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STUK's safety assessment of LDR-50 reactor conceptual design

Steady Energy Oy (SE) submitted a description of the LDR-50 reactor to the Radiation and Nuclear Safety Authority (STUK) and requested a concept-level assessment from STUK on the acceptability of the design solutions related to nuclear and radiation safety, security, emergency preparedness and safeguards from the point of view of Finnish requirements.

Introduction

Legislation on the use of nuclear energy is being reformed. The new legislation is likely to include a safety assessment of conceptual design before the construction license phase. STUK used the outline of the safety assessment drafted for the new legislation as a basis for the assessment of the LDR-50. The procedure had been agreed between SE and STUK in advance.

The safety assessment of conceptual design includes the following topics:

- plant level design bases, hazards and events considered in the design
- safety functions and how the safety principles (defense-in-depth, redundancy, diversity, separation) have been considered in their design
- structural defense-in-depth
- top-level layout and separation, protection against internal and external hazards
- structural radiation safety and control of radioactive releases
- design provisions for operation
- design provisions for ageing management
- design provisions for security
- design provisions for safeguards

- design provisions for emergency preparedness
- nuclear fuel and its handling and storage
- handling and storage of radioactive waste
- design provisions for decommissioning
- demonstrating safety
- the vendor (management system, competence)

LDR-50 reactor

The LDR-50 is a new type of a plant, albeit based on well-known and proven pressurized water technology. New features include

- Use solely for district heating, low power of the reactor (50 MW thermal power) and operating parameters different from those of traditional pressurized water reactors (significantly lower operating pressure and temperature).
- An integrated primary circuit with the primary circuit entirely within the reactor pressure vessel.
- Using passive residual heat removal at several levels of defense-in-depth.
- A containment concept where the containment is not a building but a steel vessel around a reactor pressure vessel. The containment vessel is submerged in a pool of water in the reactor hall. The reactor hall contributes to the containment of radioactive materials.
- There are several reactors in the same infrastructure. The LDR-50 has four reactors in the same reactor hall, with, for example, a common control room and operating shift.
- Natural circulation in the primary circuit during normal operation.
- Boron-free primary circuit.
- Most of the plant is located underground, in the bed rock.

Performing the safety assessment

The current requirements were used in the assessment, but the potential changes to the requirements in the renewal of the legislation were considered, too. As the legislative reform is ongoing, the assessment based on the new requirements is not definitive and may be subject to change.

The design of the LDR-50 is at early stage. The design basis is not totally fixed, and the conceptual design is not yet completed. Therefore, there was not sufficient information to allow the assessment of the acceptability of the design solutions requested by SE in its letters. STUK focused its assessment

on whether it is possible to design LDR-50 kind of a reactor and the new design solutions it contains to meet the Finnish requirements.

The results of the assessment

Conclusions

The design

The LDR-50 and its new main design solutions can be designed to meet safety requirements. However, some of the findings of the assessment may affect the design.

The vendor

SE does not yet meet the expectations there are towards the vendor at the construction license phase. However, SE has plans to develop its organization and management system, and the management seems motivated to develop the company. STUK does not see obstacles to SE developing over time into a compliant plant supplier.

Design phase

The design is not yet as far advanced as will be required in the new legislation for the safety assessment of the conceptual design that is needed before construction license application.

Assessment results by topic

The main findings from the assessment of the different areas are presented below. The accompanying safety assessment report presents further findings and background to the conclusions.

General, cross-cutting findings

The design has features that are beneficial for safety. For example, long grace-periods in case of accidents, the use of passive systems and implementation of severe accident management even if the scenarios leading to a severe accident are not obvious.

Information security has not been systematically considered in the design.

Human Factors Engineering (HFE) has not been systematically considered in design.

Some solutions have been designed with a 72-hour autonomy period. This time is in line with the current requirement (Regulation STUK Y/1/2018, 11§ paragraph 7), but the required autonomy time is likely to be increased to e.g. 7 days in the renewal of the regulations. The change may influence the safety classification of systems and equipment needed in the situation, as well as the needed material reserves on site.

The design of the systems does not consider the N+2 failure criterion (Regulation STUK Y/1/2018, 11§ paragraph 4). However, this requirement will be removed in the reform of the regulations.

Plant level design basis, hazards and initiating events considered in the design

A wide range of initiating events and external and internal hazards has been recognized. However, the work is still ongoing. For example, there is still a lack of comprehensive identification of initiating events in the different plant states, security events, possible combinations of events and/or hazards, or events or hazards affecting several reactors simultaneously. It is also not yet clear which are the bounding scenarios (e.g. for a containment or for primary circuit overpressure protection).

Based on the provided information, it is not possible to make conclusion of to the completeness of the design basis.

Safety functions and considering the safety principles in their design

Reactivity control

Safety principles have been duly considered in the conceptual design of reactivity control. In addition to the control rods, subcriticality can be ensured with emergency boron injection system. A new feature for a pressurized water reactor (in Finland) is the absence of boron in the primary circuit during normal operation. Due to that, specific attention has been paid in the design to ensure subcriticality during refueling. Similarly, particular attention has been paid to the reactivity insertion caused by unintentional withdrawal of a control rod to ensure it does not compromise safety.

In STUK's opinion, conditions are in place to design the reactivity control to meet the requirements.

Containment of radioactivity

The LDR-50 has a new containment building concept. In particular, in the event of a severe accident, the reactor hall too has a role in the containment function. The only identified scenario leading to a severe accident is a break in system connected to the primary circuit, bypassing the containment vessel.

The containment function and severe accident management do not fully meet current requirements (e.g. requirements YVL B.6 324, 328 related to containment isolation, and requirements YVL B.5 418-420 related to primary circuit depressurization in severe accidents). However, it may be possible to justify the deviations.

It is positive that the design includes severe accident mitigation measures, even if the scenarios leading to a severe accident are not obvious.

In STUK's view, it may be possible to design the proposed containment concept and severe accident management to meet the requirements.

Residual heat removal

For the removal of residual heat, a passive heat transfer chain from the reactor via the containment pool to the reactor pool is used. In general, the use of passive systems is beneficial for safety because it lessens dependence on operator actions or on the availability of components that can fail or need power to operate.

The passive heat transfer chain is used at several defense-in-depth levels (2, 3a, 3b, 4), which does not meet the current requirements (STUK Y/1/2018, 9§ paragraph 3). The renewal of the regulations may allow such solution. For the solution to be acceptable, it is essential to identify events that could prevent the heat transfer chain from functioning and that such events are highly unlikely.

There are only two feeding lines to the reactor, the lines are used by all systems feeding water to the reactor (normal make-up system, emergency make-up system, emergency boron injection system). Although reducing the number of pressure vessel penetrations is advantageous from safety point of view, the advantages and disadvantages of the solution should be studied further, e.g. whether a situation could arise where the lines would not be available when needed.

In postulated accidents and in certain design extension conditions, the reactor pool is the ultimate heat sink. Although the water in the pool has a significant heat capacity, it is not comparable to e.g. the sea or the atmosphere. The pool cannot be considered as an ultimate heat sink, because finally heat must be removed from it. If no other heat removal path is available, the heat is transferred to the bed rock. It may be possible to credit the bed rock as an ultimate heat sink. In analysis regarding the ultimate heat sink, the heat sink for the possible cooling of equipment and rooms should be included.

STUK's view is that when the findings above are considered appropriately, conditions are in place to design residual heat removal to meet the requirements.

Support functions

Support functions include for example automation and power supply. According to SE, in the LDR-50 concept cooling or heating of the premises and equipment are not needed for performing the safety functions, but this will be analyzed further as the design proceeds.

The general, cross-cutting findings above apply to support functions. Taking these into account, STUK is of the opinion that conditions are in place to design the support functions to meet the requirements.

Structural Defense-in-Depth

The structural defense-in-depth is different from the traditional one, because in addition to the containment, the reactor hall has a role in defense-in-depth. Furthermore, the primary circuit and the containment represent new design solutions (primary circuit integrated inside the reactor pressure vessel, steel containment vessel surrounding the reactor pressure vessel).

Some open questions remain concerning the design basis. The bounding events for the containment, the reactor hall or the primary circuit overpressure protection have not yet been defined. The loads on the reactor pressure vessel are still partly undefined, as well as the most loaded locations. The location of the reactor pressure vessel welds has not yet been decided.

In STUK's view, conditions are in place to design the structural defense-in-depth and structural integrity to meet the requirements.

Top-level layout and separation, protection against internal and external hazards

Separation of redundancies is applied at defense-in-depth levels 3a and 4, but not at levels 2 or 3b. This is a deviation from the current requirements (YVL B.1 434., 437., 438.), but redundancy requirements may change in the renewal of the regulations. The acceptability of the solution (under the new requirements) can only be assessed once the design is more detailed.

The principles of protection against hazards and the requirements for fire protection, for example, are well identified. However, as the hazards and their consequences are still being defined, STUK cannot yet assess the protection against hazards and how the presented principles are considered in the design.

Structural radiation safety and control of radioactive releases

SE has identified well the essential principles and requirements regarding the topic. By following them, preconditions are in place to consider structural radiation safety in design adequately. However, most of the more detailed design has not yet been carried out, so it is not yet possible to draw more precise conclusions.

Liquid releases that are below the activity limits are to be discharged into the sewerage system of the municipality where the plant is located. The operating NPPs do not discharge liquid releases to the sewerage system.

The Radiation Act sets limits to releases to sewerage systems. It is not yet clear how the reformed nuclear energy legislation will regulate this matter. Furthermore, the municipality may set its own limits to releases. The solution is therefore subject to uncertainties.

Design provision for ageing management

SE has identified the essential principles, and by following them and the presented design rules, it is possible to adequately consider ageing management in the design. It is good to ensure the inspectability and maintainability of new design solutions (e.g. pipelines within a guard pipe) at a sufficiently early stage of the design process.

Design provision for operation

The operation concept has some new features compared to the operation of current NPPs in Finland, such as a small number of staff and a common control room and operating shift for several reactors.

If the main control room is lost, the Emergency Control Post may not be permanently manned. The necessary controls are carried out from there, but after that the status of the plant is monitored from the Emergency Response Center. In all situations, it must be possible to make the necessary controls in sufficient time and to monitor the status of the plant reliably.

It is not clear if it is allowed to work alone in the control room and in the field. In areas where it is possible to work alone, it should not be possible to take measures that could endanger the safety of the plant.

Considering the above findings, STUK's view is that it is possible to design the operation to meet the requirements.

Design provision for security

Steady Energy does not yet have access to the Design Basis Threat (DBT) and has not outlined the threats against which the plant will be protected.

Information security is not systematically considered in the design.

It is not evident that security has been addressed in an integrated way with all other aspects of safety. For example, security has been excluded from the document regarding safety demonstration.

STUK's view is that there is nothing in the evidence that would prevent the implementation of security in compliance with the requirements as the design proceeds.

Design provisions for safeguards

From a safeguards perspective, the LDR-50 is very similar to traditional pressurized water reactors. SE has mapped and identified specific characteristics of the LDR-50 that may be relevant for safeguards implementation. Some key issues for detailed design are still open, e.g. the concept of fresh fuel handling and storage is still incomplete. Furthermore, the documentation does not describe how the design process will ensure that safeguards is considered in the design.

There are still open issues in the design, but STUK's view is that conditions are in place to design the LDR-50 to meet safeguards requirements.

Design provision for emergency preparedness

The design includes premises for emergency response operations and equipment and considers the need for data transfer and communication. In addition to the on-site emergency operations center, there will be an off-site emergency center in case the on-site center is not available.

Consumables (food, fuel, etc.) needed in an emergency situation are reserved for three days. The autonomy period required by the regulatory reform is likely to be increased to 7 days.

In contrast to the current requirements (YVL B.8 391), there will be no plant fire brigade, but the local fire brigade will be relied on for fire protection. This requirement is likely to be removed in the renewal of the regulations.

STUK's vies is that conditions are in place to design the plant to meet the requirements for emergency preparedness. It is good to keep in mind that the autonomy requirement may change in the renewal of the regulations.

Management and storage of radioactive waste

The waste generated is typical for a PWR and technical solutions for its treatment, storage and disposal exist. In LDR-50 design, the need for solid, liquid and gaseous waste treatment systems and waste storage has been identified. The quantities of liquid and solid low and intermediate level waste have not been estimated, so it is not possible to assess the adequacy of the space available for waste systems and the adequacy of storage capacity. For spent fuel, the submitted information describes the storage capacity in sufficient way.

A new feature is the use of dry storage for intermediate storage of spent fuel. Dry storages have not been licensed in Finland, but there are several in use around the world.

STUK's view is that the conditions are in place to design the handling and storage of radioactive waste to meet the requirements.

Design provisions for decommissioning

SE has identified the design phase matters that have effect on decommissioning, as well as principles that will be followed in the design to enable decommissioning. The design is not at a stage where it would be possible to verify how the principles are implemented in the design, but STUK's view is that by following the principles set out, the conditions are in place to ensure that decommissioning is considered in the design in a way that meets the requirements.

Nuclear fuel and design provisions for its handling and storage

The LDR-50 fuel is typical PWR fuel, but the operating conditions are different from a typical PWR (lower pressure and temperature, boron free chemistry). Operating experience from such conditions is hardly available. The demonstration of fuel safety under the operating conditions of LDR-50 is a matter to be assessed at the construction license phase. There are several fuel suppliers in the world capable of supplying fuel of the type described. The design of the plant includes facilities for the storage of fresh and spent fuel.

STUK's view is that the conditions are in place for designing the fuel and its handling to meet the requirements.

Demonstrating safety

SE will build a full-scale test facility, including the reactor, primary circuit, containment vessel and reactor pool. The facility will test, among other things, the natural circulation of the primary circuit and passive heat removal. A test facility is a good solution to demonstrate the safety of a new type of a plant, and a full-scale facility provides certainty about the representativeness of the tests.

For most of the other new design solutions (e.g. shared control room between several units, small shared operating shift to control several reactors), plans for demonstrating safety were not yet presented.

In the safety demonstration document, security had been omitted. All aspects of safety (3S: Safety, Security, Safeguards) should be addressed in an integrated way from an early stage.

The vendor

SE is a new company that is only developing its organization and management system. Only a small number of activities have a systematic and documented process, others are under development. SE aims to obtain ISO 9001 certification in 2025, and ISO 19443 possibly in 2026. ISO 19443

is an international standard for a quality management system in the nuclear industry.

SE is still a small organization but growing rapidly. During STUK's assessment, the number of staff almost doubled. In some areas, SE has only just recruited or is in the process of recruiting the expertise it needs (e.g. HFE, IT security).

SE does not yet meet the expectations of the vendor at the construction license phase. However, SE has plans to develop its organization and management system and the management seems motivated to develop the company. STUK does not see any obstacles to SE developing over time into a compliant plant supplier.

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Annex STUK's Safety Assessment of LDR-50