuclear materials are governed by the Nuclear Liability Act, which is enacted to cover compensation for nuclear damage. Nuclear liability concerns small modular reactors and related transports of fuel and nuclear waste similarly as the current nuclear power plants. Under the Nuclear Liability Act, compensation for damage occurring at a nuclear facility located in Finland is unlimited. The licensee of a nuclear facility must have insurance covering nuclear liability, which covers the damages resulting from a possible accident up to the compensation limit defined in the insurance policy.

5. Who can use nuclear energy?

The licensee is responsible for safety. Personnel and competence are required for providing safety. There are different kinds of organization forms.

In Finland, the user of nuclear energy, i.e. the licensee, is responsible for safety. Responsibility for safety cannot be removed from the licensee. The previous chapters give a quite general overview of obligations relating to nuclear safety, for the fulfilment of which the user of small modular reactor must be prepared.

In order to meet their responsibilities, the licensee must have enough competent people available. The licensee must have, among other things, expertise to construct/have a nuclear facility constructed safely, to use the facility safely and continuously improve safety as the technology progresses[10]. The licensee must also have sufficient financial resources for safe use of nuclear energy in all situations.

The licensee must put safety as its first priority in any decision-making. For example, in refurbishments or investment decisions relating to the facility, the effect of the investment or refurbishment on safety must be taken into account, as well as when deciding on organizational changes. If a change or a decision has an effect deteriorating the overall safety of the facility, it must not be made.

Generally, the licensee is a company, for example, a limited liability company, which was established to use nuclear energy. However, the licensee may also be some other legally competent person. Usually, the licensee also owns the nuclear facility, but other kinds of arrangements are also possible.

A small modular reactor licensee has the same liabilities as the licensee of a large nuclear power plant: responsibility for safety, nuclear waste and accident preparedness. To manage these liabilities, enough competent personnel and financial resources are required.

Along with small modular reactors, the operational and organization models of organizations using nuclear energy could deviate significantly from the current ones. The effects of different organizational forms on safety must be assessed during the licensing process.

10 Continuous improvement of safety is the guiding principle in nuclear safety.

6. Conclusions

Over the next decade, new kinds of nuclear power plants might arrive on the market, including so-called small modular reactors. The starting point of the safety authority in the review of new kinds of reactors is clear: small modular reactors are also nuclear power plants and they must be safe. The licensee is responsible for safety.

In this report, guidelines are presented for discussions that the authorities, decision-makers, scientific community and energy companies should hold so that sustainable preconditions for licensing, safeguarding and assessing safety of small modular reactors can be created. On account of the development of technology, the risk is that our regulatory environment will no longer in the future meet the expectations of the society.

FIGURE 3: Open questions relate to the use, safety and licensing of small modular reactors, and their resolving requires diligent examination operating environment.

To respond to the situation, STUK presents the following conclusions and measures:

1. **The needs for regulatory amendments with regard to small modular reactors must be investigated**. The current licensing procedure and safety requirements are mainly created for large, electricity generating, water cooled reactors, which are used by large nuclear power companies. Issues relating to the use, safety, licensing and regulatory control of small modular reactors may significantly deviate from a traditional nuclear power construction project, for the needs of which the current legislation is drafted. Now is a good time for the development of the licensing of small modular reactors, because the Ministry of Economic Affairs and Employment is preparing for an overall reformation of the Nuclear Energy Act.

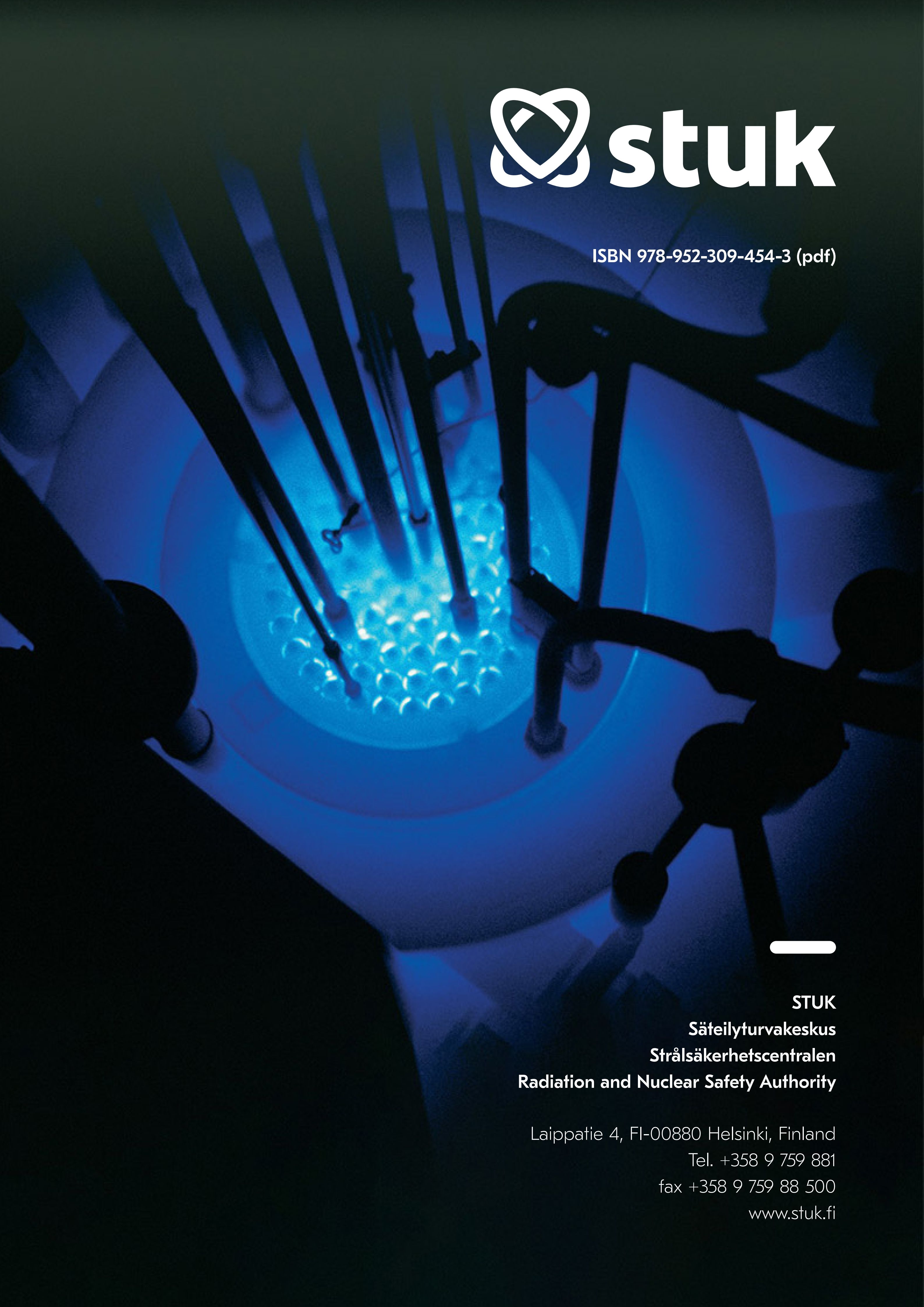
2. **Participating in international cooperation is important**. The main goal of small modular reactor manufacturers is to manufacture facility units as serial production to the international market. A challenge is that safety requirements in different countries vary somewhat from each other. Even though creating a transnational licence procedure or a perfect harmonization of requirements are not probable in the near future, the authorities of different countries are cooperating to harmonize safety requirements of small modular reactors and to enable appropriate licensing as well as to find functional practices. STUK is actively involved in this work.

3. **Data based on research and experience forms a foundation for the safety of small modular reactors.** The legislation sets the framework for the safety of small modular reactors. The safety of small modular reactors must be demonstrated in practice. There are different kinds of small modular reactors, and some of them deviate in their operating principles from the nuclear power plants in use around the world. In many small modular reactor facilities, safety is sought through solutions that deviate from the current ones. Preparing and assessing design solutions require a tremendous amount of data and competence based on research and experience as well as experimental tests, calculations and other evaluations. Creating competence and required research infrastructure for the demonstration of the safety of small modular reactors by tests and calculations requires input nationally and internationally.

4. **The safety of small modular reactors must be assessed as a whole, ensuring that the safety characteristics and locations of facilities form together a safe entity for people, the environment and property**. It is often brought up in connection with small modular reactors that they could be placed close to habitation. In the case of district heating production, a plant producing heat must be located relatively close to habitation. The size of the precautionary action zone and the emergency planning zone must be considered according to need on the basis of the risk caused to the surroundings of the plant.

5 **Nuclear waste management must be ensured**. Finland is the first country in the world to have a final disposal facility for nuclear waste under construction. The same final disposal solutions of nuclear waste also work for water cooled small modular reactors. On account of small modular reactors, new organizational models would probably also need to be found for the arrangement of nuclear waste management, and the liabilities relating to nuclear waste management should be redefined.

6 **New forms of carrying on operations must be prepared for**. The operational and organization models of organizations using small modular reactors may deviate significantly from the current ones. The effects of different organizational forms on safety must be assessed.



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