Guide YVL D.5, Disposal of nuclear waste (13/2/2018)

1. Scope of application

Guide YVL D.5 addresses the extensive disposal of nuclear waste in repositories constructed inside the bedrock. The types of nuclear waste within the scope of the present Guide include spent nuclear fuel, radioactive waste arising from the operation of a nuclear facility, radioactive waste arising from the dismantling of a nuclear facility, and other radioactive waste to be disposed of in emplacement rooms designed for nuclear waste. The Guide covers the entire life cycle of a disposal facility (site investigations, design, construction, operation and closure), and it addresses both the operational safety of disposal facilities and the demonstration of the long-term safety of disposal.

Guide YVL D.7 "Release barriers of spent nuclear fuel disposal facility" sets out the requirements for the design, manufacture, construction, installation, inspection, testing and verification of conformity of the barriers for the spent fuel disposal facility.

2. Justifications of the requirements

This Guide applies to extensive disposal of nuclear waste in the bedrock. The spent nuclear fuel originating from Finnish nuclear power plants is intended to be encapsulated and disposed of in repositories constructed deep inside the bedrock. Low and intermediate level waste arising from the operation of nuclear power plants and other nuclear facilities are to be processed and disposed of in bedrock repositories constructed at an intermediate depth. The waste arising from the eventual decommissioning of nuclear power plants and other nuclear facilities is also envisaged to be disposed of in repositories constructed at an intermediate depth.

The preparations for the disposal of nuclear waste comprise selecting and characterising the disposal site as well as developing the disposal method and technology. The development of the methods and collection of the data necessary for assessing the operational and long-term safety of the facilities will mainly be done years before commencing the construction of the facility. The implementation of the disposal involves the excavation of rock caverns and other construction works, transferring the waste packages into the emplacement rooms, the installation of other engineered barriers, if any, and the backfilling and closure of the excavated rooms. The Guide covers all the aforementioned phases, and it addresses both the operational safety of disposal facilities and the long-term safety of disposal. The Guide imposes requirements to the licensee and the licensee with a waste management obligation whose responsibilities continue until the approved closure of the disposal facility.

Justifications of the requirements by topic

Chapter 3 Limiting of radiation exposure and radioactive releases Chapter 3.1 of this Guide presents the radiation dose constraints for members of the public concerning the operation of the disposal facility. Requirement 301 notes the regulation found in Section 22 d(1) of the Nuclear Energy Decree (161/1988), according to which the constraint for the annual dose of an individual in the population, arising from the normal operation of the disposal facility, is 0.01 mSv.

Requirement 303 presents the constraints stipulated in Sections 22 b and 22 d of the Nuclear Energy Decree for the annual dose to the individual members of the public that shall remain below (0.1 mSv) as a result of anticipated operational occurrences or in the event of postulated accidents (1 or 5 mSv depending on the frequency classification).

Requirements 304a and 304b address the selection of the events that cause radioactive releases and radioactive doses to be analysed. The events to be analysed shall be selected in a manner that allows for the disposal facility's behaviour during occurrences and accidents and the emissions and radiation doses caused by occurrences and accidents to be comprehensively analysed. The events to be analysed may include, for example, a waste package handling error or dropping of a waste package. The main focus is on deterministic analyses calculating the radiation exposure to the members of the public in the vicinity in case of any accidents. Additionally, if an accident may have severe consequences, it shall be assessed by means of a probabilistic risk assessment where also the probability of accidents is taken into account. In such a case, the sequences of events selected for a more detailed analysis shall be those with consequences that may exceed a certain criterion, such as the dose constraint for a postulated accident, when it is assumed that components failed due to the initiating event and components other than those fully passive are faulty.

Chapter 3.2 presents the radiation safety requirements concerning the long-term safety of disposal. Requirement 307 quotes the requirement in Section 22 d(3) of the Nuclear Energy Decree that shall be applied over the period during which environmental changes having an impact on radiation safety can be reasonably anticipated; in practice, it shall cover at least several thousands of years. During this period, the annual dose to the representative person shall remain below 0.1 mSv, and the radiation exposure to large groups of people shall remain insignificantly small. Representative person shall refer to an individual in the population group most highly exposed to a given radiation source, whose radiation dose represents the doses received by such a population group (ICRP Publication 101). The representative person is equivalent to, and replaces, the previous term 'average member of the critical group'. The constraint of 0.1 mSv follows ICRP recommendations according to which, in order to limit the population exposure, the annual dose constraint applied to disposal of radioactive waste should be at most 0.3 mSv [1].

Requirement 310 specifies the selection of the representative person further. According to the ICRP recommendations on the radiation protection of final disposal, the selection of the representative person may be based on the anticipated development of the living environment or stylised approach where certain habits are assumed. The requirement limits the living environment of the representative person to be that of a self-sustaining family or small village community. A small lake is assumed to exist in the living environment. This does not necessarily coincide with the anticipated development of the living environment, but a conservative approach is justifiable to allow for any radioactive substances releasing from the emplacement room into the living environment to be diluted into a smaller volume of water. Requirement 311 addresses the exposure of a larger group of people. The acceptability of a large-scale radiation exposure depends on the size of the group of people exposed, and the maximum dose must be in the range of 1 to 10% of the annual dose of the representative person mentioned above.

Requirement 312 quotes the radiation safety requirement in Section 22 d(4) of the Nuclear Energy Decree that shall be applied for periods after thousands of years. At most, the radiation impacts arising from disposal may, in this case, be equivalent to those caused by naturally radioactive materials in the earth's crust, and on a large scale, the radiation impacts shall remain insignificantly low. The Nuclear Energy Decree authorises STUK to set out radionuclide-specific release constraints to achieve the level of radiation safety mentioned above.

The release constraints are set in para. 313 and they vary between nuclide groups from 0.03–100 GBq per annum. The release constraints have been derived from the above-mentioned 0.1 mSv annual dose constraint by applying dose conversion factors based on biosphere analyses and assuming exposure routes and living environments typical to the disposal site. Requirement 314 presents how the combined impact of releases of more than one nuclide are taken into account. In addition, this requirement allows the releases to be handled as moving average for a maximum period of 100 years, emphasising releases with a duration approximately the same as the lifespan of a human.

According to the requirement of Section 35(3) of the Radiation and Nuclear Safety Authority regulation on the Safety of Disposal of Nuclear Waste (STUK Y/4/2016), when applying the release constraints the radiation doses shall also be assessed by using stylized models of the surface environment. Such models include, for example, static reference biospheres like those developed in the IAEA's Biomass project. Requirements 314a–314d present instructions on applying the stylized models. The models must be sufficiently different to cover the development of the overall surface environment within the assessment period.

The radiation safety criteria described above concern radiation exposure arising from expected evolution. Requirements 315–317 present the radiation protection targets for rare events impairing long-term safety. Rare event impairing long-term safety shall refer to a potential event significantly reducing the performance of barriers that has a very low probability of occurring, but that may jeopardize long-term safety in case of occurrence. Requirement 315 reiterates the requirement to consider rare events impairing long-term safety stipulated in Section 11(1) of Regulation STUK Y/4/2016.

Requirements 316 and 316a list rare events impairing long-term safety arising from natural phenomena and human actions that at least shall be taken into account in safety analyses:

- bedrock sample drilling that hits a waste package;
- the boring of a deep well near the emplacement rooms; and
- the forming of a bedrock displacement that intersects the emplacement room.

In cases caused by human actions, it is assumed that the existence of the disposed waste is not known and that the incident may only occur 200 years following the closure of the disposal facility at the earliest.

The significance of rare events impairing long-term safety can be assessed by taking into account their frequency of occurrence and the doses caused as a result of them. The likelihood of radiation doses that can cause immediate health impacts (doses in excess of 0.5 Sv) must be very small. Since the quantitative analysis of the likelihood and consequences of rare events is not always possible, the Guide allows for using semi-quantitative or qualitative methods to assess the significance of the events.

Requirements 318–320 address the protection of other living species. ICRP has developed principles, dose criteria and analysis methods to be used to protect other living species [2]. The starting point is that organisms shall be protected on population level: the radiation exposure must stay on a considerably lower level than the radiation doses that could cause a decrease in diversity or some other significant harm to a living population. Based on present knowledge, a radiation dose of less than 0.1 milligrays per hour to a part of the organisms will not cause harmful effects to healthy populations [3]. This dose is more than thousand-fold greater compared to the dose constraint set for humans receiving the highest exposure due to a repository and several hundred-folds greater than natural background radiation. Because of the ample safety marginal, it is presumable that also the protection of endangered organisms and the biotic populations outside the living environment of humans is sufficient. However, this must be verified by analysing typical radiation doses to terrestrial and aquatic populations in the disposal site environment assuming the present kind of living populations.

Chapter 4 Planning of the disposal method

Chapter 4.1 presents the general requirements for the gradual implementation method of the disposal. Requirement 401 quotes the requirements set out in Section 8(1) of Regulation STUK Y/4/2016. Requirement 402 specifies the various stages of the implementation of the disposal:

- selection of the disposal concept;
- site investigations; may require the construction of an underground research facility;
- design of the disposal facility with related research and development work;
- construction of the disposal facility;
- waste emplacement activities and other operations;
- backfilling and closure of emplacement rooms and other underground rooms; and
- post-closure monitoring measures of the disposal facility, where required.

Requirement 403 requires the optimisation of the disposal concept in particular as regards the safety aspects. The different stages of the disposal must be implemented in a timely manner and giving priority to long-term safety. The implementation shall take into account the reduction in activity and heat generation in the waste, the adequacy of available research data, the utilisation of high-quality technology and scientific data, the need to ensure safety by means of supervision activities and other relevant factors. The preparedness for advancing to the next stage shall be assessed as a whole, taking into account the suitability of the disposal concept and site, the technological maturity of the method and the outcome and reliability of the safety case. The principle included in Section 7 h of the Nuclear Energy Act (990/1987), according to which ensuring long-term safety must be designed so that it does not require the surveillance of the final disposal site, shall be taken into account in planning monitoring activities for the time after the disposal activities.

Chapter 4.2 includes requirements for the so-called multibarrier principle in accordance with the defence-in-depth safety principle stated in Section 7 b of the Nuclear Energy Act. The multibarrier principle means that the release of radioactive substances into the environment has been prevented by means of consecutive, mutually complementing barriers and the long-term safety functions implemented by them.

Requirements 405 and 406 address engineered barriers and the long-term safety functions provided by them, and requirements 407 and 408 address the natural barrier and the long-term safety functions it provides.

Engineered barriers include, for example, the waste matrix, the package where the waste is enclosed, the buffer surrounding the waste package, the containment and closing structures as well as the backfilling of emplacement rooms. The bedrock at the disposal site serves as a natural barrier. The purpose of the long-term safety functions brought about by the characteristics of the barriers or processes is to prevent, delay and limit the release and migration of the disposed radioactive materials. Functions that prevent entry into the emplacement rooms may also be interpreted as barriers.

The long time span related to disposal means that the application of the multibarrier principle has certain specific features. Firstly, the barriers shall be passive, since no automatic or human-regulated actuator can be considered reliable over the time span of the disposal. Secondly, the performance of engineered barriers, in particular, may degrade significantly over very long periods of time. This does not necessarily result in a degradation of safety as, in accordance with the multibarrier principle, the individual barriers with declined performance are there to complement each other, and the amount of radioactive substances will also reduce quickly over time. After very long periods of time, the safety of the disposal can mainly be based on barriers with good long-term stability, such as the bedrock, favourable chemical conditions deep within the bedrock and the naturally stable materials present in the disposal environment.

The nuclide-specific variations in the performance of the barriers and long-term safety functions shall also be taken into account. Since the half-lives of radioactive materials vary significantly, the degradation over time in the performance of the barriers described above will have an impact on which part of the material will decay and which part will migrate to the living environment. In addition, solubility limits and retardation on material surfaces depend on the chemical properties of the radioactive material.

Therefore, the waste to be disposed of and its characteristics shall be taken into account when planning the engineered barriers. In the case of disposal of low level waste, for example, the significance of the waste matrix and waste container may be small in terms of safety. Although nuclear fuel has not been designed with final disposal in mind, for the purpose of long-term safety the characteristics of the fuel must remain favourable prior the final disposal.

Requirements 409–411a deal with the performance targets set to the long-term safety functions that shall be defined by the party implementing the final disposal project. Performance targets serve as the basis for the safety case and, on the other hand, the achievability of the performance targets shall be demonstrated through planning and research. Performance targets shall be based on high-quality scientific knowledge and expert judgement, and the events and environmental changes affecting the disposal conditions must be taken into account when setting them.

Engineered barriers shall ensure the isolation of disposed radioactive materials from the bedrock for a certain period of time, the length of which depends on the duration of the radioactivity in waste. For short-lived waste, this period shall be at least 500 years, and for long-lived waste, at least around 10,000 years. Short-lived and long-lived waste are defined in Section 2 of Regulation STUK Y/4/2016. In practice, all low and intermediate level waste generated during the operation of a nuclear power plant and most of the decommissioning waste from a nuclear power plant are regarded as short-lived waste. In addition to spent nuclear fuel, long-lived waste includes highly activated metal waste.

The engineered barriers are required to effectively prevent the release of disposed radioactive substances into the bedrock during the assessment period. The word “effectively” means here that when designing the barriers, the possibility that the performance of the barriers may degrade sooner than expected shall be taken into account. In addition, it is possible that the same emplacement room may be used to dispose of less active waste that require lower-level containment than those for which the facility is primarily designed for.

As a whole, the disposal concept must be sufficiently ensured in terms of, for example, incidental non-conformances and predictable environmental changes. Another design objective when designing the disposal concept shall also be that the characteristics of the waste packages or the conditions in the emplacement rooms will not change over time in a way that could have an adverse effect on the long-term safety functions.

Chapter 4.3 deals with the requirements set out for the disposal site and facilities. The bedrock surrounding of the disposed waste will serve as a barrier preventing and delaying the release of radioactive substances from the emplacement room into the living environment. The dilution of radioactive substances into large volumes of water in either the groundwater or surface water systems over a long period of time will also reduce the possibility of high individual exposure. In addition to the favourable characteristics described above, there are factors indicating the unsuitability of the disposal site, such as the proximity of exploitable natural resources, abnormally high rock stresses with regard to the strength of the rock, seismic or tectonic activity and abnormal vital groundwater parameter values. Even a single unfavourable characteristic may indicate that the area is unsuitable for use as a disposal site.

The bedrock must also offer favourable and stable mechanical and chemical conditions in order for the engineered barriers to perform effectively and retain performance as long as possible. As regards the disposal of spent fuel, bentonite is an important component to achieve this; it should withstand mechanical and chemical erosion and mineral transformation brought about by groundwater. As regards the disposal of low and intermediate level waste, concrete structures are important and should resist degradation brought about by groundwater as well as possible.

The emplacement rooms shall be placed sufficiently deep in order to prevent above-ground natural phenomena and the effects of human activity from compromising the safety. The most significant natural phenomena are the effects of glaciation which may reach to a depth of a few hundred metres. Notable human activities include rock blasting, constructing facilities inside bedrock, drilling wells and groundwater pollution. Their impacts will typically reach a maximum depth of a couple of hundred metres. When optimising the disposal depth, attention shall also be paid to the geological structures of the bedrock and the correlation between the condition parameters (tension, temperature and flow and chemistry of groundwater) and depth. The radioactivity of the waste will also affect the optimal disposal depth. Spent nuclear fuel and other high level waste shall be placed at a depth of several hundred metres, whereas a disposal depth of a few tens of metres is usually sufficient for low and intermediate level waste.

Chapter 5 Planning and design of the disposal facility and disposal operations

Chapter 5 deals with the planning and design of the disposal facility and disposal operations. According to the Nuclear Energy Decree, a disposal facility exists only until such point in time that all the faciliti's rooms are closed in an approved manner; after that, the facility shall be referred to as emplacement rooms. The obligations of the licensee also continue until the same point in time; after that, the responsibility for the emplacement rooms is transferred to State, and the Guide does not place requirements on the State.

Chapter 5.1 deals with the planning and design of radiation safety of the disposal facility and disposal operations. Chapter 5.1 refers to the YVL Guide group C pertaining the area and zone classification, layout design, radiation monitoring inside the facility and monitoring of radioactive releases.

Radiation monitoring inside the facility is required to ensure radiation safety of the workers. It is not expected that there would be any observable radioactive release in the facility environment during normal operation, but it is necessary to measure radioactive releases from the exhaust air and leak waters in order to ensure this.

Individual monitoring and stationary and portable radiation monitoring systems and equipment are used to ensure the radiation safety of the workers of the facility and its environment. The planning of the radiation monitoring shall take into account the special characteristics of the disposal functions and underground facilities including, for example, the gradual movement of the controlled area as the construction and disposal activities for the disposal of spent nuclear fuel progress. Under normal conditions, there will only be external radiation exposure, as the waste packages do not release radioactive substances into the facility rooms. External radiation exposure can be reduced by using radiation shields or remote-controlled transfers.

Chapter 5.2 deals with the design of the systems, structures and functions. Requirements 503a–505a deal with the safety classification used to target the resources for ensuring the safety of items most significant in terms of safety. The higher the safety class of the classified item, the higher the quality level required for the design, manufacture, installation, inspection and testing will be. During the operation of the disposal facility, the functions forming the basis for the classification typically include transfers of waste packages, radiation measurements and fire protection. Depending on the characteristics of the disposed waste, items to be classified also include the disposal packages and the buffer materials surrounding them, the containment structures and the host rock surrounding the underground rooms of the disposal facility that are important to long-term safety.

More specific classification requirements are included in Guide YVL B.2 “Classification of systems, structures and components of a nuclear facility”. However, the seismic classification presented therein does not apply to underground rooms as the acceleration criteria included in the Guide are determined for above-ground constructions. Seismic resistance will, nevertheless, be taken into account as an earthquake is defined to be taken into account as an external event (para. 518).

Requirements 505b–509 deal with the construction, operation and closure of the disposal facility. Before the construction of the actual emplacement rooms, the suitability of the bedrock must be confirmed by means of studies performed above-ground and at the planned disposal depth. This is important in terms of both the constructability of the rooms and the achievement of good long-term containment. The studies are employed in order to study the rock mechanical, geohydrological and groundwater chemistry characterisation of the rock volumes intended to be excavated. The studies may also include experiments to verify the long-term performance of the barriers. As the operational lifetime of the disposal facility may even be over hundred years, features related to long-term safety may to some extent be verified by means of an research and monitoring programme. The programme may include, for example, the follow-up of tensions and deformations in the bedrock by means of precision measurements, monitoring of the flow and chemistry of groundwater and specific experiments related to the performance of the engineered barriers, such as monitoring the waterlogging of the bentonite and the effects of heat generation of the waste. It is also possible that some waste packages placed in disposal for experimental purposes are removed from their positions after some decades for detailed studies.

The positioning of a disposal facility and its rooms shall be based on the rock suitability classification. Detailed requirements for the rock suitability classification for a spent fuel disposal facility are presented in Guide YVL D.7. This Guide contains general requirements for the suitability classification. In case of a disposal facility for low and intermediate level waste, suitability assessment of bedrock of a more general nature may be used for suitability classification.

The methods adopted for the construction, operation and closure of the emplacement rooms and other underground rooms shall be selected so that the bedrock retains its natural barrier characteristics and contributes in achieving and retaining the performance of the engineered barriers. The transport into the emplacement rooms of substances which are adverse to long-term safety (such as organic and oxidising substances and alkaline sealing agents) shall be limited as much as practicably possible. The disposal tunnels shall be backfilled and closed without unnecessary delay.

Safety aspects may require the disposal functions and construction functions to be separated from one another. New disposal tunnels and holes may be excavated while the ones completed previously are being filled with waste canisters, and the mutual interference between these two functions shall be kept to a minimum. Accordingly, the disposal activities and the expansion of the emplacement rooms shall be performed in phases or, alternatively, sufficient physical distance shall be maintained between these activities by, for example, separate transfer routes. Furthermore, excavation work shall not take place too close to the waste canisters so as not to compromise the rock mechanical stability of the rooms.

Requirements 511–514a deal with the structural and process-technical design of a disposal facility. It shall take account the expected lifetime of the facility and the conditions in the emplacement rooms, the need for repairs due to breakage or wear and potential occurrencies and accidents. The design of systems and structures shall take account of anticipated operational occurrences and postulated accidents. The Guide includes references to the most important YVL Guides in terms of system and structural design (general requirements, electrical and I&C systems, air conditioning systems, hoisting and transfer equipment, barriers and rock construction).

Chapter 5.3 deals with prevention of occurrences and accidents. The design principle of systems that are important to safety shall be that they must be able to operate as intended even if any single component of the system should fail. Functions the failure of which might lead to a radioactive release into the environment or to significant radiation exposure to workers shall, therefore, be ensured using the principle of redundancy and, where feasible, the principles of separation and diversity. The reliability of the system can be increased by using, where applicable, technologies that do not require an external power supply or that, as a consequence of a loss of power supply, will settle into a safe state. The functions to be ensured are determined based on the safety classification; para. 515a lists typical disposal facility functions that shall be ensured against single failures.

Requirements 515b–517 deal with internal events. Fires and explosions shall be prevented by means of room layout planning and fire compartmentation, use of non-flammable and heat resistant materials as well as limited fire and explosion loads. The explosion hazard can be minimised by, for example, placement of explosive substances and high-pressure containers and separation of the excavation and disposal activities. The various rooms of the facility shall be equipped with a fire detection system. The rooms and systems, such as the transfer vehicle, shall be equipped with suitable automatic or operational fire-fighting systems.

Requirements 518–519 deal with the consideration of external events. Natural phenomena to be considered in the design of a disposal facility include, for example, lightning strikes that cause damage to electrical equipment, earthquake and design-based flooding if possible based on the elevation of the mouths of the tunnels and shafts. Potential effects of a tunnel collapse and flooding due to a failure in the pumping of leaked waters in underground rooms shall also be considered. Measures proportionate to the threat and in compliance with the applicable provisions of the requirements set out in YVL A.11 “Security of a nuclear facility” and YVL A.12 “Information security management of a nuclear facility” shall be prepared for threats due to unlawful actions.

Requirements 520–520b address the criticality of the spent nuclear fuel. The spent nuclear fuel contained in a disposal canister shall remain subcritical also in the long term. The design shall accommodate conditions where the leak-tightness of the canister has been lost, and the canister has sustained mechanical or corrosion-induced deformations. The eventuality of criticality shall be considered in long-term criticality safety analyses as far as practicable.

Chapter 5.5 addresses the retrievability of waste packages. Retrievability refers to the reversibility of each disposal stage. Requirements 523–525 present the requirements for retrievability. The decision in principle concerning a disposal facility of spent nuclear fuel requires that retrievability shall be assessed, so the requirements will not affect Posiva's operations. Retrievability has not been taken into account in the design of disposal facilities for low and intermediate level nuclear power plant waste (VLJ facilities), and this will be taken into account in the implementation decision.

Chapter 6 Commissioning and operation of a disposal facility

Requirements 601a–601f concern the commissioning inspections of a disposal facility. A disposal facility of spent nuclear fuel, in particular, shall be constructed and commissioned one phase at a time, and commissioning inspections shall be conducted for each phase. First, the licensee shall conduct its own commissioning inspections after which it shall invite STUK to conduct a commissioning inspection. STUK will conduct a commissioning inspection of all underground spaces classified in Safety Class 3 and Class EYT/STUK.

Requirement 602 addresses the monitoring of operating experience feedback. The safety of the disposal facility shall be improved based on operating experience feedback and advances in science and technology. The safety is enhanced by systematic monitoring of the condition of the plant and the operating experience feedback received from it in order to repair defects and correct possible design errors. The research and monitoring programme to endorse the long-term performance of the barriers (para. 506) is primarily intended to gather information required for the safety case. It can be assumed that there will still be uncertainties concerning the long-term safety of disposal in the commissioning stage of the facility, the which can be reduced by a facility-specific research and monitoring programme. This may include, for example, monitoring of the bedrock and tests simulating the disposal that will continue through the operational period and beyond, if necessary.

Requirement 603 deals with the records keeping of the disposed waste packages. The information to be recorded includes the waste type and processing and packaging method as well as structural and material characteristics significant to safety (descriptions are included in the safety analysis report), the identifier and location of the waste package in the emplacement room as well as the inventories of the significant nuclides (spent fuel to an accuracy of an individual package, other waste to an accuracy of an individual emplacement room). According to Section 29(4) of Regulation STUK Y/4/2016, STUK shall be responsible for the long-term storage of information concerning disposed waste. This information and the information concerning the disposal facility are in time compiled to a collection of documentation, which is archived for future generations.

Requirement 603a deals with the acceptance criteria for the waste brought into the disposal facility. The licensee of the disposal facility shall define waste acceptance criteria for the waste brought into the disposal facility based on the operational and long-term safety of disposal. The waste acceptance criteria and their justification shall be presented in the preliminary and final safety analysis reports.

Requirement 604 deals with plant modification procedures, the requirements of which are also included in Section 112 of the Nuclear Energy Decree. STUK may approve plant modifications that are within the limits of the terms and conditions of the operating licence. The procedures observed in different types of plant modifications are specified in more detail in Guide YVL A.1 "Regulatory oversight of safety in the use of nuclear energy". A disposal facility of spent nuclear fuel is intended to be implemented in phases with the surveying and positioning of emplacement rooms, excavation of new rooms, positioning of waste canisters in the rooms and filling of tunnels where the disposal activities have been brought to completion take place simultaneously. The transfer from one phase to another is regulated with the plant modification procedure.

Requirements 608–610 deal with the monitoring of radioactive releases and radiological situation in the environment of the disposal facility. Guides YVL C.3 "Limitation and monitoring of radioactive releases from a nuclear facility" and YVL C.7 "Radiological monitoring of the environment of a nuclear facility" shall be applied, where applicable. Prior to the start of construction and commissioning of the disposal facility, a baseline study on the radiological situation in the environment of the facility shall be prepared, and during the operation, a radiation monitoring programme shall be implemented. The extent and focus of the radiation monitoring programme shall be determined based on the foreseen releases of radioactive materials. In addition, the amount of radioactive materials released to the environment from the disposal facility shall be monitored at the potential release pathways.

The radiation protection and exposure monitoring of the operating personnel of a disposal facility are addressed in Guide YVL C.2 "Radiation protection and exposure monitoring of nuclear facility workers".

A disposal facility shall have emergency response arrangements in place to protect its personnel and other people within the plant site in case of an accident causing radiation hazard or other threat. The extent of the emergency response arrangements shall be proportioned based on the foreseen accidents. Emergency response arrangements are covered, where applicable, by Guide YVL C.5 "Emergency arrangements of a nuclear power plant".

Chapter 7 Documents to be submitted to STUK

Chapter 7.1 concerns the decision-in-principle and licensing processes. The Nuclear Energy Decree lists the documents that shall be submitted together with the application for a decision-in-principle. The Guide emphasises that documents related to the plant's design bases, technical plan, location and safety descriptions must be sufficiently detailed to allow STUK to carry out a preliminary safety assessment based on them as provided in Section 12 of the Nuclear Energy Act. As regards the construction licence for a nuclear facility and the operating licence, references are made to the list of documents to be submitted included in Guide YVL A.1, in addition to which the geological, hydrogeological and groundwater chemistry model for the disposal site, as well as the room positioning plan, shall be submitted.

Additions to the respective documents shall be submitted in case the nuclear facility is extended, or an extension is commissioned under the terms and conditions of an existing licence. In this case, a report on the impact of the extension work on the safety of the existing nuclear facilities shall also be submitted. In such cases, STUK approves the commissioning of the extension part based on Section 20 of the Nuclear Energy Act.

Requirement 703i deals with a situation where an underground research facility, intended to constitute a part of the foreseen disposal facility, is constructed at the disposal site prior to the issuance of the construction licence. Prior to the construction of the research facility, the following documents listed in the requirement shall be submitted to STUK: a description of the research facility and its implementation, a description of the potential effects of the construction on the bedrock, a proposal for a safety classification document, a report on quality management during construction, a description of the arrangements for facilitating STUK's regulatory control and a plan for arranging the necessary safeguards to prevent the proliferation of nuclear weapons insofar as nuclear materials are intended to be emplaced in the facility.

Requirements 704–704b deal with the demonstration of the long-term safety through a safety case. The safety case includes, among other things, a description of the disposal system and a description of the processes delineating the future behaviour and the evolution of the disposal system, i.e. scenario analysis, a calculational analysis of the release and migration of radionuclides from the disposed waste as well as complementary considerations insofar as quantitative analyses are not feasible or involve considerable uncertainties. Detailed requirements for the safety case are provided in Annex A of the Guide.

Safety case is an extensive material demonstrating the safety of the disposal, requiring a lot of resources to compile. It is therefore necessary for STUK to follow the preparation of the safety case at as early a stage as possible. For this reason, the plan for the preparation of the safety case shall be submitted to STUK for information before submitting the licence application or conducting a periodic safety review. In connection with the review of the safety case, STUK conducts comparative analyses or have such conducted by an outside expert. Due to the scope of the analyses, not all the necessary input data is always included in the application materials. When required, STUK will request the licence applicant to submit data required for the analyses.

Requirements 706–707 deal with the preliminary and final safety analysis reports, which shall be submitted to STUK for approval together with the construction licence application and operating licence application for a nuclear facility, and which shall be kept up-to-date. The requirements present a list of reports that shall be included in the safety analysis reports. The information may be presented to the required level of accuracy in the safety analysis report or, alternatively, summarised in the safety analysis report and specified in more detail in separate topical reports supplementing it.

Requirements 708–711 deal with the periodic safety review including, in particular, assessments of the nuclear facility's safety status and potential development targets in view of maintaining and enhancing safety with due consideration given to the results of the research and monitoring programmes. The periodic safety review of a disposal facility shall be conducted every 15 years. The periodic safety review of a disposal facility of spent nuclear fuel shall be combined with the review of the encapsulation facility. The safety analysis report and safety case shall be updated to reflect the periodic safety review. More specific requirements on the periodic safety review are included in Guide YVL A.1.

Chapter 7.5 deals with reporting. Reporting is a form of regulatory control, and it supplements the other procedures, such as the supervision visits and inspections performed at the facility site.

Reporting aims to provide STUK with an up-to-date view of the state of the facility based on which STUK can plan its activities and evaluate where the supervision should be focused.

During construction, the aim of reporting is to provide all parties involved in the project with up-to-date and sufficient information on project schedules, progress, organisations operating at the facility site and their respective interfaces, as well as significant deviations and events concerning the safety of the project and the corrective and preventive actions to eliminate them.

When reviewing the reports during operation, STUK verifies that:

- the nuclear facility is being operated in line with legislation and regulations; and
- the operation of the nuclear facility, as well as events having an impact on safety, are sufficiently documented so that they can be analysed afterwards.

With regard reporting during the construction and commissioning, references are made to Guide YVL A.5 “Construction and commissioning of a nuclear facility”, and, with regard to reporting during the operational period of VLJ facilities, to Guide YVL A.9 “Reporting on the operation of a nuclear facility”. The results of the investigation and monitoring programmes carried out at the disposal site shall be reported once a year.

Chapter 8 Regulatory oversight by the Radiation and Nuclear Safety Authority

Chapter 8.1 deals with the oversight of the construction, commissioning, operation and closure of a disposal facility. Requirement 805 deals with a situation where an underground research facility, intended to constitute a part of the foreseen disposal facility, is constructed at the disposal site prior to the issuance of the construction licence. In such a case, STUK will oversee the construction of the research facility with procedures equivalent to those applied in overseeing the construction of the disposal facility, with due consideration given to the importance of the research facility to safety.

Requirement 806 describes the application of regulatory oversight during the construction phases and operation of the disposal facility. STUK shall approve the commissioning of the new facility part following the plant modification procedure described above in para. 604.

When disposing spent fuel, in particular, it is appropriate that the disposal tunnels are backfilled and closed as the respective emplacement activities have been brought to completion. As provided in para. 813, the plant modification procedure shall be observed, meaning that the backfilling and closing of the tunnels can only commence after STUK has approved the plans and safety assessments concerning them.

Requirements 814 and 815 deal with the permanent closure of the disposal facility. A precondition for the permanent closure of a disposal facility is that STUK has approved the closure plan, which shall include a description of the technical implementation of the closure and an update of the safety case. The update shall take into account the results from the bedrock investigations and monitoring programmes received over the entire operation period. A plan for post-closure surveillance shall also be provided at the same time as, for example, nuclear safeguards at the site of the disposal facility of spent nuclear fuel may continue even after the closure of the repository. The licensee shall also provide a proposal for the restriction zone with the prohibition on measures referred to in Section 85 of the Nuclear Energy Decree. The purpose of this is to maintain the information on the disposal and thereby reduce the likelihood of rock drilling or other activities compromising the safety of disposal at the site.

Chapter 8.3 deals with the review of the safety case. Safety case is a collection of documents that STUK approves when reviewing the licence application and the periodic safety review. If necessary, STUK conducts comparative analyses or have such conducted by an outside expert, and the results are compared with those from the safety case.

Annex A Safety case

According to Regulation STUK Y/4/2016, compliance with the requirements concerning long-term radiation safety, and the suitability of the disposal method and disposal site shall be demonstrated by means of a safety case that must study both possible evolutions and rare events impairing long-term safety. The safety case is comprised of a calculational safety analysis based on experimental studies and complementary considerations insofar as quantitative analyses are not feasible or involve considerable uncertainties. Detailed requirements for the content of the safety case are provided in the Annex to the Guide.

As provided in requirement A02, the safety case shall include a sufficiently detailed description of the disposal system. The safety case shall describe the disposed waste packages, structures and materials used as engineered barriers, rock caverns and their respective backfilling methods as well as the natural environment at the site.

Requirements A03–A03b specify that the safety case shall define the barriers and long-term safety functions. The setting of performance targets to be set out for the long-term safety functions is discussed in requirements A03c–A03e, including the setting of the respective performance targets.

Requirements A04–A05c deal with the scenario analysis: the systematic compilation of potential future disposal system developments from features, events and processes that may be of relevance to long-term safety. The scenarios may be composed of physicochemical processes internal to the disposal system and external events, such as climate changes, geological processes or human actions. In accordance with requirements A05–A05b, the scenarios are classified into three groups:

- the base scenario that is based on the assumption that the performance targets defined for the long-term safety functions are met;
- the variant scenarios assuming that the performance of one or several of the long-term safety functions may have declined; and
- the disturbance scenarios concerning the impacts of rare events impairing long-term safety; these are discussed in para. 316 of the Guide.

Requirements A06–A06b deal with the modelling of release and migration of disposed radioactive materials. In the first phase, the conceptual models describing the features and processes that settle the long-term safety functions are formulated. To support these, condition models describing, for example, the characteristics of the bedrock at the site and their evolution, are often needed. The conceptual models are used to derive calculational models used to analyse the release and migration of radioactive materials through the engineered barriers and rock to the biosphere. In the modelling and when acquiring the input data, it is often necessary to make simplifications. In such cases, the so-called conservativeness principle shall be applied: the objective shall be that the performance of a long-term safety function will not be overestimated nor, on the other hand, overly underestimated.

Preparation of a safety analysis requires multidisciplinary expertise. According to requirements A07–A07c, the modelling and the determination of input data shall be based on high-quality scientific knowledge and expert judgement obtained through laboratory analyses, site investigations and evidence from natural analogues. The models and input data used shall be sufficiently disposal site-specific. The models and input data may be scenario- and period-dependant, further complicating the preparation of the analyses. There are significant random variations in the characteristics of bedrock, in particular, due to which the application of stochastic parameter values increases the practicability of the analyses.

Requirement A08 present the so-called conservativeness principle, i.e. that the basis shall be that the actual radiation exposure and quantities of radioactive materials released remain below the results of safety analyses, with a high degree of certainty. Requirements A08a–A08f specify further the assumptions made in the radiation safety analyses as regards to, among other things, changes in the environment and human habits. The changes in the living environment that arise due to land uplift at the disposal sites must be taken into account. There are no such foreseeable trends in the climate type or human habits, nutritional needs and metabolism that could justifiably be taken under consideration; therefore, it can be assumed that the current state will prevail over the entire assessment period. The Guide also specifies the significant exposure routes and self-sustaining communities of the population that at least are assumed to reside at the disposal site, and its vicinity; the annual dose constraint applied to these is 0.1 mSv. In addition to the exposure routes mentioned in the Guide, a dried bog, for example, may in some cases be significant.

Requirement A09 deals with the treatment of uncertainty. The significance of the uncertainties involved in the safety case shall be assessed by means of appropriate methods, such as sensitivity analyses or probabilistic methods.

The impacts of all features and events affecting the safety of the disposal cannot be assessed comprehensively and reasonably by means of calculational safety analysis. Requirements A10–A10b allow for the assessment of the significance of such scenarios by means of so-called complementary considerations, such as calculations by stylized methods, comparisons with natural analogues or observations of the geological history of the disposal site. The significance of such considerations grows as the assessment period increases, and the assessment of safety beyond one million years can mainly be based on the complementary considerations. Complementary considerations are also required to be applied parallel to the actual safety analysis in order to enhance the confidence in the results of the analysis.

The results of the safety analyses shall be compared against the requirements related to long-term safety. In addition, the safety case shall include an assessment of the level of confidence with regard to compliance with the safety requirements and of the uncertainties with the greatest impact on the level of confidence.

Requirements A11–A11d address the documentation of the safety case. Documentation shall aim clarity so that the basic assumptions, methods, results and the coupling to the entirety in each part of the safety case can easily be ascertained. Additional aims shall be transparency and traceability so that the rationale for the assumptions, input data and models adopted shall be easy to find in the documentation. The models and their respective input data shall be described to a level of precision that allows for performing comparative analyses in order to verify the analyses made.

Requirements A12 and A13 specify that the quality of the safety case shall be ascertained through the management system related to the design, construction and operation of the disposal facility. The party implementing the project shall have an appropriate organisation, access to adequate expertise and an appropriate information management system in place. The various phases of the preparation of the safety case shall be systematically planned, and the results of crucial studies and analyses shall be assessed by use of experts or parallel methods of analysis, for example. Requirement A14 specifies that the key selections, assumptions and conclusions related to the drafting of the safety case shall be documented. The aim is to ensure that it is possible to determine the rationale behind the selection of a certain solution afterwards, i.e. if the selection was based on, for example, technical possibilities reasoned to be sufficient with respect to safety.

4. International provisions concerning the scope of the Guide

Key IAEA guide concerning the scope of this Guide:

- Disposal of Radioactive Waste. Specific Safety Requirements. IAEA Safety Standards Series No. SSR-5.

Other IAEA guides on final disposal:

- Geological Disposal Facilities for Radioactive Waste. Specific Safety Guide. IAEA Safety Standards Series No. SSG-14.
- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste. Specific Safety Guide. IAEA Safety Standards Series No. SSG-23.

Key ICRP recommendations:

- ICRP, 1998. Radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste. ICRP Publication 81. Ann. ICRP 28 (4).
- ICRP, 2013. Radiological protection in geological disposal of long-lived solid radioactive waste. ICRP Publication 122. Ann. ICRP 42(3).

During the 2012 IRRS mission, the requirements were compared to the predecessor of SSR-5 (Geological Disposal of Radioactive Waste. Safety Requirements. IAEA Safety Standards Series No. WS-R-4). The correspondence was found to be good. The Guide also corresponds to the SSR-5 requirements.

WENRA reference levels for radioactive waste disposal were being prepared at the same time with the Guide. The Guide corresponds with international recommendations.

5. Impacts of the Tepco Fukushima Dai-ichi accident

No practical impacts on disposal facilities. At the time of the disposal of spent fuel, active cooling is no longer required, and the amount of fuel being processed is small. The Guide requires that flooding and earthquakes possible in Finland shall be taken into account in the design.

6. Needs for changes taken into account in the update

The needs for changes due to changes made to international and national laws/regulations and the change proposals made in connection with the preparation of the YVL Guide implementation decisions (SYLVI) together with others recorded in STUK's change proposal database have been considered when updating the requirements. In addition, the possibilities to reduce the so-called administrative burden have been considered.

According to Section 35(3) of Regulation STUK Y/4/2016, several thousands of years after the closure of the disposal facility when release constraints are applied in the assessment of safety, the radiation exposure shall be assessed using stylized surface environment models alongside analysis. The Guide provides more detailed requirements on the use of the stylized models.

The decision-in-principle concerning the disposal facility of spent nuclear fuel requires retrievability. Requirements requiring consideration of full retrievability in the design have not been added to the Guide. However, requirements concerning the reversibility of the disposal stage have been added to the Guide.

Requirements concerning the oversight of the safety case have been added to the Guide. Due to the extensive nature of the material in question, plan for its preparation shall be submitted to STUK for information prior to the filing of the licence application and the preparation of the periodic safety review. In addition, the Guide now includes a requirement stating that the input data of the analyses related to the safety case shall be submitted to STUK upon request for the purpose of comparative analyses conducted or commissioned by STUK.

The Guide and, in particular, the Annex A to it have also been further specified based on experience received in connection with reviewing Posiva's construction licence application.

The requirements of the Guide do not contain any possibilities for administrative burden reduction.

Requirements no longer needed have been removed from the Guide, and the requirements concerning the design, manufacture, construction, installation, inspection, testing and verification of conformity of barriers have been moved to Guide YVL D.7.

References

1. ICRP, 2013. Radiological protection in geological disposal of long-lived solid radioactive waste. ICRP Publication 122. Ann. ICRP 42(3).
2. ICRP, 2014. Protection of the Environment under Different Exposure Situations. ICRP Publication 124. Ann. ICRP 43(1).
3. Beresford, N., Brown, J., Copplestone, D., Garnier-Laplace, J., Howard, B., Larsson, CM., Oughton, D., Pröhl, G. & Zinger I. (Eds.) 2007. D-ERICA: An integrated approach to the assessment and management of environmental risks from ionising radiation – Description of purpose, methodology and application. EC Project, FI6R-CT-2004-508847.

Annex

Nuclear waste classification

Annex Nuclear waste classification

Nuclear waste is classified according to the processing method and disposal. The classification considers the safety requirements for waste processing and the requirements for isolation from the living environment due to the safety of disposal. The requirements for the engineered barriers and their durability and the depth to which the emplacement rooms shall be positioned are determined based on the classification.

The waste is classified for processing based on the activity concentration:

- Low level waste (LLW)
  - can be processed without any special radiation protection arrangements;
  - the activity concentration of the waste is usually less than 1 MBq/kg;
  - majority of the miscellaneous solid waste accumulated during the outages of nuclear power plants is classified as low level waste.
- Intermediate level waste (ILW)
  - requires effective radiation protection arrangements, such as radiation shielding and remote handling, when processed;
  - the activity concentration of the waste is usually 1 MBq/kg–10 GBq/kg;
  - for example, the ion exchange resin used in purification of a nuclear power plant's primary circuit water is classified as intermediate level waste.
- High level waste (HLW)
  - requires highly effective radiation protection arrangements when processed, and usually also cooling;
  - the activity concentration of the waste is usually more than 10 GBq/kg;
  - the spent nuclear fuel originating from Finnish nuclear power plants is classified as high level waste.

All the waste mentioned above is disposed of in the bedrock. Part of the low level waste may be classified as very low level waste (VLLW) that can be disposed of in the ground. In this case, the average activity concentration of the waste is not more than 100 kBq/kg.

Disposal means that the waste is isolated from the living environment. For the purpose of selecting the isolation time, the waste is classified into short- and long-lived waste. Short-lived waste contains nuclides the majority of which have half-lives of not more than 30 years or so. Long-lived waste contains nuclides the majority of which have longer half-lives than those contained in short-lived waste. Short-lived waste may also contain nuclides with half-lives in excess of 30 years. The amount of such nuclides is limited based on safety analysis.

	Short-lived waste[1] Shall be isolated from the living environment for a minimum time of several hundreds of years.	**Long-lived waste**[2] Shall be isolated from the living environment for a minimum time of several thousands of years.
Very low level waste[3] A < 100 kBq/kg	For example, waste accumulated during the outage and decommissioning of a nuclear facility. Disposal in the ground surface layers.	
Low level waste[4] A < 1 MBq/kg	For example, waste accumulated during the outage and decommissioning of a nuclear facility. Disposal inside bedrock at a depth of dozens of meters.	
Intermediate level waste[5] 1 MBq/kg < A < 10 GBq/kg	For example, the ion exchange resin used in purification of a nuclear power plant's primary circuit water. Disposal inside bedrock at a depth of dozens of meters.	For example, activated components of the reactor of a nuclear power plant, reactor pressure vessel. Disposal inside bedrock at a depth of dozens of meters.
High level waste[6] A > 10 GBq/kg		Spent nuclear fuel. Disposal inside bedrock at a depth of hundreds of meters.

[1] Short-lived waste shall refer to nuclear waste the calculated activity concentration of which after 500 years is below the level of 100 MBq/kg in each disposed waste package, and below an average value of 10 MBq/kg in waste in one emplacement room.
[2] Long-lived waste shall refer to nuclear waste the calculated activity concentration of which after 500 years is above 100 MBq/kg in a disposed waste package, or above an average value of 10 MBq/kg in waste placed in one emplacement room.
[3] Very low level waste shall refer to nuclear waste whose average activity concentration of significant radionuclides does not exceed the value of 100 kBq per kilogram and the total activity of which does not exceed the limits laid down in Section 6(1) of the Nuclear Energy Decree (161/1988).
[4] Low level waste shall refer to nuclear waste that, because of its low level of activity, can be processed without any special radiation protection arrangements. The activity concentration of the waste is usually not more than 1 MBq/kg.
[5] Intermediate level waste shall refer to nuclear waste that, because of its high level of activity, requires effective radiation protection arrangements when processed. The activity concentration of the waste is usually 1 MBq/kg–10 GBq/kg.
[6] High level waste shall refer to nuclear waste that, because of its high level of activity, requires highly effective radiation protection arrangements when processed, and usually also cooling. The activity concentration of the waste is usually more than 10 GBq/kg.