Radiation monitoring systems and equipment in nuclear power plants

continues

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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 Finnish 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 otherwise stated by STUK.

Translation. Original text in Finnish.

1 General

Installed and portable radiation measuring equipment are used in the protection of personnel in the nuclear power plant and the population in its environment from radiation. By them radiation dose rate, radiation dose and concentrations of radioactive substances within the plant and in its systems as well as radioactive releases are monitored.

The following are carried out within the plant: external radiation dose rate measurements, the surface contamination measurements of work areas, equipment, individuals and protective equipment, air activity concentration measurements as well as determination of the external dose rate and internal radiation exposure of the personnel. Radiation measurements of process streams monitor the transport of radioactive substances in liquid and gas systems inside the plant. Measurements of releases monitor radioactive liquid and gaseous effluents from the plant. The external radiation exposure of nuclear power plant personnel is monitored using both regularly read and continuous-display radiation dose meters. Internal radiation exposure is determined by counting the intake of radionuclides by the body using measuring equipment suited for the purpose.

The use of nuclear energy is prescribed in the Nuclear Energy Act (990/1987) and the Nuclear Energy Decree (161/1988) as well as in the Council of State Decision (395/1991) issued by virtue of the Act. In addition, the provisions of section 2 (General principles) and chapter 9 (Radiation work) of the Radiation Act (592/1991) apply to the use of nuclear energy.

This guide presents requirements for the design, characteristics, qualification tests, control of manufacture, pre-operational testing and operation of the installed radiation measuring systems and portable radiation measuring equipment of a nuclear power plant and describes regulatory control pertaining to these matters. In addition, requirements concerning accident situations are presented. This guide does not address reactor neutron flux measurements or radiation measurements made in the laboratory of the nuclear power plant. This guide also applies to other nuclear facilities.

Basic requirements for the measurement of releases have been given in Guide YVL 7.6.

When applicable, the technical requirements of this guide cover environmental radiation monitoring equipment for measuring the external dose rate and the activity concentration of air, which have been dealt with in Guide YVL 7.7.

In addition, when applicable, the requirements of Guide YVL 1.0 as well as those of Guides YVL 5.2 and YVL 5.5 apply to systems and equipment addressed in this guide. In addition, several international standards include detailed recommendations applicable to these equipment.

The quantities used and their measuring units are dealt with in Guide ST 1.2 and in [1–4].

2 General requirements

Section 3 of the Council of State Decision (395/1991) on general safety requirements for nuclear power plants, issued by virtue of the Nuclear Energy Act (990/1987), presents that *the general objective is to ensure nuclear power plant safety so that nuclear power plant operation does not cause radiation hazards which could endanger safety of workers or population in the vicinity or could otherwise harm the environment or property.*

Chapter 3 of the Decision states general requirements pertaining to radiation exposure and radioactive releases from a nuclear power plant. According to section 7, *radiation exposure arising from the operation of a nuclear power plant shall be kept as low as reasonably achievable. A nuclear power plant and its operation shall also be designed so that the limits presented in this decision are not exceeded.*

According to section 11 of the Radiation Decree (1512/1991), *working conditions affecting radiation exposure shall be determined and monitored at the workplace in such a way that undue radiation exposure can be detected and prevented.*

According to section 12, *methods and equipment used for monitoring radiation exposure and the relevant working conditions are subject to approval by STUK.*

According to subsection 2.1 of Guide YVL 1.0, *to ensure radiation monitoring, there shall be a sufficient number of fixed and portable radiation measurement devices at the plant for determining the external dose rate and what radioactive substances there are in the air, systems or on surfaces. There shall also be appropriate laboratory facilities and equipment for sample analysis and equipment for individual dose monitoring.*

Furthermore, alarming measurement devices shall be used for radiation monitoring in such a way that, during the nuclear power plant's operational conditions, nobody is exposed to radiation without knowing it and in a degree harmful to health.

According to subsection 2.1, *when designing radiation monitoring, provision shall also be made for accidents. It shall be possible to take at least the following measures during accidents:*

- *measurement of dose rate inside the containment*
- *determination of the concentration of radioactive substances in gas phase inside the containment*
- *determination of the concentration of radioactive substances in the coolant.*

According to subsection 3.6 of Guide YVL 1.0, *for the purpose of accident monitoring and management, appropriate measuring and monitoring instrumentation shall be designed for the plant by which the operating personnel obtains sufficient data for event assessment and for the planning and implementation of countermeasures.*

[— —]

The measurement systems designed for accident monitoring and management shall maintain operability even in the event of a single failure.

According to subsection 2.2, *it must be possible to monitor the releases of radioactive substances along planned pathways also in the event of a single failure during operational conditions and accidents.*

According to subsection 3.6, *the control equipment shall be designed to record process parameters indicating plant state and also system control signals so that the plant's operational events can be analysed afterwards.*

3 Monitoring equipment

3.1 Installed equipment for measuring external radiation

The controlled area shall be provided with installed equipment for measuring external radiation, particularly those inaccessible areas of the controlled area where changes in the plant operating state, or other events, may cause an essential increase in the local dose rate.

In LWRs, measuring instruments shall be placed within the plant at least as follows:

- the reactor containment
- the reactor hall
- spent fuel stores as well as the fuel handling machine
- radioactive waste treatment and storage facilities
- decontamination facilities.

3.2 Systems for measuring air activity concentration

The activity concentration of air shall be determined for such accessible rooms of the controlled area where gaseous radioactive substances can occur in amounts that can affect the occupational radiation dose. Determination can be based on continuously measuring devices or the analysis of separately collected samples in the plant laboratory.

It shall be possible to continuously measure the activity concentration of air within the containment of a PWR.

It shall be possible, even during severe accidents, to assess the radionuclide concentrations within the containment gas plenum, based on sampling or some other method.

The requirements pertaining to systems for measuring radioactive releases are set forth in Guide YVL 7.6.

3.3 Other installed radiation measuring equipment

Nuclear power plant systems shall be fitted with installed radiation measuring equipment for monitoring the activity of fluids and gases, if necessary. These measurement data are necessary for the detection and monitoring of possible fuel failures and radioactive releases. Corresponding measurements can also be used to control the operating condition of filters and tanks.

Installed radiation measuring equipment shall be used at least for monitoring the activity concentration of the primary coolant of PWRs and of the main steam of PWRs and BWRs. Radioactive gas treatment systems and the primary coolant purification systems of PWRs shall be fitted with measuring equipment. Radiation measuring instruments shall also be placed in such steam and water circuits that may become significantly contaminated in case leaks occur in circuits containing radioactive substances.

In an accident situation, it shall be possible to determine the activity concentration of water that is inside the containment. Sampling equipment shall be available for this purpose even during severe accidents.

3.4 Portable radiation measuring equipment

The nuclear power plant's installed measuring equipment shall be complemented with portable measuring equipment.

A sufficient number of portable equipment for measuring the gamma radiation dose rate during the nuclear power plant's various operating conditions shall be available. Some equipment shall be provided with a telescopic arm for making measurements by remote control. For the making of measurements during accidents, a sufficient number of equipment shall be available having a measuring range upper level of at least 10 Gy/h.

Portable measuring equipment shall be available for situations during which neutron radiation can occur (spent fuel transfers, for example).

A sufficient number of portable equipment for measuring the activity concentration of air shall be available for use in working areas where installed equipment do not yield representative results.

A sufficient number of portable measuring and sampling equipment (primarily for beta, but also for alpha radiation) shall be available for use during the various operating conditions of the nuclear power plant.

At least one measuring location shall be available for the analysis of samples of surface contamination.

3.5 Personnel monitoring equipment

All exit routes of the controlled area shall be provided with a sufficient number of measuring equipment to ensure that the protective clothing and skin of those exiting the area are free from radioactive substances.

The facility shall have equipment for measuring internal contamination to ensure that any radioactive material taken into the body in the nuclear power plant's controlled area is detected and the dose arising from it can be assessed.

The facility shall have a dosimetry system for registering the individual radiation doses of those working in the controlled area. The system consists of personal dose meters as well as dose reading devices.

In addition to the individual dosimetry system, the plant shall also have a real-time work dosimetry system consisting of instruments for measuring external radiation dose, which are equipped with a display and an alarm, reading devices placed near the entrance of the controlled area and equipment to process and display the data stored in the system. There shall be a sufficient number of work dosimeters to cover all individuals working in the controlled area.

4 Features of the equipment

4.1 Applicable standards

The licence-holder shall present and specify the norms and standards to be complied with in the design of systems and equipment, and how they have been applied. The most important requirements for radiation measuring equipment, which have been set forth in this chapter, are based on recommendations given in various standards [5–10, 13–20].

4.2 Measuring range and response

According to Guide YVL 1.0, *the measurement systems shall be capable of measuring accurately enough over the entire range within which the measured parameters vary during operational conditions or accidents.*

Measuring devices shall be capable of indicating, with a good margin, measurement results greater than the highest value of an assessed measured variable. If it is necessary to use two or more measuring channels to cover the measuring range of the object, the measuring ranges of the channels must sufficiently overlap.

The response of external gamma radiation measuring devices shall satisfy the requirements of standards [5, 6] both with calibration radiation (gamma radiation emitted by the nuclide ^{137}Cs) and as a function of the energy of radiation, at least when the energy emitted by radiation is between 80keV…1.5 MeV.

If the primary source of radiation is ^{16}N, the response to the gamma radiation emitted by ^{16}N must be known. If radiation other than gamma radiation (beta radiation, neutrons) can occur in the point of measurement, their response and effect on measurement shall be established and considered, and also the need for a separate measurement, if any, shall be established.

The response of devices intended for the measurement of activity concentration and surface contamination using anticipated nuclide compositions shall be known [7–10].

4.3 Environmental qualification

Measuring systems must maintain their operability under design basis operational conditions. When their operation is evaluated, at least the following shall be considered

- temperature
- pressure
- humidity
- mechanical vibrations
- effect of radiation
- changes of operating voltage.

The environmental qualification of radiation measuring equipment shall be demonstrated by tests. Requirements for qualification tests are given in Guide YVL 5.5 as well as in standards pertaining to radiation measuring devices.

4.4 Measuring equipment for accident situations

The measuring equipment for containment external dose rate, which are intended to function during severe accidents, shall be capable of displaying the dose rate that follows when a significant part of the radioactive substances inventory is released to the containment. The measuring range shall cover dose rates of at least up to 10^6 Gy/h.

The measuring range of the containment sampling devices shall cover concentrations of iodines and aerosols up to at least 10^{15} Bq/m^3.

Reasoning for the location of sampling places shall be given.

The range of the measuring system for gaseous effluents shall be such that the system will be available even during severe accidents. Release measurements shall not be prevented by external radiation.

4.5 Other requirements

Installed radiation measuring equipment must usually have local alarms to indicate their malfunctioning and if the set value of the measured variable is exceeded. Alarms must be transmitted to the main control room or to a corresponding control station to promptly detect any exceeded set limits or unavailability of the measuring devices. The implementation of alarm limits and other equipment adjustments shall be designed in such a way that erroneous changes are prevented and when an alarm has been actuated it does not end without operational action.

The design of measuring instruments shall consider overloading according to applicable standards.

The display of a measuring equipment must follow the actual measuring values of the measured object quickly enough, so that safety will not be jeopardised by any delay times.

The design of equipment for measuring radioactive substances must promote their easy and infrequent decontamination.

The design and location of the equipment shall allow for the necessary calibration, testing and maintenance.

If the signal of a measuring device is employed to actuate protection systems, the whole radiation monitoring system shall meet the functional requirements set for the protection system.

The requirements of Guide YVL 5.5 apply to the programmable components of radiation monitoring systems and equipment.

The radiation measurement data yielded by installed measuring equipment must be displayed in the plant control room, grouped according to their purpose of use. The data shall be registered and kept for a period of time specified in the plant procedures and in a manner suitable for their later purpose of use.

Power supply to the nuclear power plant's installed radiation measuring systems shall be assured.

Measurements of air activity concentration shall be conducted in a way that makes the sampling representative irrespective of possible large local differences in concentrations. In addition, measuring devices shall be placed or sampling carried out in such a way that no significant air contamination goes unnoticed. The location of possible sources of contamination as well as the ventilation systems shall be considered [11].

Portable surface contamination meters for general radiation protection measurements shall be capable of measuring both alpha and beta radiation. In their calibration, a radiation source shall be used that well represents the contamination occurring within the plant. The measuring device shall be capable of detecting at least the maximum amounts of radioactive substances referred to in Guide ST 1.5 against normal background radiation. The measuring ranges shall exceed at least by a factor of ten those contamination limit values set in Guide YVL 7.9 for the highest class of the controlled area.

It shall be possible to ensure by measuring devices that radioactive contamination of the protective clothing and skin of individuals exiting the controlled area do not exceed the maximum amounts set forth in Guide ST 1.5.

With an internal contamination measuring device, it shall be possible to observe any such ^{60}Co activity in the lungs as is 1% of the ALI value [12], and such ^{131}I activity in the thyroid gland as is 1% of the ALI.

Dosimetry systems shall be capable of measuring depth dose H_p (10) and surface dose H_p (0.07). They shall also fulfil, when applicable, the requirements of [13] within the energy area of photon radiation, which is 80 keV…3 MeV. The transfer of dose data into the dose registers of the nuclear power plant and the Finnish Radiation and Nuclear Safety Authority shall be reliably implemented. The data used in dose calculation shall be recorded. Other requirements for dose measurements are given in Guide YVL 7.10.

The energy response and measuring accuracy of the dose measuring devices of the real-time work dosimetry system shall, when applicable, fulfil the requirements for measuring equipment for external gamma radiation.

5 Commissioning of systems and components

5.1 General requirements

The characteristics of radiation monitoring systems and equipment for nuclear power plants shall be demonstrated by qualification tests, tests in connection with manufacturing as well as pre-operational testing at the plant site.

5.2 Installed measuring systems for external radiation

In connection with pre-operational testing, measuring channels shall be calibrated for every decade of the scale, normally at least up to the dose rate value of 10^{-2} Sv/h. Systems for measuring containment external radiation shall be calibrated for their full measuring range in a laboratory approved by STUK.

It shall be checked during pre-operational testing that alarm limits, visible and audible alarms as well as failure alarms function properly. In addition, an installation inspection shall be conducted during which couplings, switches and actuators are checked and tested.

5.3 Other installed radiation monitoring systems

Every measuring channel shall be calibrated in connection with pre-operational testing, using a suitable radiation source. The purpose of calibration is to establish the response of a measuring instrument with a known radionuclide concentration under normal operating conditions. A detector's activity response shall be established using actual measuring geometries where possible. If a radioactive calibration source or measuring geometry deviate from the measuring instrument's operating situation, the analogy between the calibration measurement results and those for operation shall be assessed and recorded.

Alarm limits shall be tested in at least two points of the measuring range (in the areas of highest and lowest decades). The functioning of visible and audible alarms as well as failure alarms shall be checked. The effect of background radiation shall be measured using a suitable radiation source. Installations, couplings, switches as well as the tightness of flow channels and joints shall be checked.

5.4 Portable measuring equipment for external radiation

Prior to their commissioning, all equipment for gamma radiation measurements shall be calibrated for every decade of the scale, at least up to the dose rate value of 10^{-2} Sv/h. Possible alarm limits and alarms shall be checked.

Prior to their commissioning, gamma radiation measuring equipment for high dose rates shall be calibrated for their full operating range in a laboratory approved by STUK.

The linearity of measuring equipment for neutron radiation in relation to detector signal shall be checked prior to the commissioning of the equipment. In addition, possible alarm limits and alarms shall be checked. Equipment representing each type used shall be sent to a laboratory approved by STUK for calibration.

5.5 Measuring equipment for surface contamination

The functioning of devices for measuring surface contamination shall be checked at each decade of their measuring range using three appropriate surface sources of beta radiation. The activity emitted by two of these shall be equivalent to the beta radiation limit values set for the highest and lowest surface contamination levels in the controlled area, as presented in subsection 4.2 of Guide YVL 7.9. The functioning of alarm limits shall be checked.

In addition, the measuring and alarm functions of dosimetry equipment shall be correspondingly checked in their measuring range.

The couplings and switches of installed equipment shall be checked and their actuators tested.

6 Operation, periodic tests and maintenance

Operating instructions shall be prepared for radiation monitoring systems and equipment. They shall cover those normal operating states and accidents during which the systems and equipment must remain operable. The instructions shall be updated in a way defined in more detail in the licence-holder's quality system. The instructions shall be sent to STUK for information.

The condition of radiation monitoring systems and equipment shall be regularly followed during plant operation. Preventive maintenance, condition surveillance and periodic testing programmes pertaining to the radiation monitoring systems and equipment shall be drawn up for this purpose. The Technical Specifications of the nuclear power plant must include requirements concerning the operability and regular periodic testing of radiation monitoring systems and equipment important to safety.

The preventive maintenance programme shall include maintenance procedures for radiation monitoring systems and equipment to ensure their reliable operation according to design. Condition surveillance ensures that the overall operability of the equipment is maintained and that conditions in the measuring points for example are maintained in accordance with design. Documents relating to preventive maintenance and condition surveillance shall be available at the plant site for review by STUK. Preventive maintenance and condition surveillance programmes shall be sent to STUK for information.

The periodic testing programme shall present the system and equipment specific functional tests carried out at regular intervals to verify that the systems and equipment function according to design. The programme shall state the testing frequencies or plant operating states (or their changes) that require tests. The acceptance criteria for testing procedures and tests shall be specified in instructions. Test documentation shall be kept at the plant site for review by STUK. The periodic testing programme shall be sent to STUK for information.

The dosimetry system annual inspection shall be conducted according to a plan approved by STUK.

Radiation monitoring systems and equipment shall be repaired according to procedures stated in the licence-holder's quality system. The preventive maintenance, condition surveillance, periodic testing and fault repair documentation shall be regularly assessed to identify any type faults and weaknesses of the equipment. Advances in radiation monitoring technology shall be followed and justified modifications made possible by technical advances shall be implemented, if necessary.

7 Regulatory control

7.1 Preliminary inspection of systems and equipment

When applicable, the Finnish Radiation and Nuclear Safety Authority conducts the pre- inspection of radiation monitoring systems and equipment according to Guide YVL 5.5.

The descriptions of radiation monitoring systems and equipment are reviewed as part of the nuclear power plant's safety analysis report.

Pre-inspection documentation for all radiation monitoring equipment referred to in this guide shall be sent to STUK. Pre-inspection ensures that the equipment are suitable for their intended use and satisfy the requirements of this guide. A pre-inspection shall be requested for systems and system entities that are deemed suitable in other respects.

7.2 Control of manufacturing, installation and pre-operational testing

STUK shall be reserved the opportunity of controlling the qualification tests of systems and equipment and quality control during manufacturing. The qualification test programmes, test results and result documentation for quality control during manufacturing shall be sent to STUK for information.

In addition, STUK controls the installation of radiation monitoring systems as deemed necessary.

STUK controls the pre-operational testing of radiation monitoring systems and equipment by reviewing the pre-operational testing programmes, witnessing tests at the plant in an extent deemed necessary and reviewing the pre-operational test result reports.

STUK conducts the commissioning inspection of all radiation monitoring systems whose preliminary inspection documentation it has approved. The objects of the commissioning inspection are stated in Guide YVL 5.5.

7.3 Control during operation

STUK controls radiation monitoring systems and equipment by inspecting their repairs and modifications as well as reviewing the licence-holder's operations, which aim to ensure the reliable operation of these equipment and systems. The licence-holder's operations are assessed by making inspections according to the periodic inspection programme as well as other inspections, if necessary.

STUK controls any additions and modifications to the radiation monitoring systems and equipment in the same extent as it controls the original construction project.

8 References

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