Radiation protection aspects in the design of NPPs

This Guide is in force as of 1 February 1997 until further notice. It replaces Guide YVL 7.18 issued on 14 May 1981.

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Authorisation

By virtue of section 55, second paragraph, point 3 of the Nuclear Energy Act (990/87) and section 29 of the Council of State Decision (395/91) on General Regulations for the Safety of Nuclear Power Plants, the Radiation and Nuclear Safety Authority (STUK) issues detailed regulations concerning the safety of nuclear power plants.

YVL guides are rules an individual licensee or any other organisation concerned shall comply with, unless STUK has been presented with some other acceptable procedure or solution by which the safety level set forth in the YVL guides is achieved. This guide does not alter STUK's decisions, which were made before the entry into force of this guide, unless stated otherwise by STUK.

Translation. Original text in Finnish.

1 General

The Nuclear Energy Act (990/1987) stipulates that the use of nuclear energy must be safe for man, the environment and property. An essential objective in the design of nuclear power plants is that the radiation dose to workers during operation is kept as low as practicable and that authorised dose limits are not exceeded. The maximum values of individual radiation exposure are prescribed in the Radiation Decree (1512/1991), issued by virtue of the Radiation Act (592/1991).

The Council of State Decision (395/1991) presents general safety requirements for nuclear power plants. Chapter 3 of the Decision gives regulations relating to radiation exposure and radioactive releases. Chapter 4 presents design requirements pertaining to nuclear safety.

The safety principles for nuclear power plant design, which specify the provisions of the Council of State Decision (395/1991), are presented in Guide YVL 1.0. Guide YVL 1.1 describes how the Radiation and Nuclear Safety Authority (STUK) regulates the design, construction and operation of nuclear power plants. The design of nuclear fuel handling and storage systems is addressed in Guide YVL 6.8. Detailed requirements for physical protection and emergency preparedness are given in Guides YVL 6.11 and YVL 7.4. The limitation of public exposure in the environment of nuclear power plants and the limitation of radioactive releases from the plants are addressed in Guide YVL 7.1.

This guide sets forth the detailed radiation safety principles to be observed in design of nuclear power plants. Modifications, which are made later at the plants, are addressed in Guide YVL 1.8. The principles set forth in this guide can be employed in the design of structures of other nuclear facilities to promote radiation safety when applicable.

2 Design bases

2.1 General

Section 2 of the Radiation Act (592/1991) sets forth general principles for the use of radiation and for other activities causing radiation exposure: the principles of justification, optimisation and individual protection. Dose limits for radiation exposure are set forth in chapter 2 of the Radiation Decree.

Sections 8 to 12 of the Council of State Decision (395/1991) present requirements applicable to any radiation exposure to workers and radioactive releases from a nuclear power plant. Sufficient radiation protection expertise must be available in all stages of plant design to ensure that these requirements are observed.

In order to keep radiation exposure low, not only individual but also collective doses shall be examined during plant design by every work area and worker group. Guide YVL 7.9 sets an annual average limit for collective radiation dose per net electrical power.

Guide YVL 1.0 presents general requirements for plant design to limit radiation exposure. In the design phase both operational conditions and accidents shall be considered.

2.2 Plant layout

2.2.1 Rooms and access routes

All nuclear power plant rooms in regular use shall be designed in such a way that the external dose rate and the internal exposure hazard are kept low. During the plant design all rooms shall be classified into at least three zones on the basis of their likely dose rate, surface contamination and airborne radionuclide concentration; the zones constitute the controlled area. The classification of rooms is addressed in Guide YVL 7.9.

The plant design and layout shall ensure that the necessary operational, maintenance and repair work can be carried out during and after accidents. In addition, emergency preparedness shall be considered in the design.

Those rooms in which the dose rate or concentration of airborne radionuclides may unexpectedly increase and which must be habitable during plant operation shall be identified. They shall be provided with installed radiation monitoring equipment, if necessary. Guide YVL 7.11 deals with radiation monitoring equipment.

The plant shall have rooms for the collection, measurement, sorting and storage of low and intermediate level radioactive waste. The rooms must be large enough to avoid temporary storage of radioactive waste or equipment in corridors or rooms designed for other purposes.

The plant shall have sufficient facilities for the decontamination, repair and maintenance of activated and contaminated equipment and their components.

Arrangements that facilitate work and thus reduce radiation dose, such as the supply of compressed air, water, electricity and lighting to working areas, shall be considered in plant design.

One objective in ventilation systems design is the distribution of clean air to all rooms. The principal rule is that air shall be so clean that no respirators are needed. The ventilation system shall be so designed that the origins of any airborne radioactivity can be identified, for example by providing the ventilation exhaust ducts with appropriate sampling points. Guide YVL 5.6 deals with the ventilation systems of nuclear power plants.

The alarm system shall be as audible to all employees as possible. The noise levels of work locations and the possible use of protective equipment shall be considered in plant design.

Routes for personnel and transportation routes for goods in the controlled area shall be so designed that the radiation exposure of workers who use these routes is in compliance with the optimisation principle. The maintenance, inspection and sampling routes shall be unobstructed and suitable for their purpose as regards radiation protection. In addition, leaving work areas shall not cause high radiation exposures even in accidents. All escape routes shall be clearly marked.

When arranging personnel traffic routes, the high number of workers during outages shall be considered. The effective implementation of radiation protection measures requires that congestion is avoided. Specific attention shall be paid to personnel locks within the facility.

The access routes shall be so dimensioned that those wearing protective clothing can easily move within the facility. Provision shall be made for the mechanical transportation of irradiated or contaminated articles by making the transport routes sufficiently spacious, durable and unobstructed.

A storage place for tools and accessories as well as sufficient space for workers for preparatory measures shall be reserved if possible outside rooms in which work is done during the maintenance period and which have a significant dose rate.

Work areas and corridors shall be fitted with emergency lighting to provide against a power blackout. Fire protection requirements to be taken into account in the room layout design are given in Guide YVL 4.3.

2.2.2 Entering and leaving the controlled area

Personnel traffic as well as the transport of radioactive substances and contamination shall be monitored on the boundary of the controlled area.

A decontamination room with emergency showers for the personnel and a laundry for contaminated protective clothing shall be placed in the controlled area before portal monitors. In addition, there shall be rooms and facilities for first aid and decontamination of workers.

Equipment for measuring the body and clothing as well as dosimeters for dose control shall be placed on the boundary of the controlled area and in rooms having a low background radiation in all plant operational states and accidents. In the same way, tools and equipment used in a nuclear power plant shall be measured in an area where the background radiation is low. Requirements for radiation monitoring equipment are set forth in Guide YVL 7.11. Monitoring of occupational exposure is dealt with in Guide YVL 7.10.

Equipment and personnel facilities shall be dimensioned taking into account the high number of workers during maintenance outages.

2.3 Radiation shields

Radiation shields shall be designed with sufficient safety margins. Specific attention shall be paid to rooms where work is done continuously or which may have to be visited during or after an accident; for example: the main control room, rooms containing equipment belonging to the emergency cooling systems, sampling rooms and the laboratory as well as related access routes. To provide against accidents, the closing of shut-off valves important to safety must be possible from outside the radiation shields.

The scattering of radiation, transport of activity as well as penetrations and openings in the shields shall be taken into consideration in design. Where necessary, labyrinth structures shall be utilised.

Components containing significant amounts of radioactive substances that are located in rooms continuously used for working shall be protected by permanent radiation shields. In case permanent shields cannot be used, the room shall be dimensioned to accommodate temporary shields. These shields shall be designed for quick installation and disassembly. In addition, any components that may obstruct the installation of the shields shall be quick to remove and re-install. It shall be possible to shield piping containing radioactive fluids or corrosion products for example by the use of concrete troughs, if necessary. The structure of rooms where radiation shields may have to be constructed shall be designed to withstand the loads caused by the shields.

In the design of the shields, special attention shall be paid to the transfer and storage of spent fuel and components removed from the reactor.

2.4 Materials and their corrosion resistance

The materials of components, systems and welded seams of the primary circuit that come into contact with the coolant shall be carefully chosen. Of activation products, especially the nuclides ^{58}Co and ^{60}Co shall be avoided by using construction materials with a low cobalt and nickel content. When choosing materials and deciding the structural solutions of components, not only resistance to corrosion but also decontaminability shall be considered. Information about the choice of materials shall be given in the design bases.

During power operation and transients, the monitoring of primary circuit water chemistry by sampling and continuous-operation analysers shall be so arranged that corrosion and activity transport are kept low by water chemistry adjustments. A BWR shall be designed an efficient condensate purification system to keep the amount of activation products formed in the reactor to a minimum.

In the design of the primary water purification system, one basis for dimensioning shall be the highest anticipated corrosion product content of the primary circuit. The purification system shall function effectively in all operational conditions and effectively limit the spreading of radioactive substances released from potential fuel leaks.

2.5 Decontamination of rooms and equipment

Floors and wall surfaces shall be easy to decontaminate. Their coatings shall facilitate and withstand decontamination.

The floors and walls of rooms into which radioactive fluids may be released shall be insulated against water. The insulation shall be extended on the walls over the height of the highest fluid level that can be regarded as a dimensioning basis. The juncture of the walls and the floor shall be rounded, if necessary. Coatings are dealt with in more detail in Guides YVL 4.1 and YVL 4.2.

It shall be possible to place in the decontamination room all systems and equipment essential for decontamination. A separate room shall be reserved for the decontamination of heavily activated and contaminated equipment. It shall be possible to handle the equipment and items to be decontaminated by remote control or shielded, if necessary.

Any equipment requiring decontamination and also their transport shall be designed so as to avoid significant radiation doses to the workers who disconnect and move them to the decontamination room.

It shall be possible to decontaminate the primary circuit, its various parts as well as the drainage system of the controlled area according to need. It shall be possible to connect the necessary flushing and decontamination equipment to systems and piping, which may contain radioactive fluids during normal operation or accidents. In the plant design phase, sufficient tank volume shall be reserved for the decontamination of systems or sub-systems.

3 Systems design

3.1 Individual systems and components

The operation, inspections and maintenance of components shall be so designed that the number of work phases while exposed to radiation is low and of a short duration.

As far as possible, systems containing radioactive substances shall be so placed that they and their components and equipment do not cause any unnecessary radiation exposure to workers during plant operation, inspections or maintenance. Systems containing significant amounts of radioactive substances shall be placed primarily in their own rooms.

In the design and dimensioning of rooms for components and systems, the necessary tests, maintenance, inspections and repairs shall be considered. As far as possible, all adjustment, measurement, control and ancillary equipment shall be placed apart from components containing radioactive substances in a separate room or shielded.

As far as possible, components and their parts shall be so chosen that the undue build-up of radioactive material is avoided. Radioactive materials build-up in individual components and systems shall be anticipated; areas with a tendency for material build-up must be easy to shield and, if necessary, decontaminate.

Where possible, surfaces shall be treated to reduce contamination.

Components and their parts that become activated or contaminated shall require little maintenance. They shall be easy to disconnect, move and reassemble. As far as possible, components and standard parts that are quick to replace shall be used in the systems.

Maintenance hatch shall be large enough to facilitate the easy access of a worker wearing protective clothing to an item to be serviced. There shall also be enough room to work in protective clothing inside systems provided with a maintenance hatch.

Work phases that would entail significant doses to workers shall be planned to be carried out either by remote control or shielded.

The heat insulation of systems that contain radioactive substances and are subject to maintenance and periodic inspections shall be easy to remove and re-install. All insulation dimensioned for a specific location shall be marked accordingly. As far as possible, the heat insulation materials and structures used shall minimise the penetration or adherence of contamination.

Attention shall be paid to component and system documentation. It is recommended that the installation and disassembly of components involving significant radiation exposure be videotaped to facilitate planning and implementation of later work. In addition, components placed in closed quarters and their location shall be videotaped or photographed to save time that would be spent searching for work items during later work assignments. All components and systems shall be explicitly and unambiguously marked.

3.2 Pipelines

Pipelines containing radioactive fluids shall not be placed near clean piping and they shall be located far enough from items that require maintenance. Sufficient space for inspections as well as repairs and modifications shall be left between the pipelines and walls.

The uncontrolled build-up of particles containing radioactive substances shall be prevented by the correct design of the fluid flow and chemistry and also by the use of piping with a smooth and even inner surface.

Pipelines shall be so designed that few venting and drainage lines are needed. Drainage shall lead to a sump or a closed system. In pipeline design, points that encourage fluid collection shall be avoided.

In pipeline design the number of welded seams requiring inspection shall be small and the welded seams shall be easily accessible.

Sampling lines shall be designed to facilitate sampling from the reactor and condensation pool water and the containment airspace in all operational conditions and accidents. The lines shall be centrally located in vented cubicles connected to a sewer system. The diameter of the sampling lines shall be large enough to prevent blockage.

The control of nuclear power plant piping is addressed in Guide YVL 3.3.

3.3 Drainage and leak collection systems

The sump system shall be extended to all rooms having systems that contain radioactive fluids. The rooms shall be so designed that the floor channels and tilts are capable of controllably draining dimensioning-basis leaks to systems intended for active fluids. The sump system shall be so designed that there will be no flooding in case of clogged sumps or insufficient suction. In the design of the sump system, changes in room temperature and pressure shall be considered. The sumps or rooms shall be provided with alarming liquid-level detectors, if necessary.

There shall be enough tank volume so that any temporary transfers of radioactive water do not burden systems intended for other purposes. Sufficient tank volume shall also ensure that any releases to water systems will remain small.

It shall be possible to separate waste water according to its consistency to facilitate further treatment. For example leak waters that contain boron shall be separated from other waters, where possible.

The airing of tanks containing radioactive materials shall be arranged as part of the radioactive gas treatment system.

3.4 Treatment of resins and concentrates

The deposition of resins and evaporation concentrates in the piping and components of the waste treatment system as well as their crystallisation and deposition in tanks shall be reduced by structural solutions.

The design of waste treatment systems shall provide against leaks. The possibility of uncontrollable leaks of resin and concentrates from the tanks shall be small. Any leaks shall be promptly detected.

It shall be possible to carry out reverse flow flushing, washing, regeneration, and change of resins by remote control or shielded.

4 Regulatory control

The Preliminary and Final Safety Analysis Reports of a nuclear power plant shall present how the requirements and recommendations of this guide will be or have been implemented in the design and construction of the plant. The descriptions can also be in the form of separate documents attached to the safety analysis reports.

STUK oversees the implementation of the plans during construction.

In connection with both the Preliminary and the Final Safety Analysis Report, reports assessing the radiation dose to workers from operation of the plant shall be submitted to STUK for approval. The analysis shall also consider any single activity that is anticipated to cause an annual collective dose in excess of 0.01 manSv. The Safety Analysis Reports shall include a summary of the dose assessments and of anticipated factors due to which doses can occur. The dose assessments attached to the Safety Analysis Reports can be divided by activity (radiation protection, operations, servicing and maintenance, periodic inspections, fuel handling and waste treatment) or worker group. The summary shall give the average dose rate of each work area, working time, number of workers and recurrence of activity. Dose estimates for other work assignments shall be presented in a similar way.

5 References

1 Design Aspects of Radiation Protection for Nuclear Power Plants, A Safety Guide, Safety Series No. 50-SG-D9, IAEA, 1985.

2 Radiation-field Control Manual prepared by H Ocken and C J Wood, EPRI – 1991 revision.