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RADIATION SAFETY ASPECTS IN THE DESIGN OF A NUCLEAR POWER PLANT

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Authorisation

By virtue of the below acts and regulations, the Radiation and Nuclear Safety Authority (STUK) issues detailed regulations that apply to the safe use of nuclear energy and to physical protection, emergency preparedness and safeguards:

- Section 55, paragraph 2, point 3 of the Nuclear Energy Act (990/1987)
- Section 29 of the Government Resolution (395/1991) on the Safety of Nuclear Power Plants
- Section 13 of the Government Resolution (396/1991) on the Physical Protection of Nuclear Power Plants
- Section 11 of the Government Resolution (397/1991) on the Emergency Preparedness of Nuclear Power Plants
- Section 8 of the Government Resolution (398/1991) on the Safety of a Disposal Facility for Reactor Waste
- Section 30 of the Government Resolution (478/1999) on the Safety of Disposal of Spent Nuclear Fuel.

Rules for application

The publication of a YVL guide does not, as such, alter any previous decisions made by STUK. After having heard those concerned, STUK makes a separate decision on how a new or revised YVL guide applies to operating nuclear power plants, or to those under construction, and to licensees' operational activities. The guides apply as such to new nuclear facilities.

When considering how new safety requirements presented in YVL guides apply to operating nuclear power plants, or to those under construction, STUK takes into account section 27 of the Government Resolution (395/1991), which prescribes that *for further safety enhancement, action shall be taken which can be regarded as justified considering operating experience and the results of safety research as well as the advancement of science and technology.*

If deviations are made from the requirements of the YVL guides, STUK shall be presented with some other acceptable procedure or solution by which the safety level set forth in the YVL guides is achieved.

Translation. Original text in Finnish.

1 General

In accordance with the Nuclear Energy Act (990/1987), *the use of nuclear energy must be safe; it shall not cause injury to people, or damage to the environment or property*. In the design of a nuclear power plant, one of the fundamental principles is to ensure the radiation safety of the workers and the environment. The objective is to keep the radiation doses of workers during operation as low as reasonably achievable with practical measures and not to exceed the authorised dose limits. The maximum values of individual radiation exposure have been given in the Radiation Decree (1512/1991) issued in accordance with the Radiation Act (592/1991).

The Government Resolution (395/1991) lays down general safety requirements for nuclear power plants. Chapter 3 of the Resolution contains regulations concerning radiation exposure and releases of radioactive materials. Chapter 4 gives the design requirements for nuclear safety.

Guide YVL 1.0, which defines the safety principles for the design of a nuclear power plant, specifies the Government Resolution (395/1991). Guide YVL 1.1 contains a detailed description of the licensing procedure for the construction and operation of a nuclear power plant and regulatory control by the Radiation and Nuclear Safety Authority (STUK). Guide YVL 2.2 gives the requirements for transient and accident analyses of a nuclear power plant and Guide YVL 2.8 defines the requirements for probabilistic safety analyses. Guide YVL 6.8 deals with design of the systems linked with the handling and storage of nuclear fuel. Guide YVL 7.4 presents the requirements for emergency preparedness arrangements. The limitation of exposure in the nuclear power plant environment and the limitation of radioactive releases from a nuclear power plant are discussed in Guide YVL 7.1, radiation protection of nuclear power plant workers during plant operation in Guide YVL 7.9, monitoring of occupational exposure in Guide YVL 7.10, and radiation monitoring systems in Guide YVL 7.11.

The size of the personnel's radiation doses can be affected, for instance, by design of the plant and systems and by the planning of work procedures during operation. This Guide defines the detailed structural principles linked with the radiation safety of workers to be considered in the design of a nuclear power plant. The principles presented in this Guide can also be applied in designing the structural radiation safety of other nuclear facilities, where applicable. Modifications made at a nuclear power plant during operation are discussed in Guide YVL 1.8.

2 Design bases

2.1 General requirements

Guide YVL 1.0 defines the general requirements for plant design to limit radiation exposure. Guide YVL 2.0 contains detailed requirements for the design of nuclear power plant systems and for the design organization. Sufficient expertise in radiation protection shall be available in all phases of the plant design. The design shall take account of normal operation, operational transients, potential accidents and decommissioning of the plant.

In addition to individual doses, the plant design shall consider collective doses by both work task and worker group to keep the radiation exposure low enough. In designing and constructing a nuclear power plant, calculations must be performed to verify that, in the planned and anticipated regular work tasks, the collective annual dose of the plant unit personnel does not exceed the value of 0.5 manSv per net electric power of 1 GW during normal operation of the plant, averaged over the designed operational life of the plant.

2.2 Radiation sources and shields

The locations and activity amounts of radiation sources during normal operation of a nuclear power plant shall be assessed in the design phase. Radiation sources include, for instance, the reactor and the systems related to the reactor, and radioactive waste, waste handling systems and spent fuel.

Radiation shields shall be designed with adequate safety margins. Particular attention shall be focused on the transfer and storage of spent fuel and components removed from the reactor, and on the areas where people work continuously.

Scattering of radiation (incl. skyshine radiation), migration of radioactive materials, and penetrations and openings of the shields shall be taken into account in the estimates and analyses connected with the design of radiation shields. Labyrinth structures shall be used, if necessary, to prevent direct radiation from penetrating, e.g., doors.

In a workroom, components that contain significant amounts of radioactive materials shall be shielded by installed radiation shields. If it is not possible to use installed shields, provision shall be made in the dimensioning and structures of the room for the use of temporary shields. These shall be designed to be easy to assemble and disassemble. Furthermore, it shall be possible to easily remove and reinstall any components that may hinder assembly of the shields. If necessary, it shall be possible to shield the pipes that contain radioactive liquids or corrosion products with, e.g., concrete shields. The structures of the rooms where the installation of radiation shields may be necessary shall be designed to withstand the load caused by radiation shields.

2.3 Choice of materials and precautions against corrosion

Special attention shall be drawn to the choice of materials of the components, systems and welded seams in the primary circuit that come into contact with the coolant. Using materials that have a low content of nickel, cobalt and antimony helps prevent the formation of activation products ^{58}Co, ^{60}Co and ^{124}Sb in particular. Besides corrosion resistance, the feasibility for decontamination of the components shall be taken into account in the choice of materials and structures of the components. Information on the choice of materials shall be given in the design bases for the components and structures concerned.

During normal operation and changes in operational conditions, the monitoring of the primary circuit water chemistry shall be designed and implemented with the aid of sampling and continuous analysers in such a way that enough measurement data is obtained to control corrosion and the migration of radioactive materials. The condensate purification in a boiling water reactor shall be designed to be efficient, such that the amount of activation products formed in the reactor can be kept small. In a boiling water reactor, steam drying shall also be designed in such a way that dose rates and surface contamination of the turbine plant are kept low.

In designing the primary water purification systems, one of the dimensioning bases shall be to assess the highest anticipated corrosion product concentration of the primary circuit. The purification systems shall be capable of operating efficiently in all operational states and of effectively limiting the spreading of radioactive materials released from potential fuel leakages.

2.4 Layout design

2.4.1 Rooms and access routes

Those nuclear power plant rooms where it is necessary to work regularly shall be designed in such a way that the external dose rate and the probability of radioactive materials getting inside the body are low. In the design phase, rooms shall be classified on the basis of the probable ambient dose rate, surface contamination (surface activity) and the airborne radionuclide concentration into at least three zones, which together form the controlled area. The conditions for the lowest and highest zones of the controlled area are presented in Guide YVL 7.9.

Sufficient rooms shall be reserved for the collection, measurement, sorting and storage of low- and intermediate-level radioactive waste. Guide YVL 8.3 defines the requirements for the treatment and storage of radioactive waste.

If work is done during a maintenance outage in such rooms where the dose rates are high, the storage place for tools and equipment shall be provided in such a way that the workers are consequently not exposed to excessive doses of radiation.

In designing rooms, attention shall be focused on arrangements that facilitate and speed up the work, thus also reducing radiation doses, such as the nearness and availability of compressed air, water and electricity supply, and the lighting of working areas.

In designing ventilation systems, one of the objectives shall be to provide all rooms with clean air. In general, the air shall be so clean that it is not necessary to wear respiratory protectors. The ventilation system shall be designed in such a way that the origin of any airborne radioactivity can be established by, for instance, fitting the ventilation exhaust ducts with appropriate sampling points. Guide YVL 5.6 deals with the ventilation systems and equipment of nuclear power plants. Emergency lighting shall be provided in the working areas and corridors in case of power cuts. Guide YVL 4.3 defines the requirements for fire protection to be considered in the design of room layout.

Alarm signals shall reach all workers in all situations. The design shall take account of the room-specific noise levels and any protective equipment worn in the working points.

The routes reserved for personnel and transportation of goods in the controlled area shall be designed in such a way that the workers' radiation exposure is low while using the routes. The maintenance, inspection and sampling routes shall be designed appropriately in terms of radiation protection. Radiation protection aspects shall also be taken into account in designing emergency exit routes in case of accidents.

The arrangements linked with personnel traffic shall be designed considering the large number of workers during outages. Congestion shall be avoided to enable radiation protection measures to be implemented effectively. Particular attention shall be focused on personnel locks inside the plant.

The access routes shall be dimensioned in such a way that a person wearing protective equipment against radiation can easily move at the plant. Provision shall be made for mechanical transportation of activated or contaminated objects by dimensioning the transport routes sufficiently spacious, structurally strong and clear.

2.4.2 Entry into and exit from the controlled area

Monitoring of the radioactive contamination of workers and tools shall be provided on the boundary of the controlled area.

A personnel decontamination room, including an emergency shower, and a laundry room for contaminated protective clothing shall be located in the controlled area. The personnel decontamination rooms shall be located in the controlled area before personnel monitors. Furthermore, rooms and facilities shall be reserved for first-aid treatment and decontamination of the injured.

Measuring instruments for the workers' bodies and clothing, and dosimeters used for personnel monitoring shall be located on the boundary of the controlled area in such rooms where background radiation remains low under all operational conditions and accidents at the plant. Similarly, measurement of the tools and equipment used at a nuclear power plant shall be provided in such an area where background radiation remains low.

In dimensioning equipment rooms and staff changing rooms, the large number of workers during maintenance outages shall be taken into account.

2.5 Decontamination of rooms and components

The floors and walls of those rooms into which radioactive liquids may leak shall be watertight above the height to which a rise in the liquid level, considered as the design basis, may reach.

The floor and wall surfaces shall be easy to decontaminate. The coatings shall be selected in such a way that they enable and withstand the planned decontamination measures. Component surfaces shall be treated, as far as possible, so as to reduce contamination. Coatings are dealt with in more detail in Guides YVL 4.1 and 4.2.

Sufficiently large rooms shall be provided at the plant for the decontamination, repair and maintenance of activated or contaminated components and their parts.

It shall be possible to locate all systems and equipment essentially involved in decontamination in the decontamination rooms. In addition, separate rooms shall be provided for the decontamination of highly activated and contaminated components. If necessary, it shall be possible to handle the components and objects to be decontaminated remotely or using a shield.

The components that need decontamination and their transport arrangements shall be designed in such a way that the detachment and transfer of components for decontamination does not result in significant radiation doses to workers.

It shall be possible to decontaminate the primary circuit, its different sections and the sewer system of the controlled area. It shall be possible to connect the necessary flushing and decontamination equipment to systems and piping that may contain radioactive liquids. In designing the plant, enough tank volume shall be provided for the decontamination of systems and subsystems.

2.6 Decommissioning of the plant

In designing the plant, the requirements for radiation protection during decommissioning of the plant shall be taken into account. Numerous arrangements useful for the decommissioning are equally important for radiation protection and waste management during the plant operation. These include, for instance, selection of construction materials in such a way that

- the activation is low;
- the spreading of activated corrosion products is limited;
- the surfaces can be decontaminated easily.

The radiation sources and amounts of activity during the decommissioning of a nuclear power plant shall be assessed in the design phase of the plant. Radiation sources include, for instance, activated components and structures of the reactor pressure vessel and those in its vicinity, and the contamination accumulated in the reactor cooling system.

From the point of view of major repairs and decommissioning, it is also important that the following issues, for instance, are considered in designing the plant layout:

- facilitating the removal of large components;
- facilitating the handling of activated components;
- enabling the decontamination of systems.

2.7 Accidents

In layout design and arrangements, provision shall be made for the capability of performing the necessary operations, maintenance and repairs during both design basis accidents and severe accidents and after them. Furthermore, the functions required by emergency planning shall be taken into account in the design.

In the design phase of the plant, an estimate shall be made for the amounts of activity of the radioactive materials released from the reactor or the systems during an accident and for their locations and migration paths at the plant. In designing radiation shields, the scattering of radiation and the penetrations and openings of the shields shall also be taken into account. Particular attention shall be focused on the rooms where permanent habitability is necessary or which possibly have to be visited during an accident or afterwards. These include, for instance, the main control room, emergency control posts, local control centres, sampling rooms, laboratory, emergency preparedness centre and related access routes.

Air contamination shall be prevented from spreading to areas that have to be accessible during accidents.

Radiation doses received from various control and emergency measures during an accident shall be assessed in the design phase of the plant, and they shall not exceed the normal dose limits for radiation workers. In the event of a real accident, it is permissible to exceed the dose limits in accordance with Section 8 of the Radiation Decree (1512/1991) (immediate measures to restrict radiation danger, to bring the radiation source under control and to save lives).

Furthermore, such places at the plant site where the dose rate remains low during an accident shall be reserved in the design phase. These places can be used for gathering workers and measuring their contamination.

3 Radiation safety aspects of the system design

3.1 Individual systems and components

The systems and components shall be designed and located in such a manner that the number of work stages to be performed at a high dose rate is small and their duration is short.

The systems that contain considerable amounts of radioactive materials shall be primarily located in rooms of their own. The systems that contain radioactive materials shall be located, as far as possible, in rooms in such a way that the systems and their parts and components do not unnecessarily expose workers to radiation during plant operation, inspections, maintenance and repairs.

In designing and dimensioning rooms reserved for components and systems, the necessary testing, maintenance, inspections and repairs shall be taken into account. Adjustment, measuring, control and auxiliary equipment shall be located, as far as possible, separate from a component that contains radioactive materials, either in a separate room or in a shielded area.

Components and their parts shall be chosen, as far as possible, in such a way that radioactive materials do not unintentionally accumulate in them. The accumulation of radioactive materials in individual components and systems shall be anticipated in such a way that the accumulation points can be shielded and, if necessary, decontaminated easily.

The need for maintenance of the components and their parts exposed to activation or contamination (e.g. pumps, valves, electrical and automation equipment) shall be small. The components and parts shall be easy to detach, remove and reinstall. Quickly replaceable components and parts shall be used in the systems, as far as possible.

Manholes shall be adequately large that it is possible for a worker wearing protective equipment to easily access an item to be maintained. Inside the systems fitted with manholes there shall be enough room to work whilst wearing protective equipment.

The highly radiating components and objects shall be designed to be handled remotely or using a shield.

In the systems that contain radioactive materials, it shall be easy to remove and reinstall the heat insulation placed around the components subject to maintenance and periodic inspections. The insulation dimensioned for particular locations shall be marked. Materials and structures to which contamination cannot easily penetrate or stick shall be used in the heat insulation, as far as possible.

It is advisable to video or photograph the installation and removal of components that involve significant radiation exposure, thus making work tasks to be carried out later easier to plan and implement. The components placed in closed rooms and their locations shall also be videoed or photographed, so that no time needs to be wasted in searching for the component to be handled during later work tasks. All components and systems shall be marked clearly and unambiguously.

3.2 Pipelines

The pipelines that contain radioactive liquids shall be located separate from clean piping and at a sufficient distance from components that require maintenance. Enough space shall be left between pipelines and walls for inspections as well as repairs and modifications.

The uncontrolled accumulation of particles containing radioactive materials shall be prevented by designing proper systems for fluid flow and chemistry and by using pipes whose inner surface is smooth.

The pipelines shall be designed in such a way that the number of necessary vent and drain lines is small. The drainage shall be led to a floor trap or a closed system. In designing pipelines, places where any liquid remains must be avoided.

The pipelines shall be designed in such a way that the number of welded joints to be inspected is as small as possible and that the welded joints are located in places that are easy to inspect.

The sampling lines shall be designed in such a way that it is possible to take samples of the reactor water, containment water and containment gas space in all operational conditions and during potential accidents. The sampling lines shall be bundled up into vented cubicles with drainage.

Guide YVL 3.3 deals with the control of nuclear power plant piping.

3.3 Drainage and leak collection systems

Such rooms in which there are systems that contain radioactive liquid shall be fitted with a floor trap system. The rooms shall be designed in such a way that floor chutes and the inclination of floors enable dimensioning-basis leaks to be conducted in a controlled manner to the systems intended for active liquids. The floor drainage system shall be designed in such a way that no flooding occurs on the room floors. In designing the floor trap system, variations in the room temperature and pressure shall be taken into account. In the rooms significant for safety, the floor traps shall be fitted with level switches that trigger an alarm and, if necessary, with level transmitters.

Enough tank space shall be provided in order not to burden systems intended for other purposes with temporary transfers of waters that contain radioactive materials.

It shall be possible to sort the wastewaters on the basis of their composition to facilitate further treatment. Boron-containing leak waters, for instance, shall be separated from other waters, as far as possible.

Ventilation of the tanks that contain radioactive materials shall be provided through the treatment system of radioactive gases.

3.4 Treatment of resins and concentrates

The accumulation of resins and evaporator concentrates in the piping and components of the waste treatment system and their crystallization and deposition in tanks shall be reduced by structural means.

The probability of an uncontrolled release of resins and concentrates from the tanks shall be low. In designing the waste treatment systems, however, provision shall be made for leaks. It shall be possible to detect the leaks quickly.

It shall be possible to perform the backflushing, washing and regeneration of the filters and emptying of the filter media remotely or using a shield.

3.5 Special systems for reducing releases

In accordance with Guide YVL 1.0, *systems and components containing radioactive substances shall be designed in such a way that releases of radioactive substances and the radiation exposure of the population living in the vicinity of the plant can be kept low.* The release paths of radioactive materials shall be identified, and systems that efficiently reduce releases shall be designed for collecting and decontaminating liquids and gases that contain such materials.

Releases can be reduced by the treatment of radioactive materials. Potential liquid treatment methods include, for instance, mechanical filtration, ion exchange, centrifugation, evaporation and chemical concentration. The treatment method employed shall be suitable for the type and amount of contamination present in the liquid, minimize the amount of solid waste produced and enable further treatment of the waste so as to fulfill the requirements set for final disposal.

In designing the gas treatment system, the different radionuclides shall be taken into account. Sufficient delay systems of off-gases shall be provided to reduce the releases of noble gases. The gas treatment and ventilation systems of the plant shall be fitted with effective particle filters and activated carbon filters to reduce aerosol and iodine releases.

4 Regulatory control

The preliminary and final safety analysis reports of the nuclear power plant and the inspection documentation of the systems, structures and components shall contain a description of how the requirements established in this Guide will be fulfilled or have been fulfilled in designing and constructing the nuclear power plant. Furthermore, a separate report shall be submitted on the most important radiation safety solutions by means of which the ALARA principle has been complied with at the nuclear power plant.

As part of both the preliminary and the final safety analysis report, a separate report containing an assessment of the radiation doses received by workers from plant operation shall be submitted to Radiation and Nuclear Safety Authority for approval. The assessment shall take account of the separate tasks causing radiation doses, of which a collective radiation dose of more than 0.01 manSv is anticipated to accumulate annually. The safety analysis report shall include a summary of the dose assessments and of the factors that are anticipated to cause doses. The radiation dose assessments to be attached to the safety analysis report shall also be classified by measure (radiation protection; operation, maintenance and repair measures; periodic inspections; fuel handling; and waste treatment) or by worker group. The summary shall show the average dose rate in the working point, the working time and the number of workers, and the frequency of the measure.

Assessments concerning the radiation safety of the plant decommissioning and accident situations in accordance with Chapters 2.6 and 2.7 above shall be submitted as separate reports.

As part of the handling of the application for a construction licence and an operating licence, the preliminary and final safety analysis reports and related documents are submitted to the Radiation and Nuclear Safety Authority for approval. The Radiation and Nuclear Safety Authority supervises the implementation of the plans at the plant site during construction.

5 References

1. Radiation Protection Aspects of Design for Nuclear Power Plants, Draft Safety Guide, Safety Standards Series No DS 313, IAEA, 2003.
2. Radiation Field Control Manual, EPRI-1997 revision.
3. Decommissioning of Nuclear Power Plants and Research Reactors, A Safety Guide, Safety Standards Series No WS-G-2.1, IAEA, 1999.