Standards for Radiation Protection Instrumentation
Design of safety standards and testing procedures

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Abstract. This paper desribes by means of examples the role of safety standards for radiation protection and the testing and qualification procedures. The development and qualification of radiation protection instrumentation is a significant part of the work of TÜV NORD SysTec, an independent expert organisation in Germany. The German Nuclear Safety Standards Commission (KTA) establishes regulations in the field of nuclear safety.
The examples presented may be of importance for governments and nuclear safety authorities, for nuclear operators and for manufacturers worldwide. They demonstrate the advantage of standards in the design of radiation protection instrumentation for new power plants, in the upgrade of existing instrumentation to nuclear safety standards or in the application of safety standards to newly developed equipment. Furthermore, they show how authorities may proceed when safety standards for radiation protection instrumentation are not yet established or require actualization.

KEYWORDS: Radiation Protection Instrumentation; Safety Standards; Type Tests; Authorities; TÜV NORD; KTA

1. Introduction

In nuclear power reactors, nuclear research reactors and other nuclear or radioactive applications it is essential to use adequate radiation protection instrumentation which is suited to the applications and to the corresponding operation conditions. The particular requirements are usually prescribed in the regulations given by the authorities. The testing, qualification and approval of the radiation protection instrumentation forms a significant part of the licensing process.

In this paper we describe the role of the radiation protection instrumentation, particularly those components which are fixed in nuclear installations, and we present examples of the safety standards prescribing particular requirements in Germany and abroad (US and Finland). Further we describe the procedure how the type approval and qualification are performed.

2. Radiation Protection Instrumentation

Radiation protection instrumentation, although the basic principles are well known since decades of years, has many specific applications in modern installations e.g. from medical institutes to nuclear power plants. Still today it consists of a suited radiation detector and an electric or electronic system to generate signals which can be used for display and registration as well as for the generation of binary signals. Nowadays digital systems are more and more introduced so that software is also part of the radiation protection instrumentation.

Radiation protection instrumentation is needed for the protection of the personnel by measurement of the personal dose, the dose rate and the contamination at certain areas. Further, the control of the exposition of the public and the environment by measurement of the emissions and radioactivity in the

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vicinity of a nuclear installation is an essential task. For nuclear power plants, also the control of the radioactivity inside the systems and rooms of any nuclear control area is important as well as the measurement and documentation functions in the case of a postulated accident. In order to fulfil all these tasks, stationary and mobile radiation protection instrumentation is used. In this paper we mainly deal with the stationary radiation protection instrumentation designed for monitoring and surveillance tasks. Usually a higher quality level is assigned to the stationary instrumentation than to the mobile equipment.

Taking into account the different applications of radiation protection instrumentation it is obvious that the requirements that have to be met by the components vary strongly. Personal dose surveillance needs a small but precise and stable system which operates at normal room conditions while a dose rate measurement under severe accident conditions of a power reactor must withstand high moisture, temperature and of course dose rate without any loss of correct and required signals.

3. Safety Standards for Radiation Protection Instrumentation

3.1 National safety standards in Germany: KTA

The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met to provide against damage arising from the construction and operation of a nuclear power plant. This is part of and defined in the German law (Atomic Energy Act, Sect. 7) which includes that these requirements have to be in accordance with the state of science and technology in order to fulfill the protective goals specified in the Atomic Energy Act, the “Safety Criteria for Nuclear Power Plants”, and in the Radiation Protection Ordinance (StrlSchV). Technical details are not included in these regulations, but it is required that the radiation protection instrumentation is appropriate to accomplish the task in question (Radiation Protection Ordinance, Sect. 67). In Germany, among others the KTA safety standards specify the detailed safety-related requirements for the respective tasks.

The Nuclear Safety Standards Commission KTA consists of 50 members in five groups of ten members each. These groups are:

- Licensing and supervisory authorities
- Independent expert organisations for safety assessment (like TÜV NORD SysTec)
- Manufacturers
- Members of Utilities
- Miscellaneous (like unions)

Thereby, TÜV NORD SysTec participates in the development and application of guidelines and safety standards in Germany and has specific knowledge about the international requirements for the qualification of radiation protection instrumentation.

The protection of persons inside and outside the facility from ionizing radiation as well as the monitoring of the specified normal functions of the equipment

- for the retention of solid, liquid and gaseous radioactive substances within the provided enclosure,
- for the handling and controlled conduction of radioactive substances within the facility
- for the monitoring of the release of radioactivity

is achieved by stationary and by mobile radiation protection instrumentation. These tasks comprise monitoring the dose rate within nuclear power plants (KTA 1501), monitoring of the radioactivity in the inner atmosphere of nuclear power plants (KTA 1502), surveilling the release of gaseous and particulate radioactivity during normal operation and during design basis accidents (KTA 1503), and monitoring and assessing the discharge of radioactivity in water (KTA 1504).

The stationary system for monitoring local dose rate, according to the safety standard KTA 1501, serves to monitoring in the controlled access areas during specified normal operation and to warn when thresholds are exceeded. During and after design basis accidents the system shall give information regarding the accessibility of the monitored areas.

The radiation protection instrumentation which measures the concentration of radioactivity in the inner atmosphere of the facility automatically shall give signals when alarm thresholds are exceeded to initiate the required measures. It is further suited to identify compartments where increased concentration of radioactivity can lead to an increased discharge with the exhaust air of the nuclear power plant. Additionally, such instrumentation can indicate leaking systems or components if increased concentration of airborne radioactivity is detected. These objectives are defined in the safety standard KTA 1502.

In the German Radiation Protection Ordinance (StrlSchV, Sect. 47 and 48) it is required that any uncontrolled discharge shall be prevented and that the released radioactivity is as low as possible, the release surveilled and that the discharge is specified and reported to the proper authority. The safety standard KTA 1503 therefore requires that radiation protection instrumentation is installed and operated to achieve a basis for evaluating radiological effects and to generate automatically initiated alarm signals when threshold values are exceeded.

Monitoring and assessing the discharge of radioactivity in liquid effluents according to the safety standard KTA 1504 has the objective of determining the radiological effects and automatically initiating alarm signals when threshold values are exceeded.

The standards of the German Nuclear Safety Standards Commission KTA include the detailed properties of the radiation protection instrumentation. For illustration, a specific example is given in Table 1.

Table 1: Characteristic parameters of the noble gas measuring equipment specified in Sect. 4.2.1 of the KTA safety standard KTA 1502.

Characteristic Parameters	Values for the characteristic parameters for		
	stationary measuring equipment PWR and BWR	stationary measuring equipment of compartment group 1 PWR	mobile measuring or sampling equipment PWR and BWR
Detection limit of noble gas concentration	1 x 10^4 Bq/m^3	5 x 10^4 Bq/m^3	1 x 10^5 Bq/m^3
Reference nuclide to be used	Xenon 133		
Upper limit of measuring range	5 x 10^8 Bq/m^3	5 x 10^9 Bq/m^3	5 x 10^8 Bq/m^3

In the case of incidents or accidents it is required that the radiation protection instrumentation displays and records information on the condition of the facility before, during and after a design basis accident or in the case of events which can lead to an increased release of radioactivity. It is specified that the radiation protection instrumentation

- delivers sufficient data on the condition of the power plant in order to enable the required protective measures with respect to the personnel and the plant

- gives indications on the sequence of events during the incident and will enable the documentation
- allows an estimation of the effects on the environment

The KTA safety standard 3502 specifies the requirements for the accident instrumentation which includes the measurement of the activity concentration for noble gases in the exhaust air, the measurement of the absorbed dose rate and meteorological data like the wind direction and velocity.

Concerning the radiation protection of the personnel, the KTA has further released the safety standard "Radiation Protection Considerations for Plant Personnel in the Design and Operation of Nuclear Power Plants" (KTA 1301) which includes the surveillance of personnel and working areas by radiation protection equipment.

3.2 National safety standards from other countries

The Nuclear Regulatory Commission (NRC) is the US authority for the licensing and supervision of civil nuclear installations. The NRC regulations 1.21 ("measuring, evaluating, and reporting radioactivity in solid wastes and releases of radioactive materials in liquid and gaseous effluents from light-water-cooled nuclear power plants") state that information on the identity and quantity of radionuclides in liquid and gaseous effluents and solid wastes from light-water-cooled nuclear power plants, together with meteorological data representative of principle release points, are needed

- for evaluation by the licensee and the Regulatory staff of the environmental impact of radioactive materials in effluents and solid wastes, including estimates of the potential annual doses to the public,
- to ascertain whether the regulatory requirements and limiting conditions of operation have been met and whether concentrations of radioactive materials in liquid and gaseous effluents haven been kept as low as practicable,
- for evaluation by the licensee and the Regulatory staff of the adequacy and performance of the containment, waste treatment methods and effluent controls.

The NRC guide points out that it is essential to have a degree of uniformity in the methods used for measuring, evaluating, recording, and reporting data on radioactive material in effluents and solid wastes. Further, the NRC guide describes gross monitoring programs which include noble gases, iodine isotopes, particulates and tritium, specific monitoring of liquid effluents and solid wastes.

The specific NRC guide 1.97 ("Criteria for Accident Monitoring Instrumentation") requires operating reactor licensees to provide means for monitoring the reactor containment atmosphere, spaces containing components to recirculate LOCA fluids, effluent discharge paths, and the plant environs for radioactivity that may be released as a result of postulated accidents.

Detailed technical requirements for the radiation protection instrumentation are given by the Institute of Electrical & Electronics Engineers (IEEE).

In many countries, the NRC and IEEE regulations are adapted or are part of the national standards for instrumentation. On behalf of technical specifications and procedures, the guides of the International Electrotechnical Commission (IEC) are also considered. In the safety standards design basis accidents and severe accidents are considered and those components of the radiation protection instrumentation which are used for these scenarios have to meet highest technological specifications.

A project in Europe to be mentioned here is the European Pressurized Reactor (EPR) which is under construction at the site Olkiluoto in Finland and for which the radiation protection instrumentation is being designed actually. In Finland, the Radiation and Nuclear Safety authority STUK has published the national guide YVL which applies to the safety of nuclear power plants. Concerning the radiation protection instrumentation, VYL requires that to ensure radiation monitoring, there shall be a sufficient number of stationary 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. Furthermore, alarming measurement devices shall be used for radiation monitoring in such a way, during the operational conditions of the nuclear power plant, nobody is exposed to radiation without knowing it and in a degree harmful to health.

According to the respective safety guide YVL 7.11 the permanently installed (stationary) and portable radiation monitoring systems and equipment are used to ensure the radiation safety of a nuclear power plant and its environment. Their purpose is to measure the radiation dose rates and radiation exposures within the plant as well as to monitor the concentrations of radioactive materials in the systems and the radioactive releases. The measurements conducted at a nuclear power plant include dose rate measurements of external radiation, surface contamination measurements, air activity concentration measurements and workers' dosimetry and determination of internal radioactivity (whole body counting). The purpose of radiation measurements of the systems is to monitor the transport of radioactive materials in the liquid and gas process systems inside the plant. The measurements of radioactive effluents are aimed to monitor liquid and gaseous release of radioactive materials from the plant.

Releases of radioactive materials from a nuclear power plant and their concentrations in the environment shall be effectively monitored. The plant shall be provided with systems which monitor all planned release pathways of radioactive substances. These systems shall be designed to measure and record data about the amount of radioactive substances to be released to the environment during operational conditions and accidents. Release limits shall be defined for the various release pathways and also the necessary measures to restrict the releases if these limits are exceeded.

In the finnish safety standards YVL it is further required that 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. The guide YVL points out that when designing radiation monitoring, provision shall 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 of the containment
- determination of the concentration of radioactive substances in the coolant.

Thus, for the purpose of accident monitoring and management, the radiation protection instrumentation shall provide sufficient data for event assessment and for the planning and implementation of countermeasures.

4. Testing and Qualification Procedure

Type tests with the aim of a qualification have to verify that the radiation protection instrumentation components meet all the requirements of the regulations in question. The qualification demonstrates and documents the ability of equipment to perform safety function(s) under applicable service conditions including design basis accidents, reducing the risk of common-cause equipment failure (according to IEEE-323). Therefore, the components and systems shall be designed, manufactured, installed and operated in a way that their quality level and the inspections and tests required to verify their quality level are adequate. Sometimes, the systems are therefore classified into safety classes. The safety class 1E from the NRC safety standards is often taken as a basis for the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment. Those components of the radiation protection instrumentation which are needed in design basis accidents and in severe accidents are often assigned to this safety class. Other safety classes apply for the otherwise used radiation protection instrumentation.

In Germany, the test procedures follow the requirements of the safety guide KTA 1505 (Verification of Suitability of Radiation Measuring Equipment) or the KTA 3500 series for higher safety classes in the case of the reactor safety systems. Qualifications in accordance with IEC guide 60780 are acknowledged.

Within the frame of the nuclear licensing and supervision procedure, it shall be certified that the radiation protection equipment is suited for the measurement objective. In order to confirm this, the quality, design and manufacturing processes are inspected and test procedures are performed.

In many cases, the authorities for the licensing and supervision of nuclear installation rely on type tests and qualifications performed by independent experts rather than on the test procedures of the manufacturer himself. This is pointed out either for the KTA safety standards used in Germany and the YVL guides in Finland:

In the German safety standards, plant-independent test organizations in the field of radiation and radioactivity surveillance are competent persons who are (in accordance with the legal requirements, standards, guidelines, provisions and instructions) required to be consulted during the tests. They shall not be involved in the manufacturing and marketing of the radiation protection instrumentation to be tested and they shall not represent interests of the manufacturer. The certification of suitability for radiation protection instrumentation is achieved if it is documented that the equipment fulfils the measurement objective at the respective location with ambient conditions and for the particular operating conditions and if this is confirmed by an authorized expert.

Similarly, the finnish guide YVL 5.5 ("Instrumentation Systems and Components at Nuclear Facilities") presents the requirements for licensees concerning the design, implementation and operation of the instrumentation and control system and equipment at a nuclear facility and how the authority STUK controls and inspects these. The design of the instrumentation comprises explicit steps like general requirements, requirement specification and documentation, followed by a qualification plan. The qualification plan includes the design and manufacturing process and tests. Further, all equipment in Safety class 2 and essential accident instrumentation in Safety Class 3 (NRC Regulatory guide 1.97) shall possess a type acceptance certificate according to an applicable nuclear engineering standard awarded by an accredited body or a body performing inspections with corresponding competence. The certificate shall cover the assessment of the equipment design and the quality management of its manufacturing. The equipment conformity to the requirements shall be demonstrated by tests and analyses and by practical type tests. In all cases, qualification plans and test plans are established.

Figure 1: Ionisation chamber KG 50 SEC manufactured by MGP Instruments H&B (Mirion Technologies), tested and approved up to dose rates of 1E5 Gy/h

An example of a radiation detector (ionisation chamber) which was tested by TÜV NORD SysTec is given in Fig.1. This ionisation chamber is designed for the monitoring of the dose rate during and after design basis accident and severe accident conditions. For the qualification in high dose rates up to the order of 1E5 Gy/h the exposure was performed by accelerator irradiation. The detector was approved and certified by TÜV NORD SysTec along a complete qualification plan according to the IEEE standards and the standards for class 1E equipment, according to NRC safety guide 1.97.

The testing, qualification and approval of radiation protection instrumentation and software in nuclear power reactors, in research reactors and in other nuclear installations forms a significant part of the work of TÜV NORD SysTec in Hamburg, Germany. TÜV NORD SysTec is acknowledged as an independent and authorized expert organization and is accredited for testing electronic equipment and software qualification.

Examples for the practical tests are:

- investigation of the operation under normal conditions
- behaviour at different temperatures
- electromagnetic compatibility tests
- radiological tests
- mechanical tests
- seismic tests
- simulation of accident or post-accident conditions
- chemical tests (e.g. boron spraying)
- radiation stability (total integrated dose assessment)
- aging tests

Required tests are performed in our laboratory in Hamburg, Germany, but for testing under extreme conditions (high pressure, additional spraying with boron solutions, high radiation or seismic shocks) the testing procedures may be performed close to the manufacturer or need to be performed in external institutes or laboratories which offer the respective possibilities to expose the components to the extreme conditions. Additionally, the manufacturing process has to be examined and the complete documentation which is prepared by the manufacturer is part of the qualification process. Modern systems also rely on software which is investigated and qualified in the accredited TÜV NORD SEELAB and TÜV NORD SEECERT testing centre.

5. Conclusion

As it has been pointed out by examples, the tasks of radiation protection instrumentation in nuclear power plants and other nuclear installation are defined in safety standards which may vary between different countries but essentially comprise the same features. These examples may be of importance for governments and authorities, for nuclear operators, and for manufacturers of instrumentation worldwide.

They demonstrate the advantage of experienced standard procedures in the setup of radiation protection instrumentation for new reactors, in the upgrade of existing instrumentation to new nuclear safety standards or in the application of existing standards to newly developed instrumentation. Authorities may rely on the given examples of existing safety standards when their national safety standards for radiation protection instrumentation are not yet established or require actualization.

Furthermore it was pointed out that the qualification of the radiation protection instrumentation, depending on tasks and/or safety classes, is a defined procedure and is usefully performed and certified by independent experts.