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American National Standard Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents

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Foreword

The Joint Subcommittee of American National Standards Committees N13 and N42, which was responsible for the development of this standard, was established by authority of the Chairmen of American National Standards Committees N13 and N42 to represent the interests of the respective parent committees. The Joint Subcommittee comprises 50 percent manufacturer and 50 percent user membership; thus this standard includes the additional feature of incorporating the experience of both the manufacturer and the user.

The American National Standards Committee on Radiation Protection, N13, which, together with the American National Standards Committee on Instrumentation, N42, reviewed and approved this standard, had the following membership at the time of approval:

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American National Standard Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents

1. Introduction

The release of radioactivity from nuclear facilities to the environment generally is monitored by installed instrumentation. The objective of such instrumentation is to measure the quantity or rate, or both, of release of radionuclides in the effluent streams and to provide documentation useful for scientific and legal purposes. This standard applies to continuous monitors that measure normal releases, detect inadvertent releases, show general trends, and annunciate radiation levels that have exceeded predetermined values.

2. Scope

This standard provides recommendations for the selection of instrumentation specific to the continuous monitoring and quantification of radioactivity in effluents released to the environment. The effluent streams considered may contain radioactive gases, liquids, particulates, or dissolved solids singly or in combination. This standard specifies detection capabilities, physical and operating limits, reliability, and calibration requirements and sets forth minimum performance requirements for effluent monitoring instrumentation. Unless otherwise specified, the criteria herein refer to the total system. This standard applies only to monitoring during routine operation that includes abnormal releases. Emergency situations, where additional performance capability will be required, are a matter of separate consideration.

Also outside the scope of this standard are sample extraction and laboratory analyses, normally used for intercomparison between monitor calibrations and laboratory analyses, and other applications for continuous monitoring instrumentation such as environmental monitoring or process control. Sampling techniques are covered in ANSI N13.1-1969, Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities.

3. Definitions

These definitions are restricted to the purpose of this standard.

accuracy. The degree of agreement with the true value of the quantity being measured.

NOTE: Accuracy is subject to the influence of unknown systematic errors.

authorities. Any governmental agencies or recognized scientific bodies which by their charter define regulations or standards dealing with radiation protection.

calibrate. Adjustment of the system and the determination of system accuracy using one or more sources traceable to the NBS (National Bureau of Standards).

check. The use of a source to determine if the detector and all electronic components of the system are operating correctly.

detector. Any device for converting radiation flux to a signal suitable for observation and measurement.

effluent. The liquid or gaseous waste streams released to the environment.

extracameral effect. Apparent response of an

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instrument caused by radiation on any other portion of the system than the detector.

in line. A system where the detector assembly is adjacent to or immersed in the total effluent stream.

off line. A system where an aliquot is withdrawn from the effluent stream and conveyed to the detector assembly.

on site. Location within a facility that is controlled with respect to access by the general public.

plate out. A thermal, electrical, chemical, or mechanical action that results in a loss of material by deposition on surfaces between sampling point and detector.

precision. The degree of agreement of repeated measurements of the same property, expressed in terms of dispersion of test results about the mean result obtained by repetitive testing of a homogenous sample under specified conditions. The precision of a method is expressed quantitatively as the standard deviation computed from the results of a series of controlled determinations.

primary calibration. The determination of the electronic system accuracy when the detector is exposed in a known geometry to radiation from sources of known energies and activity levels traceable to the NBS.

quality assurance. All those planned and systematic actions necessary to provide adequate confidence that a system or component will perform satisfactorily in service.

response time. The time interval from a step change in the input concentration at the instrument inlet to a reading of 90 percent (nominally equivalent to 2.2 time constants) of the ultimate recorded output.

secondary calibration. The determination of the response of a system with an applicable source whose effect on the system was established at the time of a primary calibration.

sensitivity. The minimum amount of contaminant that can repeatedly be detected by an instrument.

system. The entire assembled equipment excluding only the sample collecting pipe.

4. Factors Influencing Selection of Instrumentation

4.1 Effluent Stream Factors.

4.1.1 ***Radiological Characteristics of the Effluent Stream.*** The radiological characteristics of an effluent stream influence system capability requirements. The concentration of each radionuclide present with its particular half-life and type (alpha, beta, and photon) and the energy of radiation emitted must be considered in the selection of detectors. Alpha and beta radiation may be particularly subject to energy absorption in the detector housing of the effluent materials, thus influencing the sensitivity of the system. Alpha and low-energy beta radiation will not be measured at all if there is any appreciable thickness of material between the effluent and the detector. If a detector housing or the wall of the effluent line separate the effluent from the detector, the absorption of photons and charged particle equilibrium must be considered. In addition, a delay between sampling and measurement may significantly affect the detection capability of the system for radionuclides with short half-lives.

4.1.2 ***Physical Characteristics of the Effluent.*** Physical characteristics of a gaseous or liquid effluent that may influence system capability include temperature, pressure, humidity, size and number of suspended particles, and flow rate. Since the sensitivity of detection may be related to one or more of these physical characteristics, they must be considered so that the sample characteristics are accurately related to those of the effluent stream.

The size and distribution of suspended particles in the effluent will affect the choice and location of the sampling device and detector. It should be recognized that the density or accumulation of collected particles might cause self-absorption losses and that the detector could become contaminated.

Effluent flow rate may also govern the type of sampling device, particularly for an off-line monitoring system. Since most monitoring systems directly measure the concentration of radioactivity in an effluent stream, the stream flow rates must be determined accurately to derive the total released activity. And since

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most monitoring systems measure only a portion of the radioactivity in the effluent stream, a representative sample must be assured.

4.1.3 ***Chemical Characteristics of the Effluent.*** The major chemical characteristics that may influence system capability include sample plate out, corrosiveness, and combustibility. Plate out can result in differences in the concentrations of radionuclides in the sample and in the effluent. The corrosiveness of the sample can damage the system components such as the detector, sampler, filter medium, piping and pump. Damage of any of these could result in a nonrepresentative sample and eventual system failure. If an effluent contains combustible or highly reactive materials, care must be taken to prevent conditions that could permit explosion or combustion.

4.2 Environmental Factors.

4.2.1 ***Temperature.*** Both the detector and the electronic portions of an effluent monitoring system may be influenced by temperature variations. The effects may vary from minor calibration shifts to severe degradation of performance and, in some instances, permanent damage. When selecting monitoring instrumentation, therefore, it is particularly important to consider the manufacturer's specifications in light of the anticipated ambient thermal operating extremes. Additionally, other heat loads, such as those from nearby instruments or from direct sunlight, must be taken into account.

4.2.2 ***Mechanical.*** Mechanical effects such as shock, vibration, pressure, and noise may adversely affect the system operation. Instrument locations should be chosen to minimize these effects. When other technical or practical considerations dictate location in an area where the instrument may be subjected to such forces, appropriate measures such as shock mounting or sound baffling should be considered.

4.2.3 ***Chemical.*** While effluent monitors are rarely located in atmospheres containing corrosive or highly reactive chemicals, it should be recognized that small amounts of certain chemicals (for example, H_2SO_4, HNO_3, HF) can lead to deterioration and failure of electronic components. Where such chemicals are expected to be present, precautionary measures such as potting, hermetically sealing components, or providing appropriately rated enclosures should be employed.

4.2.4 ***Ambient Ionizing Radiation.*** The ambient level of external penetrating radiation, even if below that of personnel protection concern, may cause an unacceptable response in an effluent monitoring system. While the detector is usually the most sensitive element, certain circuits or components may also be affected. Such effects are minimized by shielding, anticoincidence, or other compensating techniques, or some combination of these. High-intensity short-duration radiation fields (for example, criticality spikes) may cause an adverse effect on system response and should be considered.

4.2.5 ***Humidity.*** Instruments may have to be located in areas with high relative humidities. This can result in measurement error, and in some cases hygroscopic detectors or components can be damaged.

4.2.6 ***Other.*** Such effects as power variations, high current contact closures, power transients, and, in some cases, magnetic and radio frequency fields may damage equipment or cause spurious readings and alarms and should be considered in system installation, particularly in system cable routing. Also, the effects of atmospheric dust should be considered.

4.3 Standards, Regulation, and Public Responsibility. The careful selection of an effluent monitoring system will assist in the quantitative evaluation of compliance with applicable federal, state, and local regulations. If applicable regulations require the monitoring of radioactivity in effluent streams below the measurement capability of monitoring instruments within the scope of this standard, sensitivity can be enhanced by recourse to sample extraction and laboratory analysis.

4.4 Calibration. Ease and relevance of calibration, as well as instrument stability, are important factors affecting the selection of the system. The primary initial calibration should encompass the entire system, including the detector and sample collector and should be performable after the system has

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been installed. Secondary calibration and periodic maintenance of the partial system should be possible without using primary calibration techniques.

5. Effluent Monitoring Systems

5.1 General Considerations. Effluent monitors are conveniently classified according to the location of the detector with respect to the effluent stream. When the detector is immersed in or otherwise directly monitors the effluent stream, the system is categorized as *in line.* A system in which a portion of the primary effluent stream is diverted through a bypass loop, or similar mechanism for monitoring by the detector, is categorized as *off line.*

In-line systems are those where the detector looks directly at the effluent stream and requires no external fluid mover or sampling line. Plate out, detector contamination, and nonuniform mixing can create errors and therefore should be considered. In-line systems are primarily useful for determining the gross activity of the effluent stream. The lack of concentrating mechanisms, geometry, and background shielding considerations of in-line systems are such that high sensitivity is difficult to achieve. Direct calibration of in-line systems is also difficult.

Off-line systems, although more complex and subject to problems associated with representativeness of sample, provide a higher degree of sensitivity by concentrating or separating various components (for example, particulates, radioiodines). Additionally, off-line detectors may be used with less shielding and optimum geometry. Those off-line systems that collect and concentrate the sample may also provide a sample convenient for subsequent laboratory analysis. Calibration of the detector-readout system is relatively simple, but the sample collector and mover also need calibration.

Fixed and moving filter monitors are two types of off-line systems. The fixed filter system, which is mechanically simple, removes particulate activity (or occasionally other constituents) from the effluent by drawing an aliquot through a filter medium. The detector(s) continuously and directly monitor(s) the buildup of radioactivity on this filter as collection takes place. In the moving filter system, a tape or strip filter is commonly used. The filter may be advanced either stepwise or in continuous mode through the sample chamber. The detector may directly monitor the filter as collection takes place, or it may be located away from the collection point to monitor the filter after it has advanced to the detector location. Moving filter systems require a rather complex filter advancement mechanism, but they are less subject to filter loading. They may be subject to leakage, mechanical failure, and tape breakage. Electrostatic or thermal precipitation may also be used to deposit concentrates of airborne radioactive particulates in defined geometries before a detector.

Another important consideration is the buildup of background level due to plate out or settling of radioactive material in sight of the detector. This commonly occurs in flow-through systems, in line and off line, as most of the liquid monitoring systems are. Since the background level determines the maximum sensitivity of the system, the ease of cleaning and other maintenance of the detector assembly are important.

5.2 Selection Criteria. When choosing an effluent monitoring system, consideration should be given to the sensitivity, energy response, response time, dynamic range, and accuracy of the system for the radionuclide(s) of interest. The environmental factors discussed in Section 4.2 should also be considered.

The presentation and storage of data are an important aspect of the total system capability and deserve special consideration. Other factors such as remote or local readout, digital versus analog readout, compatibility with other systems, and alarm modes should also be considered.

5.3 Specification of Performance. The specification of performance and the method and units of characterizing performance include a specific method, procedure, form, or other means of determining or observing a given operational characteristic. The intent of this section is to provide guidance to the manufacturer to achieve uniformity in the reporting of instrument capabilities.

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5.3.1 ***Detection Capabilities.***

5.3.1.1 *Type of Radiation.* The type(s) of ionizing radiation(s), (for example, alpha, beta, and photon) that the instrument is capable of measuring shall be clearly stated along with an appropriate energy range for each specific type (see Section 5.3.1.2).

5.3.1.2 *Energy.* The range of energies for each specific type of ionizing radiation measured shall be given in units of megaelectronvolts. The change in response as a function of energy shall be stated or presented graphically. For alpha and beta detectors, the minimum particle energy detected as well as the thickness of the detector wall window in milligrams per square centimeter shall be given.

5.3.1.3 *Range.* The dynamic detection range of the system shall be expressed as a concentration in units of microcuries per milliliter or curies per cubic meter, as appropriate, referenced to a specific nuclide. Saturation or other irregular responses at concentrations above the stated upper detection limits shall be indicated.

5.3.1.4 *Sensitivity.* Maximum sensitivity or minimum detectable level shall be stated in terms of the smallest concentration of a specific nuclide measurable at a given confidence level in a stated time period at a given flow rate, where applicable, under specified background radiation conditions.

5.3.1.5 *Accuracy.* The accuracy of the reading over its stated range shall be given as percent of reading for logarithmic or digital readouts or percent of full scale of the scale being read for linear readouts.

5.3.1.6 *Precision.* The precision of the instrument shall be given as percent deviation up and down scale from the mean reading at the 95 percent (2 sigma) confidence level for a mid-scale or mid-decade reading.

5.3.1.7 *Response Time.* The electronic time constant of the system shall be stated. For off-line systems, the time required for the sample to travel from the instrument inlet port to the detector at a specified flow rate shall be stated. For moving filter particulate monitors, a curve of activity buildup versus time should be stated. The buildup coordinate should be expressed in percentages from 0 to 100 percent for the system response to nuclides in equilibrium deposited on the filter paper.

5.3.1.8 *Radiation Alarm.* The abnormal and high level radiation alarm capabilities shall be described, including time to alarm, latching capability, the form output mode (that is relays or driver transistor), the range of alarm set points, and reproducability of alarm points. When two alarms are provided, the interaction between alarms, if any, shall be specified.

5.3.2 ***Physical and Electrical Operating Limits.***

5.3.2.1 *Temperature.* The operating temperature range in degrees Celsius shall be stated along with temperature dependence. Temperature dependence shall be expressed as a percent change in readout per degree Celsius over a range of 0 to 60 °C or as a total percent change over that range. If the range exceeds the design operating temperature range it shall be stated. The time to reach thermal equilibrium shall also be stated.

5.3.2.2 *Pressure.* If the system operation is affected by ambient pressure variations, the magnitude of that effect shall be stated over a range of 500 to 800 torrs. If the system or certain components of the system are specifically designed for pressurized operation (for example, a detector for insertion in a pressurized pipe), the design pressure and safety factor shall be stated.

5.3.2.3 *Relative Humidity.* Effects from humidity shall be expressed in percent relative humidity. The capability of a system to resist moisture and corrosive atmospheres should be stated. A statement of storage and handling requirements should be included.

5.3.2.4 *Electrical Effects.*

5.3.2.4.1 *Switching Transients.* The duration of switching transients shall be stated in terms of the length of time in seconds required for the instrument to indicate the final value within its stated accuracy on the most sensitive scale or decade.

5.3.2.4.2 *Power Variations.* The effect on instrument accuracy of line voltage and frequency variations shall be stated over a range of ± 15 percent from the design values.

5.3.2.4.3 *Power Transients.* The length of time in seconds for the instrument to indicate the final value within its stated accuracy on the most sensitive scale after a total power interruption of 1 second shall be stated.

Additionally, any effects on alarms shall be noted.

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5.3.2.4.4 *Magnetic Fields.* The effect on instrument accuracy due to an external magnetic field shall be stated.

5.3.2.5 *Mechanical Effects.* The minimum vibration level (of loading) or acceleration that perturbs readings or damages components shall be specified over a frequency range of 1 to 30 Hz.

5.3.2.6 *Power Requirements.* The operating power requirements shall be stated. For ac-powered instruments this statement shall include the operating voltage range, frequency, waveform, number of phases, and power and current requirements.

5.3.2.7 *Background Radiation.* The response of the instrument to ambient beta, photon, and neutron fluxes should be stated. Instrument response should be referenced to or normalized to 0.8 MeV ($^{90}Sr^{90}Y$ average energy) for beta fluxes, 1.2 MeV (^{60}Co) for photon fluxes, and 5 MeV (AmBe) for neutron fluxes. The response to natural airborne radioactivity (that is, radon in equilibrium with daughters) up to a concentration of 5×10^{-9} μCi/ml should be stated. Alternatively, the response of the instrument to background may be referenced to isotopes comparable to its intended use. The minimum level of detectability for the instrument should be specified with consideration given to interferences from ambient sources; for example, the detection limit might be stated as X μCi/ml in an ambient photon field of P mR/h with a photon energy of 1.2MeV, and Y μCi/ml in an ambient photon field of O mR/h with a photon energy of 1.2 MeV.

5.3.3 *System Reliability.*

5.3.3.1 *Attainment of Reliability.* The methods of attaining system reliability should be stated. These may include the choice of components, power duration factors, and parallel or redundant circuitry.

5.3.3.2 *Expendable Components.* The rated lifetime of expendable components (for example, brushes, batteries, and recorder paper) shall be stated, along with a statement of the method for determining the need for replacement, where applicable.

5.3.3.3 *Radiation Damage.* Radiation degradation or failure of the system due to external radiation fields should be stated.

5.3.3.4 *Extracameral Effects.* Extracameral effects and the intensity at which these occur should be stated.

5.3.3.5 *Malfunction Alarm.* The method(s) of communicating mechanical or electrical malfunctions, together with an evaluation of possible failure modes that would not be annunciated, should be described.

5.3.3.6 *System Warranty.* The warranty term shall be clearly defined.

5.3.3.7 *Quality Assurance.* The quality control procedures used in the manufacture of effluent monitoring systems shall be available.

5.3.4 ***Calibration.*** The exact conditions of calibration shall be specified, including the calibration point(s), range, and traceability to the NBS. The calibration shall encompass the entire system.

5.4 Standards of Performance. The intent of this section is to provide minimum standards of performance for user instrumentation. This does not preclude different or more stringent standards to meet specific requirements.

5.4.1 ***Detection Capability.*** The quantity or concentration of a radionuclide or mixture of radionuclides in an effluent stream is most commonly determined by quantification of the corpuscular radiation associated with radioactive decay. In some cases, specific photon radiations, bremsstrahlung, or daughter product radiations may be used for this purpose. Occasionally, nonradiological procedures may be used. While this standard is primarily concerned with quantification by radiological methods, the use of other methods such as wet chemistry, chromatography, and mass spectrometry is not precluded, providing these methods meet the standards of performance cited below.

5.4.1.1 *Detection in Gaseous Streams.* Instruments designed to continuously monitor radioactivity in gaseous effluent streams shall have a minimum level of detectability for the nuclide(s) in question as given in Table 1, under the column labeled "Gaseous." If radionuclides are monitored collectively with no differentiation of individual species, the smallest applicable level of detectability should be chosen from the column labeled "Gaseous," Table 1, based on nuclides known to be present. Where greater sensitivity is required, sample collection together with laboratory analysis shall be considered.

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Nuclide (in order of increasing A)	Effluent Stream	
	Gaseous (μCi/ml)	Liquid (μCi/ml)
^{3}H	5×10^{-6}	—
^{14}C	5×10^{-7}	—
^{24}Na	5×10^{-11}	5×10^{-7}
^{32}P	2×10^{-11}	—
^{41}A	2×10^{-7}	4×10^{-7}
^{51}Cr	8×10^{-10}	3×10^{-6}
^{54}Mn	4×10^{-7}	1×10^{-6}
^{56}Mn	2×10^{-10}	1×10^{-6}
^{58}Co	2×10^{-11}	9×10^{-7}
^{59}Fe	2×10^{-11}	5×10^{-7}
^{60}Co	8×10^{-11}	3×10^{-7}
^{64}Cu	4×10^{-10}	2×10^{-6}
^{65}Zn	2×10^{-11}	1×10^{-6}
^{84}Br	2×10^{-11}	3×10^{-7}
^{85}Kr	3×10^{-7}	8×10^{-5}
^{85m}Kr	2×10^{-7}	3×10^{-7}
^{87}Kr	2×10^{-7}	2×10^{-7}
^{88}Kr	2×10^{-7}	2×10^{-7}
^{88}Rb	2×10^{-11}	1×10^{-6}
^{89}Rb	2×10^{-11}	2×10^{-7}
^{89}Sr	3×10^{-12}	—
^{90}Sr	4×10^{-12}	—
^{90}Y	3×10^{-11}	2×10^{-3}
^{91}Sr	9×10^{-11}	3×10^{-7}
^{91}Y	2×10^{-11}	1×10^{-4}
^{92}Sr	4×10^{-11}	4×10^{-7}
^{92}Y	2×10^{-11}	2×10^{-6}
^{95}Zr	6×10^{-11}	4×10^{-7}
^{95}Nb	8×10^{-10}	4×10^{-7}
^{99}Mo	7×10^{-11}	1×10^{-6}
^{103}Ru	8×10^{-10}	8×10^{-7}
^{105}Ru	2×10^{-10}	1×10^{-6}
^{129}Te	1×10^{-10}	8×10^{-6}
^{129m}Te	9×10^{-11}	7×10^{-6}
^{129}I	8×10^{-10}	2×10^{-4}
^{131}I	4×10^{-12}	3×10^{-7}
^{132}Te	2×10^{-11}	3×10^{-7}
^{132}I	3×10^{-12}	1×10^{-7}
^{133}I	3×10^{-12}	3×10^{-7}
^{133}Xe	5×10^{-7}	6×10^{-6}
^{133m}Xe	4×10^{-7}	2×10^{-6}
^{134}Te	4×10^{-7}	4×10^{-7}
^{134}I	2×10^{-11}	1×10^{-7}
^{134}Cs	4×10^{-12}	2×10^{-7}
^{135}I	3×10^{-11}	3×10^{-7}
^{135}Xe	5×10^{-6}	3×10^{-7}
^{135m}Xe	3×10^{-7}	4×10^{-7}
^{136}Cs	6×10^{-12}	1×10^{-7}
^{137}Cs	5×10^{-12}	4×10^{-7}
^{138}Xe	2×10^{-7}	1×10^{-7}
^{138}Cs	2×10^{-11}	2×10^{-7}
^{140}Ba	3×10^{-12}	6×10^{-7}
^{140}La	3×10^{-11}	2×10^{-7}
^{144}Ce	8×10^{-12}	3×10^{-6}
^{144}Pm	2×10^{-12}	2×10^{-5}
^{147}Pm	2×10^{-11}	4×10^{-7}
^{210}Po	2×10^{-12}	—
^{220}Rn	1×10^{-8}	—
^{222}Rn	1×10^{-8}	—
^{226}Ra	2×10^{-12}	—
^{232}Th	2×10^{-12}	—
^{233}U	2×10^{-12}	—
^{234}U	2×10^{-12}	—
^{235}U	2×10^{-12}	—
^{238}U	2×10^{-12}	—
^{238}Pu	2×10^{-12}	—
^{239}Pu	2×10^{-12}	—

NOTES: (1) The numerical values in Table 1 refer to the sensitivities for detection of an effluent stream consisting solely of the nuclide as stated and under conditions specified in accordance with Section 5.3.2.7. The numerical values apply at the detector locations. In the event that mixtures of nuclides are present, the sensitivity will vary greatly from nuclide to nuclide. The detection limits for the mixture would be dependent on the relative sensitivities and the detection limits for a given pure nuclide may not be obtainable.

(2) This table assumes continuous monitoring with the levels cited measurable at the 95 percent confidence level within a 4 hour period. It represents what is reasonably obtainable consistent with state-of-the-art measurement.

(3) These values represent current minimum standards. Improved sensitivities are always encouraged and should be used when improved state-of-the-art and commercial availability are realized.

Table 1
Minimum Levels of Detectability for Radionuclides in Effluent Streams

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5.4.1.2 *Detection in Liquid Streams.* Instruments designed to continuously monitor radioactivity in liquid effluent streams shall have a minimum level of detectability for the nuclide(s) in question as given in Table 1, under the column labeled "Liquids." If radionuclides are monitored collectively with no differentiation of individual species, the smallest applicable level of detectability shall be chosen from the column labeled "Liquid," Table 1, based on the nuclides known to be present.

5.4.2 ***Range.*** The dynamic range of the instrument shall be at least 10^4 minimum detectable levels and should be stated in units of microcuries per milliliter relative to a given isotope. The range of the instrument should overlap with the range of emergency instrumentation.

5.4.3 ***Sensitivity.*** The sensitivity of an effluent monitoring system should also be stated in terms of a signal count rate associated with a specific nuclide detectable at the 95 percent confidence level in the presence of a specified background count rate for the convenience of the user. The following formula can be used to calculate the signal count rate at a 95 percent confidence level for a given count rate using the system efficiency and a typical background:

$$n_s = 2\sqrt{n_b/2RC}$$

where

n_s = signal count rate in counts per minute

n_b = background count rate in counts per minute

$2RC$ = two times the instrument time constant in the range or decade associated with the background count rate in units of minutes

and the number 2 is the constant associated with the 95 percent confidence level.

5.4.4 ***Accuracy.*** The instrument error shall not exceed ± 20 percent of reading over the upper 80 percent of its dynamic range where the error is defined as:

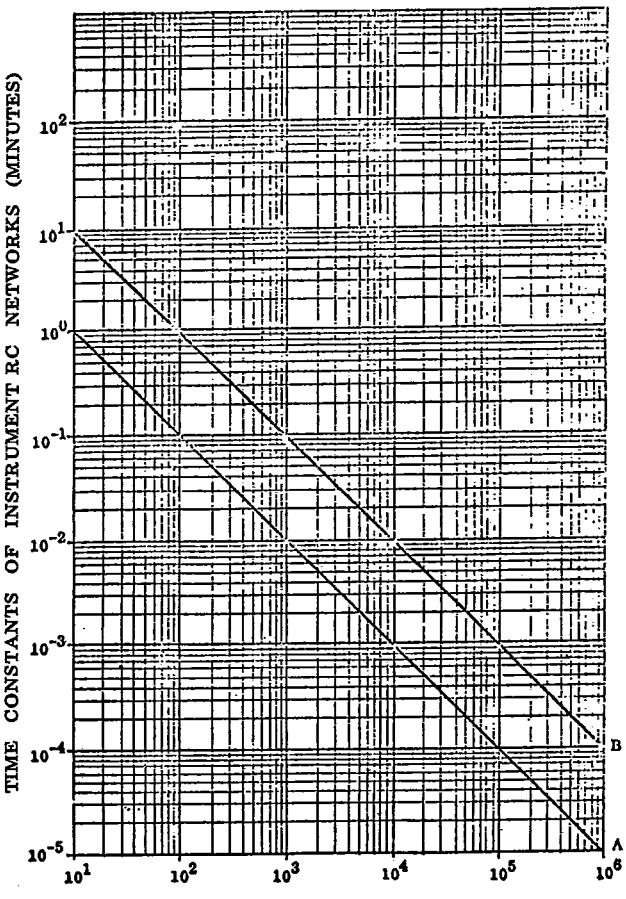
$$\text{percent error} = \frac{R_t - R_r}{R_t} \times 100 \text{ percent}$$

where

R_r = indicated quantity

R_t = true quantity

For this determination, the indicated quantity R_r shall be taken from the most accurate readout format, for example, recorder output or analog-to-digital converter. It is recognized that the usual instrument panel meters may significantly contribute to the error (particularly in logarithmic devices), but these are rarely used as the primary quantitative readout. Typical time constants for given count rates are illustrated in Fig 1.



(Curve *A* depicts a 1 min time constant at a count rate of 10 counts per minute; curve *B* depicts a 10 min time constant at 10 counts per minute.)

Fig 1
Instrument Time Constants at Specific Count Rates for a Five-Decade Logarithmic Count Rate Meter

5.4.5 ***Precision.*** The reproducibility of a system for any given measurement over its stated range should be within ± 10 percent at the 95 percent confidence level for a mid-scale or mid-decade reading.

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5.4.6 ***Response Time.*** The response time of the electronic system shall not be less than that required to maintain background readings within the required accuracy.

5.4.7 ***Physical, Mechanical, and Electrical Requirements.***

5.4.7.1 *Temperature.* Regardless of the temperature of the effluent stream, the instrument system should be capable of operating with less than 5 percent change in calibration or response over a temperature range of 0 to 60°C. Where greater temperature extremes are expected or greater accuracy is required, protection from the environment shall be provided.

5.4.7.2 *Pressure.* The instrument system should be capable of continuous operation under ambient pressures from 500 to 800 torrs as a minimum with no change in calibration or response. When the system is to be placed in a reactor containment vessel, it shall be capable of continuous operation under ambient pressures from 500 to 2500 torrs.

5.4.7.3 *Humidity.* The instrument shall be capable of continuous operation in relative humidities of 10 to 95 percent within the accuracy required.

5.4.7.4 *Other Environmental Effects.* Instrument systems and their component parts shall be resistant to corrosive atmospheres when they are used in such atmospheres.

5.4.7.5 *Power Requirements.* Voltage and frequency variations of ± 15 percent within the design values shall result in reading variations of no greater than ± 5 percent at the minimum detectable level.

5.4.7.6 *Electrical Effects.* Radio frequency and microwave signals of ≦ 10 $\mu W/cm^2$ shall result in reading variations of no greater than ± 5 percent at the minimum detectable level.

5.4.7.7 *Mechanical Effects.* Accelerations of ≦ 1 *g* in each of three mutually orthogonal axes over the frequency range 1 to 33 Hz shall result in reading variations of no greater than ± 5 percent at the minimum detectable level.

5.4.8 ***Radiation Alarm.*** The instrument system shall be equipped with an alarm capable of being externally set to annunciate at any point over the stated range. The alarm should be both audible and visible and should be capable of adjustment and reset without removing the instrument from service.

5.4.9 ***Failure Alarm.*** The instrument shall be equipped with an alarm device that provides appropriate notification at any time the system is incapable of monitoring radiation. A latching contact shall be provided to indicate loss of signal detector operating voltage or circuit power.

5.4.10 ***Calibration.*** A thorough primary calibration of the entire system shall be performed at least once using a radionuclide (liquid, solid, or gaseous) of known concentration. The radionuclide shall permit calibrating the range of energy and rate capabilities intended for the system. Traceability to the NBS shall be maintained. The calibration shall be related to a secondary source or method which will be used for periodic in-plant recalibration. The source-to-detector geometry shall be maintained identical to that established during the primary calibration. The surface dimensions of the secondary source shall be the same as the detector window.

Systems where the concentration of radionuclides changes significantly between the sample point and the detector, as in off-line particulate monitoring, shall be tested by using radioactive material or a known tracer such as dioctyl phthalate (DOP) to determine the loss in the sample lines.

Flow-rate-measuring devices associated with the system shall be calibrated to determine actual flow rate at the conditions of temperature and pressure under which the system will be operated. These flow-rate devices shall be periodically recalibrated.

A check source that is actuated remotely should be installed for integrity checks of the detector and the associated electrical system. A calibrated electrical signal should be provided to verify the circuit alignment.

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