Assessment Plan for Radiation Monitoring System (RMS) Instrumentation and Maintenance

Background

Radiation monitoring equipment must be designed, installed, and calibrated to various regulatory expectations, standards, and requirements.

Licensees are required to monitor effluents for two primary purposes: to demonstrate compliance with routine regulatory effluent limits and to evaluate off-normal/accident effluents. Effluents may be liquid or gaseous and may exhibit a range of six or more orders of magnitude of necessary monitoring, particularly for gaseous effluents.

Area radiation monitors have regulatory requirements and licensing commitments like those specified in US Code of Federal Regulations 10 CFR Part 20 and US Nuclear Regulatory Commission (NRC) Regulatory Guide 1.97. Area monitoring instrumentation may be placed in normally occupied areas or in the case of accident monitoring instrumentation, in locations important to accident assessment or habitability during accident mitigation efforts.

Purpose

This tool is meant to guide a system vulnerability assessment. It is not intended for a full radiological release program assessment. The Offsite Dose Calculation Manual (ODCM) is used here only to the extent of assessing if the instrumentation is meeting the needs of that program. Equipment Reliability assessments should use CHEM 2024-009, Radiation Monitoring System Health Metrics to guide the evaluation process.

This document provides a detailed overview of the elements that should be included in an assessment plan that would be used to perform assessments of a site's Radiation Monitoring System (RMS) and the associated maintenance and surveillance requirements. The assessment is intended to review the installation, maintenance, calibration, and operating conditions and bases of the installed plant RMS equipment and associated maintenance practices. The results of the assessment will verify and / or provide feedback and possible improvement recommendations to ensure that the radiation monitoring equipment and programmatic support meet regulatory requirements and industry practices.

Assessment Scope

The assessment will review the suitability of:

- Equipment
- Installation
- Initial calibration
- Energy response
- Magnitude response
- Limiting condition calculations (normal and emergency procedures)
- Setpoints
- Operational parameters such as lower and upper limit of detection ranges
- Periodic maintenance (including calibrations or response checks)

Sites may have multiple liquid and gaseous release points, each with effluent monitoring and sampling. The assessment will review each monitor / sampling system. Monitor systems may include multiple channels, and in some cases separate, independent redundant channels. Each channel / redundant device is assessed.

Several methods for effluent evaluations are described in US NRC Regulatory Guide 1.21.

Discussion

Liquid Effluent Monitors and Other Liquid Monitoring Systems:

Liquid effluent (outfall) monitors should provide continuous monitoring for planned and unplanned releases and should also provide for routine sampling of the effluent stream. They should be designed and installed to observe the expected isotopes and have sufficient detection limits above background to provide annunciation of 'out of spec' releases. Liquid release control monitors may also be used for control and monitoring of plant operations, for example radwaste system batch release monitors.

Gaseous Effluent Monitors and Other Gaseous Monitoring Systems:

Gaseous effluent monitors provide continuous monitoring for normal continuous, planned, unplanned, non-routine, abnormal, and accident releases. They should be designed and installed to observe the expected isotopes and, depending on the monitor / channel, have sufficient detection limits above background to detect normal effluent up to beyond design basis accident releases.

Low range gaseous effluent monitors are primarily intended to meet design requirements consistent with fulfilling the requirements of the ODCM. Systems should provide for continuous or grab sampling of the effluent stream, sampling for particulates and iodine,

and should be designed to ensure the sample collected is representative of the effluent stream.

Higher range channels (mid/high-range) are intended primarily for evaluation of off-normal releases, up to releases that might occur from beyond design basis accidents. These channels should be calibrated to the expected isotopes and be capable of detecting the upper magnitude of releases possible in a severe accident.

Area Radiation Monitoring Systems:

Although not intended as 'effluent monitors' other monitoring systems such as area monitors may be used for emergency gaseous effluent assessment or for defining / determining emergency operating limits. These may include high range containment area post-LOCA radiation monitors, area direct radiation monitors in specific plant regions, and PWR main steam line radiation monitors which often use gamma area monitoring detectors.

Any Monitor Used for Routine or Emergency Assessment Should Have:

- Applicable vendor manuals
- An initial calibration to relevant isotopes using a volumetric source or geometric analysis, as applicable
- Monitor systems may have more than one channel, with different detector / observed volume configurations
- Separate monitor systems may have different channel configurations
- Energy response / isotope response calibration
- Periodic calibration traceable to secondary standards with specific maintenance surveillance defined
- Periodic linearity verification with specific maintenance surveillance
- Periodic response check with specific maintenance surveillance; and
- Defined maintenance surveillance documents or procedures for repair, calibration, and testing

References

1. Note: These references are US regulations. There may be additional references that are applicable to international utilities.US Code of Federal Regulations 10CFR 20 "Standards for Protection Against Radiation 2024

2. US Nuclear Regulatory Commission Regulatory Guide 1.21. "Measuring, Evaluating, and Reporting Radioactive Material in Liquid and Gaseous Effluents and Solid Waste". Revision 2 2009

3. US Nuclear Regulatory Commission Regulatory Guide 1.109. “Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part50, Appendix I”. Revision 1 1977

4. US Nuclear Regulatory Commission NUREG 0737. “Clarification of TMI Action Plan Requirements”. November 1980.

5. US Nuclear Regulatory Commission NUREG 0737 supplement 1. “Clarification of TMI Action Plan Requirements: Requirements for Emergency Response Capability”. February 1989

6. US Nuclear Regulatory Commission NUREG 0133. “Preparation of Radiological Effluent Technical Specifications for Nuclear Power Stations”. October 1987

7. US Nuclear Regulatory Commission Regulatory Guide 1.97. “Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident". Revision 5 2019 (applicable version may depend on licensing commitments),

8. EPRI Document Chem 2024-009. “Radiation Monitoring System Health Metrics”. December 2024

Recommended resources

1. Site Offsite Dose Calculation Manual

2. Site emergency operating procedures

3. Site emergency dose assessment procedures

4. Site engineering design calculations relating monitors to emergency action levels

5. Site engineering design calculations defining use of monitors in emergency dose assessment

6. Vendor equipment manuals

7. Vendor original ‘type’ calibration documentation

Assessment Process

Identify liquid effluent, airborne effluent and area monitor systems used for effluent assessment and emergency action decision making. These may include:

Release Point Effluent Monitors:

- Monitors installed specifically to evaluate effluent concentrations or release rates.
    - Normal ventilation (HVAC)
    - Condenser vacuum offgas (if not vented to normal ventilation)
    - Hard vent
    - Liquid discharges (sumps, radwaste process effluent)
- May include multiple channels and each channel can have a different configuration.
- Multiple channels can have different calibration and response factor configurations.
    - Low range channels may be configured for best response to routine (offsite dose calculation manual) effluent isotopic mixes.
    - Mid and high range channels may be configured for off-normal / emergency isotopic mixes

Supplemental Monitors Used for Emergency Effluent Monitoring:

- Containment high range radiation monitors
    - May be used in emergency operating procedures to determine off normal conditions or determine emergency actions.
    - May be used in emergency dose assessment to forecast or estimate releases.
- Gamma sensitive monitors used for effluent assessment on process flow.
    - High-high range gamma external monitors used to evaluate concentrations in ventilation for emergency dose assessment.
        - Gamma detectors on normal ventilation release points
        - Gamma detectors on hard vent
    - Main steam line radiation monitors may be used to determine activity concentrations in steam for emergency effluent assessment.

Area Gamma Monitors:

- Any area monitors used in emergency operating procedures to identify off-normal conditions or determine emergency actions.

Defining Scope

Identify each installed radiation monitor and channels to be included in the assessment. Below is an example table used for documenting the installed radiation monitors including monitor description and their application.

Information shown below is for example only.

Site / Unit	Monitor Description	Designation	Usage / application	Type / range
U1	Plant vent low	RM-1-101lo	Low range effluent on plant ventilation release point. ODCM.	Flow through chamber, low range
U1	Plant vent mid	RM-1-101mid	Mid-range effluent on plant ventilation release point. Emergency operations, emergency effluent dose assessment.	Flow through chamber, mid-range
U1	Plant vent High	RM-1-101hi	high range effluent on plant ventilation release point. Emergency operations, emergency effluent dose assessment.	Flow through chamber, high range
U1	Plant vent high-high	RM-1-111	Backup high range effluent on plant ventilation release point. Emergency operations, emergency effluent dose assessment.	External gamma high range
U1	Condenser vacuum exhaust	RM-1-103	Low range effluent on condenser vacuum exhaust release point. ODCM	Flow through chamber, low range
U1	Containment purge vent low	RM-1-105lo	Low range effluent on plant ventilation release point. ODCM.	Flow through chamber, low range
U1	Containment purge vent high	RM-1-105high	high range effluent on plant ventilation release point. Emergency operations, emergency effluent dose assessment.	Flow through chamber, high range
U1	Liquid outfall monitor	RM-1-301	Liquid effluent monitor on plant liquid discharge point. Emergency operations. ODCM.	Flow through
U1	Main steam line A rad monitor	RM-1-201a	Wide range gamma monitor. Emergency operating procedures, emergency effluent dose assessment.	External gamma monitor

U1	Main steam line B rad monitor	RM-1-201b	Wide range gamma monitor. Emergency operating procedures, emergency effluent dose assessment.	External gamma monitor
U1	Containment/Drywell high range radiation monitor A	RM-1-130a	Very wide range gamma monitor. Emergency operations, emergency effluent dose assessment	Area gamma monitor
U1	Containment/Drywell high range radiation monitor B	RM-1-130b	Very wide range gamma monitor. Emergency operations, emergency effluent dose assessment	Area gamma monitor
U1	Control room area monitor	RM-1-222	Gamma monitor. Emergency operations.	Area gamma monitor
U1	Spent fuel pool area monitor	RM-1-230	Gamma monitor. Emergency operations.	Area Gamma monitor

Monitor-Specific Considerations

Assessment plan descriptions for process and area radiation monitors are provided in the tables below. The tables are intended to be used for each monitor / channel as applicable as described in Defining the Scope (see above).

Process Radiation Monitors – Table 1

Liquid Effluent Monitors

Liquid effluent monitors may be installed on the plant outfall point (at the discharge to the environment) or on process lines from radwaste systems. Liquid effluent monitors are normally configured to be consistent with the Offsite Dose Calculation Manual (ODCM) effluent limits. Emergency effluent dose calculation for protective action does not normally include dose calculation on liquid effluents. ODCM controls and emergency operating procedures may include liquid monitor measurement response requirements.

Gaseous Effluent Monitors for Normal Plant Operation

Effluent monitors installed on normal plant airborne (e.g. HVAC) release points may have multiple ranges / channels. Low range channels are normally used for observing and evaluating routine effluents consistent with requirements in the Offsite Dose Calculation Manual. Effluent monitor channels that are configured specifically for emergency effluent assessment are discussed in the next paragraph. Although these monitor channels may be configured for routine effluent assessment, they will probably also be used for emergency effluent assessment and may have controls and limits defined in the emergency plan and emergency operating procedures.

Gaseous Effluent Monitors for Emergency Monitoring

Effluent monitors installed on normal and off-normal plant airborne (e.g. HVAC, main steam lines, hard vents) release points may have multiple ranges / channels. These monitors / channels may have controls and limits defined in the emergency plan and emergency operating procedures.

Supplemental Gaseous Monitors for Emergency Monitoring

Supplemental monitors installed on normal and off-normal plant airborne (e.g. HVAC, main steam lines, hard vents) release points may have multiple ranges / channels. Supplemental monitors can include external gamma monitors on ventilation systems, hard vent monitors, and containment high range radiation monitors. These supplemental monitors may be used to evaluate effluents for emergency dose assessment and may have controls and limits defined in the emergency plan and emergency operating procedures.

Area Radiation Monitors – Table 2

Area radiation monitors may be used to evaluate plant conditions and emergency action levels and may have controls and limits defined in the emergency plan and emergency operating procedures.

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**

Liquid	Primary calibration	• Initial Calibration documentation is retrievable.
		  ○ Documentation identifies NIST traceable source.
		  ○ NIST traceable source used isotopes and magnitudes appropriate to the energy range.
		• Magnitude response linearity using at least three sources of the same isotope with activity levels approximately a decade or more apart along the response range is documented.		

Gaseous	Primary calibration	• Initial Calibration documentation is retrievable.
		  ○ Documentation identifies NIST traceable source.
		  ○ NIST traceable source used isotopes and magnitudes appropriate to the energy range.
		  ○ Modern systems may have 'Monte Carlo' based geometric calibration for specific isotopes. These calculated efficiencies should be verified with NIST reference sources.
		  ○ Very high range monitors may not be tested with sources at the upper scales.
		  ○ Magnitude response linearity using at least three sources of the same isotope with activity levels approximately a decade or more apart along the response range is documented.		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**
Liquid and Gaseous	Transfer Calibrations	• Transfer calibrations, which are used to transfer NIST traceability to onsite calibration sources, should be documented and retrievable. ○ Detector alignment to primary calibration operating condition (voltage, geometry, etc.) was performed using multi-channel analyzer (MCA) or vendor standard calibration sources (NIST traceable and dedicated during the primary calibration) and is documented. • Following detector system alignment to the primary calibration, detector responses to onsite calibration sources are documented.		

Liquid and Gaseous	On-site calibrations	• Calibration records should be retrievable.
		• Calibrations attributes
		  ○ Perform periodically (e.g. annually)
		  ○ Utilize NIST traceable sources
		  ○ Maintain fixed, repeatable geometry
		  ○ Linearity verification *
		• Source attributes
		  ○ Proper decay corrections documented
		  ○ Proper energy discrimination verified
		  ○ Utilizes appropriate isotopes
		* Magnitude response linearity using at least three sources may not be required for on-site calibration.		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**
Liquid and Gaseous	Calibration Procedures, Maintenance	• There are calibration procedures for each type of radiation monitor. • Maintenance surveillances or preventive maintenance tasks are in place for calibration performance. • Completed procedure / surveillance historical records should be available. • Maintenance on the detector, electronics, and sampling lines should be done using maintenance work orders by trained / qualified staff. • Historical Work Order records are available.		
Liquid and Gaseous	Trending	• Evaluate whether calibration parameter trending is routinely performed to identify system changes (LLD, ULD, Gain, apparent efficiency, etc.) over time. • Calibration trending should include control charts to identify out of normal conditions and bias/trends.		
Liquid and Gaseous	Potential system contamination	• Evaluate whether the sampling lines and chambers show evidence of low-level contamination build-up and if appropriate procedural triggers exist to implement decontamination.		
Liquid and Gaseous	Response checks	• Frequent response checks with non-NIST sources should be performed or the detector could have a 'keep live' source. ○ Response checks should be trended with control charts.		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**

Liquid and Gaseous	Detector Design - Response range	• Appropriate response range is identified.
		  ○ Minimum value is capable of detecting releases when background variation is accounted for.
		  ○ Upper range is capable of detecting planned special releases.
		  ○ Alarm/trip setpoints can be adjusted to support releases.
		  ○ There should be overlap between the low/mid/high channels.
		  ○ Upper range of High channel should meet detection criteria for the application.		

Liquid	Sampling system	• Sample lines to the monitor are verified to be intact and operating as intended. • Maintenance activities verify sampling system integrity. • Sampling system has capability for routine ‘grab’ samples.		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**
Gaseous	Sampling system	• Sample lines to the monitor are verified to be intact and operating as intended. • Maintenance activities verify sampling system integrity. • Sampling system has capability for routine 'grab' samples and has continuous collection samples. • Capable of providing a valid sample for iodine and particulates. • Isokinetic or representative sampling is demonstrated (minimized sample line runs and do not exceed design bend radius limits). • Sample line-losses are evaluated and corrected-for in the effluent calculation process. • The system is evaluated periodically to determine if the sample nozzles or lines need cleaning indicated by flow or pressure changes over time.		
Liquid and Gaseous	Annunciation	• Alarm setpoints per the ODCM can be adjusted to support batch releases (e.g. liquid radwaste batch tanks or waste gas decay tank). • Alarm setpoints can be adjusted to support emergency operating procedures.		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**
Liquid and Gaseous	Response / efficiency factors	• Conversion factors from raw instrument response to volumetric units (e.g. uCi/cc) or rate (e.g. uCi/sec) should be based on the expected isotopic mix. • Ideally, conversion factors would include the effect of multiple isotopes in an expected mix rather than response to a single isotope. • ODCM and dose assessments should use factors accounting for the differences in instrument response to different isotopic mixes. ○ Particularly for emergency response, differences in isotopic response should be accounted for. • This response adjustment may be by applying time /decay dependency using a predetermined mix or using isotope specific responses to any real-time mix.		

Liquid and Gaseous	Action limits	Action limits for the following should have formal calculations that use the expected isotopic mix and instrument response:
		• ODCM
		• Emergency plan and implementing procedures
		  ○ EAL thresholds
		  ○ Dose assessment
		  ○ EITER
		  ○ Etc.
		• Emergency operating procedures		

Table 1 – Process Radiation Monitors				
Type	**Topic**	**Criteria**	**Review Comments**	**Criteria Met Yes/ No**

Gaseous	Energy / isotope response	• A documented and retrievable technical basis exists for the isotope specific energy response and source term decay time dependency.
		  ○ 'Xe133 dose equivalent' if used for instrument gross response accounts for the differing responses by isotope in the ODCM mix.
		  ○ Use of Kr85 instead of Xe133 or ODCM mix has been considered / evaluated for monitors specifically for spent fuel storage areas and permanently decommissioned facilities.
		• Response factor is based on appropriate core isotope or appropriate core mix including changing accident source terms.		

Gaseous	Particulates, Iodine, Noble Gas	• Provides real-time iodine and particulate release information. • Effect of noble gases on iodine and particulate channels is known. • Iodine and particulate channel logic accounts for build-up of activity to determine instantaneous rates.		
Gaseous	Use of ODCM reference mix	• Response per the ODCM may be based on a ODCM mix normalized to 'Xe133 dose equivalent'. • This Xe133 dose equivalent should be based on the ODCM mix and RG 1.109 dose factors.		

Table 2 – Area Radiation Monitors			
Topic	**Criteria**	**Review comments**	**Criteria Met Yes/No**

Initial historical calibration	• Initial Calibration documentation is retrievable.
	  ○ Documentation identifies NIST traceable source.
	  ○ NIST traceable source used isotopes and magnitudes appropriate to the energy range.
	• Some guidance suggests that manufacturer 'type' calibration can be acceptable.		

Transfer Calibrations	• Transfer calibrations, which are used to transfer NIST traceability to onsite calibration sources, should be documented and retrievable. ○ Detector alignment to primary calibration operating condition (voltage, geometry, etc.) was performed using multi-channel analyzer (MCA) or vendor standard calibration sources (NIST traceable and dedicated during the primary calibration) and is documented. • Following detector system alignment to the primary calibration, detector responses to onsite calibration sources are documented.		

Table 2 – Area Radiation Monitors			
Topic	**Criteria**	**Review comments**	**Criteria Met Yes/No**

On-site calibrations	• Calibration records should be retrievable.
	• Calibrations attributes
	  ○ Perform periodically (e.g. annually)
	  ○ Utilize NIST traceable sources
	  ○ Maintain fixed, repeatable geometry
	  ○ Linearity verification *
	• Source attributes
	  ○ Proper decay corrections documented
	  ○ Proper energy discrimination verified
	  ○ Utilizes appropriate isotopes
	* Magnitude response linearity using at least three sources may not be required for on-site calibration.		

Calibration Procedures, Maintenance	• There are calibration procedures for each type of radiation monitor. • Maintenance surveillances or preventive maintenance tasks are in place for calibration performance. • Completed procedure / surveillance historical records should be available. • Maintenance on the detector, electronics, and sampling lines should be done using maintenance work orders by trained / qualified staff. • Historical Work Order records are available.		
Calibration Trending	• Evaluate whether calibration parameter trending is routinely performed to identify system changes (LLD, ULD, Gain apparent efficiency, etc.) over time. • Calibration trending should include control charts to identify out of normal conditions and bias/trends.		

Table 2 – Area Radiation Monitors			
Topic	**Criteria**	**Review comments**	**Criteria Met Yes/No**
Response checks	• Frequent response checks with non-NIST sources should be performed or the detector could have a 'keep live' source. ○ Use control charts to trend.		
Response range	• Response range is known and should meet guidance detection criteria (e.g. containment high rad monitors). • Some monitors may not have specific requirements or guidance (main steam).		
Location	• Detection system is located to observe the source activity.		
Energy / isotope response	• Detectors and installed geometries will vary in efficiency by isotope. • The isotope specific, energy response, or core decay time dependency should be known and should have a documented and retrievable technical basis.		
Action limits	• Action limits, such as the alarm setpoints defined in the monitor and emergency plan or emergency operating procedure action levels (e.g. table R action limits) should have formal calculations that use the expected mix and instrument isotope mix specific response.		

Acronyms/Abbreviations

µCi/cc	Microcuries per cubic centimeter
µCi/sec	Microcuries per second
EAL	Emergency Action Level
EITER	Equipment Important to Emergency Response
HVAC	Heating Ventilation and Air Conditioning
LLD	Lower Limit Discriminator
LOCA	Loss of Coolant Accident
MCA	Multi-Channel Analyzer
NIST	National Institute of Standards and Technology
ODCM	Offsite Dose Calculation Manual
PWR	Pressurized Water Reactor
RG	Regulatory Guide
RMS	Radiation Monitoring System
ULD	Upper Limit Discriminator