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NCRP DRAFT STATEMENT No. XX

INSTRUMENT RESPONSE VERIFICATION AND CALIBRATION FOR USE IN RADIATION EMERGENCIES

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Executive Summary

This Statement provides recommendations for maintaining the readiness of radiation detection equipment for use in a large-scale nuclear or radiological emergency. Various instrument inventories are retained by municipal, county, and state entities having different levels of experience and focus, including fire departments, hospitals, and emergency management agencies. These instruments can provide valuable and actionable information during an emergency.

The recommendations in this Statement consider not only the objectives of making emergency radiation measurements but also the practical aspects of maintaining equipment that is not used for regulatory compliance and that might be used only rarely. A three-tiered, mission-oriented approach is described, which includes periodic laboratory calibrations as well as quantitative and non-quantitative source-response checks. Examples are provided of accepted methods for determining appropriate calibration intervals based on records of instrument response. The recommendations are intended for equipment that measures count rate, exposure rate, or accumulated dose from external gamma or beta sources, and do not address additional capabilities such as alpha or neutron detection or radionuclide identification.

The tiered approach allows users to attain confidence in their equipment while working within available funding and personnel resources. It recognizes that a functional instrument, even if not formally calibrated, can still support certain missions during a large-scale emergency and is preferred to an absence of instrumentation.

Introduction

This Statement provides recommendations for a mission-oriented approach to maintain readiness of radiation detection equipment for use in a large-scale emergency response. It recognizes that a functional instrument, even if not formally calibrated, can still support certain missions during a large-scale emergency and is preferred to an absence of instrumentation. These recommendations are not intended to be used in place of federal, state, or local guidelines or regulations, if they exist.

Since September 11, 2001, many state and local response organizations in the United States have increased their inventory of radiation detection equipment as part of the national preparedness for potential terrorism and nuclear or radiological emergencies. These include fire services, law enforcement, emergency management, public health agencies, and hospitals. The radiological instruments are not used in routine health physics operations, regulatory compliance or evidentiary activities. Rather, they are intended to support decisions in a radiological emergency, such as determination of a radiation hazard; emergency worker exposure control; screening people, vehicles, equipment, or buildings for radioactive contamination; assessing the potential for population exposure; and prevent/counter terrorism efforts.

Radiation detection instruments can provide valuable and actionable information during an emergency. Although periodic performance verification of emergency equipment is necessary to ensure readiness and assess accuracy, the standard annual laboratory calibration procedures used in regulatory compliance applications are not always required nor appropriate for the large instrument inventories retained for homeland security or emergency preparedness. Intended uses of many such instruments in a large-scale emergency may not require the same level of measurement accuracy and reliability that is mandated in regulatory compliance programs. Additionally, state and local response agencies may not have the staffing or budget for the recurring costs associated with annual calibrations. If state and local organizations are forced to reduce capacity (i.e., number of instruments) due to calibration expenses, it would significantly decrease their response capability. Alternate cost-effective methods are appropriate to maintain instrument readiness.

In responding to large-scale emergencies that challenge conventional practices in terms of demand on scarce resources, it is essential to identify flexible alternative approaches to those typically employed in routine work practices. Such approaches are well-established for providing healthcare during national emergencies where strategies are developed for contingency and crisis capacity conditions (Hick 2009; IOM 2009). One example of such an approach that was widely applied by healthcare facilities during the COVID-19 pandemic was the use of face masks which were in limited supply (CDC 2020).

Empirical data from calibration records provided by four state, local, and laboratory instrument calibration programs indicates that for these sample groups most instruments maintain their calibration within an acceptable range for responder and public safety, for several years. For example, 91 % of the 126 instruments sent for calibration by Vermont Department of Health over a 3-y period were accepted as received and required no adjustment by the calibration vendor before being returned. This finding was consistent with other calibration data[1]. These data came from organizations with instrument inventories of various sizes and types and therefore may not represent all instrument models. Organizations may undertake similar assessments of their calibration records for their instruments[2].

An annual calibration program is not required for instruments that are not covered by institutional health physics programs or regulatory compliance requirements. This Statement provides a three-tiered, mission-oriented approach using cost-effective methods to maintain readiness and optimize confidence in instruments for use in a large-scale emergency response. The recommendations consider the objectives of emergency radiation measurements as well as practical aspects of equipment maintenance for instruments that are not covered by institutional health physics programs or regulatory compliance requirements. The tiered approach allows various users to attain the maximum achievable confidence in their instrument response while working within available funding and personnel resources. The three methods depend on the instrument capabilities and their intended use during the emergency.

[1] O'Neil F. 2021. Personal Communication. Vermont: Vermont Department of Health; Fahner D. 2021. Personal Communication. Georgia: Georgia Department of Health; Mintz JL. 2020. Personal Communication. California: Lawrence Livermore National Laboratory; Karam P. 2021. Personal Communication. New York.

[2] Such analyses are described for "Tier 1" maintenance in this Statement. Sample analyses were performed on data from the National Institute of Standards and Technology calibration laboratory.

Analysis of typical instrument failure modes due to performance degradation with time and use is not covered in this statement. Where resources allow, quality control and assurance programs can be adopted to assess the degradation of the instrument response and identify causes of instrument failures.

Instruments for Radiological Emergency Response

Radiological emergency response equipment is maintained by municipal, county and state entities having various levels of experience and operational focus, from volunteer fire departments[3] to specialized hazardous materials response teams. Inventories may include a mix of older analog devices and newer digital instruments. Older instruments include simple, rugged Geiger-Mueller survey meters procured in the 1950s and 1960s for civil defense programs that were distributed for homeland security purposes in 2003[4]. Other analog instruments procured from the 1970s through 1990s and designed for nuclear power plant operations may include more complicated survey meters having linear or logarithmic scales that require manual range changes, with a scale multiplier to interpret the readout. In contrast, newer digital instruments have significantly different displays and functionality. For example, they may incorporate two detectors and have the capability to automatically scale through multiple ranges of radiation levels, offer options for the user to select the quantities and units displayed, or have multi-functional capabilities to measure count rate, exposure rate, and accumulated dose or perform radionuclide identification.

State inventories typically include hundreds of pieces of equipment that are strategically cached at various locations, but the types of instruments vary significantly among states. As an example, one state department of health maintains approximately 700 digital instruments, consisting of electronic dosimeters (50 %), handheld alpha, beta, gamma survey meters (36 %), personal radiation detectors (11 %) and radiation portal monitors (3 %). For comparison, the emergency operations center in a different state retains a mix of about 500 analog and digital instruments, including survey meters (25 %), personal radiation detectors (7 %), radionuclide identifiers (2 %), count rate meters (13 %), and civil defense instruments (53 %).

In the absence of a radiation emergency, stockpiled instruments are generally unused except for training and exercise purposes. In a nuclear or radiological emergency, these equipment caches would be deployed to support response operations.

[3] About 70 % of America's firefighters are volunteers (Fire Administration 2021)
[4] Civil defense instruments typically have a model name beginning with "CD-V"

Another important resource in a large-scale radiation emergency would be the equipment used by law enforcement to detect and interdict illicit radioactive material. Many such state and municipal law enforcement agencies have a large stock of belt-worn personal radiation detectors (PRDs) for this application. Although many types of PRDs will read out in exposure rate and some even track the integrated dose to the wearer, a routine calibration is not required for their detect and interdict mission. If these instruments were to be pressed into service during an emergency, it would be important to know how they can be used reliably.

Mission-Oriented Approach to Maintain Equipment Readiness

This Statement provides a generalized three-tiered, mission-oriented approach to maintaining instrument readiness for emergency response. It is intended to be adaptable to equipment that measures count rate, exposure rate, or accumulated dose from external gamma or beta sources. This Statement does not address additional capabilities such as alpha or neutron detection or radionuclide identification[5].

The maintenance tier that should be applied will be driven by many factors, including instrument type, intended use in an emergency, and likelihood of the jurisdiction facing a large-scale, high-level radiation emergency such as a nuclear detonation or radiological terrorism.

In general, a more rigorous calibration and maintenance protocol should be considered if:

- the instrument has been designated as the primary device for responder safety from radiological hazards; and
- the jurisdiction is a high-threat, high-density area[6].

The following are examples of how the tiered approach can be applied to a variety of circumstances:

Tier 1 designates the most rigorous level of equipment maintenance. It consists of periodic laboratory calibrations where the calibration frequency is to be determined by the local agency based on instrument performance and mission needs. Tier 1 is recommended for instruments that are intended to be used to perform surveys in the vicinity of a radiological incident, for example:

- exposure control and dose monitoring equipment carried by HAZMAT or other units designated as "first in" responders to a radiological incident; and

[5] This statement does not apply to cellular or smart phone detection apps intended to measure radiation.

[6] The Department of Homeland Security designates these as Urban Area Security Initiative (UASI) jurisdictions which tend to have more resources dedicated to emergency preparedness than lower-risk areas.

- designated exposure control and dose monitoring equipment in routine use in high-threat, high-density jurisdictions.

Tier 2 maintenance consists of quantitative source-response checks, where the acceptance criteria is determined by the local agency based on mission needs, and the radioactive source used depends on the type of detector. Tier 2 maintenance can be used for:

- contamination monitoring equipment (e.g., personnel or vehicle monitoring);
- extended range PRDs that have been provided to (non-HAZMAT) emergency responders to alert them to the presence of radiation and might be used as a secondary exposure control device;
- exposure control and dose monitoring equipment carried on emergency response vehicles in low-risk rural areas but not generally in use (available "just in case" of a large-scale radiological emergency);
- portal monitors used to screen the public after a nuclear incident; and
- stockpiled exposure control and dose monitoring equipment near a high-threat, high-density area.

Tier 3 maintenance consists of nonquantitative source-response checks performed at a frequency determined by each jurisdiction. Tier 3 maintenance can be used for:

- typical PRDs (defined by ANSI N43.32) that would generally be used outside the Hot Zone[7] for exposure control and contamination monitoring;
- stockpiled civil defense instruments in low-risk areas; and
- extended range PRDs whose primary purpose is for the detection of contraband radioactive materials by law enforcement but might be used by the wearer in a supplemental role during a significant nuclear or radiological incident.

All instruments regardless of use and Tier level should have documented periodic functional checks. The three approaches summarized below are described in more detail in the following sections.

Tier 1: Periodic laboratory calibrations are appropriate for exposure rate instruments designated for "first in" activities in jurisdictions that have a higher likelihood of a large-scale nuclear emergency. Calibration intervals depend on instrument design and desired performance and may be greater than 1 y. Empirical evidence indicates that multiple years between calibrations may be acceptable for instruments used during radiation emergencies if appropriate analyses are performed.

Tier 2: Quantitative source-response checks are appropriate for supplemental instruments that may be pressed into service in a large-scale emergency. The source-response check should be performed and documented at least annually. However, the interval between calibrations can be adjusted based on instrument performance and may be greater than 1 y.

Tier 3: Nonquantitative periodic source-response checks are sufficient for instruments that are not intended to be used for primary responder exposure control. Such checks are generally performed before emergency deployment to verify functionality and may be performed periodically as determined by the local jurisdictions to ensure equipment readiness.

[7] NCRP recommends establishing a Hot Zone boundary when any of the following is exceeded; 10 mR h^{-1} exposure rate (~0.1 mGy h^{-1} air-kerma rate); 60,000 dpm cm^{-2} (1,000 Bq cm^{-2}) for beta and gamma surface contamination; and 6,000 dpm cm^{-2} (100 Bq cm^{-2}) for alpha surface contamination (NCRP 2010).

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Tier 1: Laboratory Calibrations

Calibration is the process of comparing an instrument indication with the reference value of a known radiation field, and if the reading is found to be outside an acceptance range, adjustments are made to the device. In this context, both an instrument that has been adjusted, and one that was acceptable "as-found" are considered to have been calibrated. Specifications for the acceptance range and frequency of calibration can be set to define a rigorous performance maintenance program. For example, institutional health physics programs may require a ±20 % acceptance range and an annual calibration interval for instruments used in regulatory compliance measurements. Lacking other guidance, some state and city emergency response organizations have defaulted to the procedures that are required for equipment maintained to support the state or local response to a nuclear power plant (NPP) incident or accident[8]. Such state radiological emergency preparedness (REP) plans are driven by the U.S. Nuclear Regulatory Commission (NRC) and Federal Emergency Management Agency (FEMA) guidance documents previously published in 1980 (NRC/FEMA 1980) and updated in 2019[9] (NRC/FEMA 2019a). Those publications provide a useful reference and context to develop an alternate approach suitable for applications of emergency equipment that are not under NRC jurisdiction.

The 2019 NRC/FEMA publication delineates REP criteria and allows for alternate approaches to meet the intent of the planning standards that do not relax the requirements (NRC/FEMA 2019a). The REP Program Manual provides additional guidance for specific elements of plans and procedures to meet the intent of the evaluation criterion and includes an approval process for alternative approaches (FEMA 2019). It includes descriptions of operational checks and calibration, testing and maintenance to be performed, and the frequency for specific

[8] This includes the 29 states that host NPPs plus neighboring states where a NPP is in proximity to the state border. In addition, 39 NRC Agreement States have regulatory authority for byproduct, source, and certain special nuclear materials; these states maintain radiation instruments despite not having REP plans for NPP emergency planning zones. The state Radiation Control Programs may follow the calibration regulatory guidance for their licensees which vary from a minimum of every six months for radiography and well-logging to annually for medical uses of byproduct materials and panoramic irradiators.

[9] Notably, the revised publications intentionally omit use of the words "should" and "shall" to avoid implying that some criteria are requirements (NRC/FEMA 2019b)

types of equipment[10] per the appropriate national standard or manufacturer's instructions, whichever is more frequent. For radiological survey instruments, examples of operational checks are battery and radioactive source checks. For instruments in storage, operational checks are conducted periodically, before use, or on a quarterly basis. In this context, the FEMA guidance cites an American National Standards Institute (ANSI) publication ANSI N323AB-2013 (ANSI 2013) which addresses calibration frequency in detail.

ANSI 2013 specifies annual calibrations but also describes several methods to determine the appropriate time interval between calibrations based on performance records, noting that it can be extended beyond 1 y with appropriate justification. One method is based on a recommended practice (RP-1) published by the National Conference of Standards Laboratories International (NCSL International 2010) Integrated Sciences Group. The NCSL working group also developed an online tool to determine the calibration interval (ISG 2016). Using this tool, the "as-found" performance recorded in calibration reports for a set of identical instruments over several years can be analyzed to identify alternate calibration intervals. Another method described in ANSI 2013, tracks individual instrument performance using control charts. Examples illustrating these methods are presented and analyzed in a National Institute of Standards and Technology (NIST) Technical Note 2146 (Pibida et al. 2021). The NIST analysis includes samples of several years of calibration records and shows that in some cases calibration intervals could be extended to 3 y. Such analyses of historical calibration records are facilitated when individual instrument data are recorded in an electronic spreadsheet (rather than logbooks or individual instrument calibration certificates).

Procedure: Users of Tier 1 equipment should maintain a data base or spreadsheet of instrument calibration records of the "as-found" performance of each instrument over at least 3 y. Standard published methods (e.g., ANSI 2013 and Pibida et al. 2021; Figure 4) can be applied to analyze the performance data and determine an appropriate calibration interval that meets emergency response objectives. The users should develop an operating procedure describing how measurements are going to be performed and documented, and define the acceptance criteria.

[10] Three types of equipment – radiological survey instruments, direct reading dosimeters, portal monitors are

Tier 1: Periodic laboratory calibrations of radiological instruments provide rigorous performance verification. Where not specified by federal or other regulations, the calibration acceptance range and the interval between calibrations should be established to meet the required accuracy of the application and may be greater than 1 year.

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covered, but this section notes that it may not be limited to the equipment described.

Tier 2: Quantitative Source-Response Checks

Quantitative source-response checks are performed using a radioactive source with a known activity (i.e., no need to have source traceability to the SI system of units through a national metrology institute such as NIST or an equivalent organization). Each radiological instrument is exposed to the source in a well-defined reproducible geometry, and the instrument reading is compared to a user-defined acceptance range. If the instrument performance is found to be outside the acceptance range, it should be sent to a calibration laboratory for recalibration. While an acceptance range of ±20 % is commonly recommended[11] for routine health physics applications, local jurisdictions may define a different range appropriate for their mission needs; an example of an approach for catastrophic emergencies is provided (see text box). The frequency of source-response checks should be established to meet the required accuracy needs of the intended mission[12]. Generally, checks should be performed and documented at least annually to maintain awareness of equipment readiness, but longer intervals might be justified through an assessment using the procedure described for Maintenance Tier 1.

Procedure: At the time an instrument is purchased or calibrated, and periodically thereafter:

- Place the instrument in front of a radioactive source at a fixed distance between source and detector. The relative position between the source and detector must be reproducible. It is recommended that a jig be constructed or purchased such that the detector and the source are fixed relative to each other. Examples of user-made jigs have been published and model-specific devices are available from some instrument manufacturers [13];

[11] NRC (1991); NRC (2012); FEMA (2002); ANSI (2013).

[12] For routine health physics applications, ANSI N323AB provides recommendations on frequency of quantitative checks.

[13] For example, Mirion Technologies, Inc., Thermo Fisher Scientific, Inc., and Ludlum Measurements, Inc. Such commercial equipment, instruments, or materials are identified in this document to foster understanding. Such identification does not imply recommendation by the NCRP, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

- Record the instrument display readings in response to the source in a stored digital data file. The instrument may display different quantities and have options for different units; the measurements should always be performed using the same settings;
- Decay-correct the source activity at the time of the measurements to allow the comparison with initial instrument readings. Decay-correction can be performed using online radioactive decay calculators, hand calculations, decay charts, and so forth; and
- It is recommended that the instrument be recalibrated if readings of the quantitative check fall outside of the acceptance criteria. If the instrument is dropped, shocked or damaged in any way while being used, verify that the readings are within the same range as before it was dropped and check for potential physical damage that might require repair.

Catastrophic emergency - limited resources approach: Alternate acceptance ranges may be appropriate for contingency in crisis conditions. For example, if the quantitative source-response check result is within a factor of two of the initial checks and this is documented for that particular instrument, the instrument may be useful for some applications when no better instrumentation is available. However, for life safety purposes instruments with less than 20% accuracy would not be acceptable. NCRP provides guidance for instrumentation when resources are scarce (NCRP 2017, 2019).

Source Selection

Sources should be matched appropriately to the type of instrument and its detector physics to provide a meaningful test that would reveal decreased performance. For example, a source emitting low energy photons (i.e., <200 keV photons) is preferable for checking the response of scintillation detectors. This is because scintillator degradation or photomultiplier fading would reduce instrument response to low energy photons more than to higher energy photons. PRDs, spectroscopic PRDs (SPRDs), radio-isotope identification devices (RIIDs), mobile detectors and radiation portal monitors (RPMs) typically use scintillation detectors. Cesium-137 is typically used in laboratory calibrations of gamma survey meters. If the instrument is to be used for isotopes with energies different from ^{137}Cs, calibration and check source radiation energies should match those to be measured in the field.

Another factor to consider is the source activity. The source strength should be sufficient to allow for the instrument response to be assessed with an exposure time of a few minutes, while also minimizing the radiation exposure of the user. Using sources that are exempt from NRC, state, and Department of Transportation (DOT) regulations may be an advantage for some agencies to simplify handling, transport procedures and license requirements. For example, with such considerations in mind, ^{133}Ba may have advantages over ^{137}Cs because higher count rates are achievable with an exempt barium source, and its lower energy photons are easier to shield to reduce exposure during transport, handling, and storage.

The natural, long-lived primordial isotopes ^{40}K, ^{87}Rb, and ^{176}Lu offer some additional advantages as check sources for quantitative source-response tests. Sources below exemption limits may provide sufficient emission rates for quantitative source response checks of some types of equipment. Due to their long half-life, no decay correction is required, and each source of the same design will have the same emission properties.

Some recommended sources that balance these considerations are provided in Table 1.1. Other sources may be used if available (ANSI 2013). Instruments that have internal high-range detectors (dual detectors) may require higher radiation fields to verify the response[14].

[14] Mission applications involving instruments capable of high exposure rates may be best suited for Tier 1 maintenance (performed at a calibration laboratory).

Table 1.1—*Recommended radionuclides for quantitative source-response checks.*

Nuclide	Half life (years)	Annual Activity Loss	Suggested Activity Range (kBq)	Gamma[a] Energy (keV)	Beta[b] Max Energy (keV)	Instruments
^{137}Cs	30	2.3 %	up to 370	662 (31 – 35)	(589)	Gamma Survey meter
^{133}Ba	10.5	6.8 %	up to 370	81 – 384 (31 – 35)	none	Gamma Survey meter PRD, SPRD, RID, Portal Monitors
^{176}Lu (natural lutetium)	3.7×10^{10}	none	0.3 – 10	55 – 307	(589)	PRD, SPRD, RID, Portal Monitors Beta Detectors
^{40}K (natural potassium)	1.3×10^{9}	none	0.1 – 3	1,460	1,312	Beta Detectors
^{87}Rb (natural rubidium)	4.8×10^{10}	none	0.5 – 3	none	273	Beta Detectors

[a] Gamma-ray energies <40 keV in parenthesis. Their presence and relevance may vary depending on source design and detector type.

[b] Beta radiation is not present for sealed sources. These energies are shown in parenthesis.

Tier 2: Quantitative source-response checks can be performed by the user to verify that the instrument is operating within an acceptable range. Laboratory calibration is not required unless the instrument fails the source-response check.

Each instrument should be tested periodically using a known radioactive source appropriate for the detector type and positioned in a reproducible geometry. The instrument reading should be documented and tracked to verify that performance remains within the accepted range.

Tier 3: Nonquantitative Source Response Checks for Response Verification

A Tier 3 check (often called a "bump test") simply confirms that the instrument responds to the type of radiation it is designed to detect. In some cases, such as for count-rate instruments, this level of instrument performance verification provides the necessary assurance to confirm functionality for emergency applications. Generally, this type of check should be performed when the instrument is being deployed and at least daily during extended operations. Users may also wish to routinely verify the functionality of stockpiled instruments using this technique at a frequency determined by the local jurisdictions based on their specific experiences with their instruments and circumstances.

Many instruments come with their own check source affixed to the instrument. In addition, consumer products containing naturally occurring radioactive material have been used for decades for such nonquantitative tests. These include Fiesta-ware (uranium oxide glazed), thoriated welding rods, lantern mantles (thorium), old watches (radium dials), or naturally occurring radioactive materials present in commodities or environment (e.g., uranium ore samples) (Pibida 2012). Possible source damage with subsequent contamination and unknown exposure of the user cannot be excluded when using this type of sources. For these reasons, the source selection considerations discussed for Tier 2 maintenance are also applicable for nonquantitative response verification.

Procedure: Place a detector in proximity to an appropriate radioactive source (not necessarily with a known activity). Note that the meter indicates a higher count rate than when the source was absent, or that the device registers an alarm condition. One can also listen to the audible response, noting that the click rate has increased.

Additionally, it is recommended that all instruments should undergo a nonquantitative response verification check before use on each emergency deployment.

Care of Stockpiled Instruments

In addition to the three-tiered approach to periodic instrument performance verifications, it is important to consider the conditions used for long term equipment storage. It is recommended that:

- batteries should be removed;
- cables should not be bent;
- extremely low (below –10 °C) or high (above 30 °C) storage temperatures should be avoided to prevent instrument damage; and
- high humidity conditions should be avoided and the use of desiccant in storage considered to prevent instrument damage.

Conclusion

Radiation detection instruments can provide valuable and actionable information during an emergency. Checking the instrument response periodically provides confidence in emergency measurements. It is not necessary to adhere to an annual calibration program for instruments that are not used for regulatory compliance measurements. Laboratory calibration intervals greater than 1 y combined with quantitative and nonquantitative source-response checks can be used to maintain readiness of radiation detection equipment for use in a large-scale emergency response. Local jurisdictions may tailor the approach to match their equipment inventory and response missions to balance available resources and maintain response capacity.

NCRP recommends that radiological monitoring be performed whenever possible to help control and monitor responder dose, especially when high levels of radiation may be involved. The higher the likelihood that an instrument will be used in such a mission, the more rigorous the maintenance program should be to ensure it works properly. If an agency is considering removing the equipment from service due to maintenance costs, NCRP instead recommends a lower maintenance tier or frequency so that the equipment can still be used in a supplemental capacity. It is also important to remember that as stated in NCRP Report No. 165 "Medical emergencies and lifesaving take priority over radiological monitoring and the concern for the presence of radionuclide contamination. Radiation monitoring equipment, *although desirable*, is not required to begin lifesaving operations" (NCRP 2010).

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