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14. ABSTRACT

This TOP provides the standardized procedures for preparation, planning, conduct, and reporting of radiological and nuclear decontamination testing.

15. SUBJECT TERMS

radioactive; isotope; radiological; nuclear; decontamination; testing

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

[*]Test Operations Procedure 08-2-069 25 June 2020
DTIC AD No.

RADIOLOGICAL AND NUCLEAR DECONTAMINATION TESTING

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* Approved for public release; distribution unlimited.

1. SCOPE.

1.1 Purpose.

a. This Test Operations Procedure (TOP) describes the test procedures used to characterize and determine the technical performance of a decontaminant. A general discussion of minimal technical and operational performance characteristics, technical specifications, test procedures, and evaluation criteria for all equipment necessary to conduct Chemical, Biological, Radiological, and Nuclear (CBRN) decontamination in accordance with North Atlantic Treaty Organization (NATO) doctrine is provided in Allied Engineering Publication (AEP-58), Edition B, Volume 1[1**].

NOTE: Reference 1 provides a general discussion of “minimal technical and operational performance characteristics, technical specifications, test procedures, and evaluation criteria for all equipment necessary to conduct CBRN decontamination in accordance with NATO doctrine stated in Allied Tactical Publication (ATP)-3.8.1.Vol I, Standardization Agreement (STANAG) 2521.”

b. Decontamination is the process of reducing or eliminating the hazards associated with CBRN contamination in order to accomplish assigned missions.

c. This TOP addresses test methods for assessing radiological and nuclear decontaminant efficacy. Radiological and/or nuclear contaminant may include radiological or nuclear material from a plethora of malicious or non-malicious scenarios such as a Radiological Dispersal Device (RDD), nuclear detonation, reactor accident, and transport accident. The term radiological materials will be used to refer to contaminating materials from a nuclear event throughout this TOP.

d. Some test methods in this TOP require the use of radiological materials and decontaminants.

** Superscript numbers correspond to Appendix G, References.

1.2 Application.

This TOP provides the current standard for the planning and conduct of general performance tests of radiological decontaminants. The test procedures described herein will be used as the basis of a test plan. The procedures may require modification for unique items or materials or to satisfy specific testing requirements as specified in the Capability Development Document (CDD). However, modification of procedures in this TOP will be made only after full consideration of any possible effects the alterations may have upon the reliability and validity of the data to be obtained. Such alterations will be coordinated among all concerned organizations in advance of any testing. Any deviations from this TOP will be documented in the test plan and the test report.

1.3 Limitations.

a. This TOP does not include procedures intended for skin or personnel decontamination testing.

b. Decontaminant application procedures should be in accordance with (IAW) test sponsor's instructions.

c. This TOP does not include procedures for testing decontaminant applicators.

NOTE: When a decontaminant is part of a decontamination system, the integrated applicator may be required or used in applying the decontaminant to test articles.

2. FACILITIES AND INSTRUMENTATION.

Facilities and instrumentation used for testing radiological decontaminants are strictly controlled.

2.1 Facilities.

Item	Requirement
Radiological facility.	Must be designed and constructed to ensure safe and secure storage, handling, analysis, and decontamination of unsealed radiological material used for Research, Development, Test, and Evaluation (RDT&E). Facility must be equipped and licensed for work with unsealed radiological material.
Outdoor decontamination facility.	Must be designed for containment of test effluents and provide power and water for multiple system inlet needs. The facility must have sufficient environmental permits for the required work and materials (unsealed radiological material and decontaminant) used in the test.

2.2 Instrumentation.

The following instruments or their equivalents will be used. Instrumentation unique to a test will be listed in the test plan. If other parameters and/or measuring devices other than the ones listed below are used, the permissible error will be justified in the test plan.

Parameter	Measuring Device	Permissible Error of Measurement (1σ)
Contamination density or surface activity.	Direct radioactive counting by semi-conductor, scintillator, or gas-filled detectors[a].	± 30 percent[b]
Particle size.	Particle size analyzer.	± 5 percent
Particle number density[c].	Direct radioactive counting by semi-conductor, scintillator, or gas-filled detectors and correlation to the amount of particulate material.	± 5 percent
Residual contaminant in samples from test articles, rinsate, or other samples.	Direct radioactive counting by semi-conductor, scintillator, or gas-filled detectors.	± 30 percent
Temperature.	Thermocouple, remote temperature device, thermometer, or equivalent.	± 0.5 °Celsius (°C)[d]
Relative Humidity (RH).	Hygrometer or equivalent.	± 5 percent. (**NOTE**: This means that for an RH of 50 percent, 45-55 percent is within specifications.)
Absolute Humidity (AH).	Psychrometer, hygrometer, or equivalent.	± 5 percent. (**NOTE**: This means that for an AH of 10 g/m^3, 9.5-10.5 g/m^3 is within specifications.
Residual contaminant in samples from test articles, rinsate, or other samples.	Direct radioactive counting by semi-conductor, scintillator, or gas-filled detectors.	± 30 percent

Parameter	Measuring Device	Permissible Error of Measurement (1σ)
Residual contaminant in samples from test articles, rinsate, or other samples.	Direct radioactive counting by semi-conductor, scintillator, or gas-filled detectors.	± 30 percent
Temperature.	Thermocouple, remote temperature device, thermometer, or equivalent.	± 0.5 °Celsius (°C)[d]
Relative Humidity (RH).	Hygrometer or equivalent.	± 5 percent. (**NOTE**: This means that for an RH of 50 percent, 45-55 percent is within specifications.)
Absolute Humidity (AH).	Psychrometer, hygrometer, or equivalent.	± 5 percent. (**NOTE**: This means that for an AH of 10 g/m^3, 9.5-10.5 g/m^3 is within specifications.
Differential pressure (ΔP) for test chambers of fixtures only.	Pressure transducer.	± 12.5 Pascal (±0.09 millimeter (mm) Mercury (Hg), or ± 0.05 inches water gauge).
Test sample density[e].	Pycnometer, Archimedes method, mercury porosimetry, calipers and balance.	± 5 percent
Test sample dimensions.	Micrometer or equivalent.	± 1 percent
Test sample surface area.	Dinitrogen (N_2) absorption or equivalent[f].	± 10 percent
Test sample porosity.	Pycnometer, Archimedes method, mercury porosimetry, calipers and balance[g].	± 20 percent
Liquid sample specific gravity.	Volumetric glass- or plastic ware and balance.	± 5 percent

Parameter	Measuring Device	Permissible Error of Measurement (1σ)
Visual record (still).	Digital color camera.	Resolution adequate to document details of testing.
Visual record (video).	Digital video camera.	Resolution adequate to document details of testing.
Material elemental composition.	X-ray fluorescence, x-ray diffraction.	± 20 percent
Solution elemental composition.	Mass spectrometry, atomic or molecular absorption spectrometry, atomic or molecular emission spectrometry.	± 15 percent of the mass or activity of the contaminant per sample or within ± 25 percent of the device Minimum Quantification Limit (MQL).
Organic molecular composition.	Gas chromatography, liquid chromatography, mass spectrometry, nitrogen analyzers, carbon analyzers.	± 15 percent of the mass per sample or within ± 25 percent of the device MQL.

NOTES: [a] See Paragraph 4.10.d and Tables B-1 and B-2 (Appendix B) for a description of different instruments and detectors used for surface and volume contamination measurements.

[b] Per NATO STANAG 4521[2].

[c] See Appendix C for guidance on calculating particle number density with direct readings.

[d] Per AEP 7[3].

[e] Density of a solid body is sub-divided into true density and bulk density (or volumetric mass density). True density is the mass of solid divided by the volume of the mass of the solid only (excluding any fluid such as air). True density omits the effect of porosity on a solid mass. Bulk density or volumetric mass density is calculated from the mass of the solid divided by the total volume of the solid body. Bulk density includes the porous volume of the solid body.

[f] Brunauer-Emmett-Teller (BET) Method per International Organization for Standardization (ISO) 9277:2010[4].

[g] The sample porosity is calculated by dividing the difference in the true density and bulk density by the true density and is unitless. See also Table 5-1 of American Petroleum Institute (API) Recommended Practice (RP) 40[5].

2.3 Test Controls.

Parameter	Tolerance (unless otherwise specified)
Positive control (contaminated but not decontaminated) using test articles.	Concentration, in (mass or activity)/area, ± 15 percent, or at the MQL ± 25 percent. Contaminant per sample, in (mass or activity)/volume, ± 15 percent, or at the MQL ± 25 percent.
Negative control (not contaminated, but decontaminated residual liquid) using test articles.	Concentration, in (mass or activity)/area, ± 15 percent, or at the MQL ± 25 percent. Contaminant per sample, in (mass or activity)/volume, ± 15 percent, or at the MQL ± 25 percent.
Dose confirmation samples. May be taken before, during, and after test article contamination.	Contaminant per sample, in (mass or activity)/area, ± 15 percent, or at the MQL ± 25 percent.
Process quality samples for Gas Chromatograph (GC), Liquid Chromatograph (LC), Inductively-Coupled Plasma (ICP), optical emission spectroscopy, or Atomic Emission Spectroscopy (AES), or mass spectroscopy, or equivalent. These may be samples of a known mass or periodic calibration standards.	Contaminant per sample, in mass or activity, ± 15 percent, or at the MQL ± 25 percent.

3. REQUIRED TEST CONDITIONS.

3.1 Familiarization.

The test planning phase includes identifying potential problem areas by reviewing previous records and the results of similar tests. Review and consider data from previous similar tests to avoid duplication of testing. This review may possibly reduce the scope of the current test effort. Relevant laboratory and method-specific Standing Operating Procedures (SOPs) and other procedures should be reviewed for applicability, completeness, and adequacy.

3.2 Test Planning.

a. Based on the testing requirements in the test planning documentation [Test and Evaluation Master Plan (TEMP), Systems Engineering Plan (SEP), etc.], a test plan will be developed that will include, at a minimum, a test design, test execution matrix, detailed procedures, Quality Assurance/Quality Control (QA/QC) measures, data management, statistical data analysis, and results presentation.

b. The test plan must be prepared and coordinated with all relevant stakeholders, and approved by the test site before any testing begins. The test procedures described herein must be used as the basis for the test plan; however, the procedures may require modification for unique items or materials to satisfy specific testing requirements in a TEMP, SEP, or other program-specific documentation. Deviations from these procedures will be coordinated among all concerned organizations in advance of any testing, giving consideration to the possible effects the changes may have upon the validity and adequacy of the data. Any deviations from this TOP and the rationale for the deviation will be described in the test plan.

c. Test Design. The sample size of test articles for test methods identified in this TOP may be determined based on design of experiment, confidence required by the customer, test article size, availability, cost, or other factors. If the sample size is less than recommended, as decided by the test sponsor, a test execution matrix will be devised to maximize the ability to meet stated objectives and criteria. Statistical confidence limits will be calculated and reported.

d. When using a fallout simulant in the conduct of this TOP, the selected properties of the simulant will be verified as being as closely related to those of the contaminant as possible, with regards to the scientific principle of operation of the decontamination technology being tested. Because simulants do not have all of the same physical and chemical properties as the agent, simulant data alone are not sufficient to determine decontaminant performance. A real-simulant relationship must be established and coordinated with the test program community of interest before testing begins. See paragraph 4.8 for recommended simulants for radionuclides that have been considered in the past.

e. Security. Security considerations will be adequately determined and provided for in the planning of each test program. The Security Classification Guide (SCG) designated for each program and the installation Operations Security (OPSEC) requirements or equivalent for each facility will be followed. Additional security considerations may be required that are specific to the receipt, testing, storage of radiological materials, and its waste.

f. Test Incident Report (TIR). Unless waived by the test sponsor, TIRs (or equivalent reports), will be prepared and distributed IAW United States (U.S.) Army Test and Evaluation Command (ATEC) Regulation 73-1[6] and Department of the Army (DA) Pamphlet (PAM) 73-1[7] (Appendix V-9).

3.3 Documentation.

The Test Officer (TO) or principal investigator will have all pertinent documentation available for test planning. These documents may include government and manufacturers' publications, requirements documentation, test planning directive, TOPs, SOPs, Safety Data Sheets (SDSs), approved test plan, SCG, etc., as applicable/required.

3.4 Environmental Documentation.

The test plan must cite the approved environmental documentation for each test program.

3.5 Test Readiness Review.

If required, programs will undergo a test readiness review (as required by the performing organization's internal procedures before testing begins to ensure that the necessary resources are available to effectively and efficiently conduct the test. Representatives from essential organizations involved in the test program, which may include Warfighters, program office representatives, Test and Evaluation Integrated Product Team (T&E IPT) representatives, Operational Test Agency (OTA) representatives, and contractor(s), will participate in this review and provide input to the proposed testing. The designated TO or TO's delegate will conduct this review and present the status of all critical elements.

3.6 Safety.

a. Only facilities and organizations with appropriate license and regulatory approval to operate as a radiological facility may conduct work with unsealed radiological material and handle generated wastes. The primary emphasis in testing must be safety.

b. The safety rules and regulations established for such approved facilities and organizations will be followed. Appropriate health and safety practices for the execution of procedures in this TOP and handling of generated wastes should be established by the testing organization.

c. A composite risk management or hazard analysis may be required by the testing organization.

d. A preoperational safety survey/inspection may be required before testing can begin.

e. The SDS(s) for the decontaminant(s), contaminant(s), and associated reagents will be reviewed and maintained according to the approved laboratory procedures.

3.7 Quality Assurance / Quality Control (QA/QC).

a. A chain-of-custody process will be established before testing by labeling all test articles and all test samples to allow tracking of the data flow from test initiation to final data and to prevent misidentification during the test process.

b. The test control samples will be used to demonstrate control of the test process across trials and throughout the analytical process.

c. The radioanalytical analysis procedures will be conducted using best laboratory practices and methodologies where available and applicable to the specific samples, standards, blanks, and analytical controls associated with a specific test. Sources for these practices and methods includes the American Society of Testing and Materials (ASTM) International (https://www.astm.org), the International Organization for Standardization (ISO) (https://www.iso.org/standards.html), the National Environmental Methods Index (NEMI) (http://www.nemi.gov), and the Environmental Protection Agency (EPA) (https://www.epa.gov/homeland-security-research/sam).

d. Radionuclide source material will have documented total activity with respect to total activity and isotopic concentration either from manufacturer's certificate or subsequent analyses. These analyses shall be completed before test initiation and periodically thereafter. The purity of the source material must be analytically demonstrated at a frequency determined by the testing organization or based on the half-life of the radionuclide used.

e. All aspects of the testing will be performed with emphasis on acquiring valid, credible, repeatable, and verifiable data.

3.8 Verification and Validation (V&V).

Modifications to the procedures or test equipment (fixtures, instrumentation, etc.) must be reviewed for impact on the data collected during testing. Modifications that have a significant impact on the data will need to be verified and/or validated. Fixture modifications must be documented in the configuration control plan. Procedure modifications must be documented as soon as possible in SOPs or other controlling documents. Modifications may be necessary because of technical upgrades at the test site, test system requirements, or requirements of the test sponsor.

4. TEST PROCEDURES.

4.1 General.

a. Two types of test controls, the positive control and the negative control, will need to be used during trials. The number of controls used will be outlined in the test planning documentation.

(1) Positive Control. Positive controls use the same type of test article challenged with the same contaminant and density as the trial test article. The same test procedures are used; however, positive control test articles do not undergo decontamination. **NOTE**: Test personnel should not assume that positive controls will always have measurable contaminant. For example, it is possible that contaminant may be lost as a result of weathering or evaporation, even though no decontaminant is applied. Some radionuclides are volatile at low (e.g., iodine isotopes) or elevated temperatures (e.g., cesium isotopes).

(2) Negative Control. For negative controls, no contaminant is applied to the test articles which undergo all other test procedures with the trial test article. Positive analytical results for contamination on a negative control are an indication of cross contamination most likely showing poor test process control.

b. Test Article Blanks. A single test article of each unique type (e.g., a black painted aluminum coupon, a white painted aluminum coupon, a cabin coolant fan) that passes receipt inspection (paragraph 4.5) shall be counted identically to the test articles undergoing trial testing. The measured values will constitute the background counts for the purpose of determining the decontamination efficacy (paragraph 4.10).

c. Collect background counts for the test site.

4.2 Test Method Outline.

a. Receipt Inspection (paragraph 4.6).

b. Trial Preparation Tasks (paragraph 4.7).

c. Radioisotope Contamination (paragraph 4.8).

d. Application of the Contaminant (paragraph 4.9).

e. Aging of the Contaminant (paragraph 4.10).

f. Decontamination Efficacy (paragraph 4.11).

g. Decontaminant Pot Life (paragraph 4.12).

h. Shelf Life/Accelerated Aging (paragraph 4.13).

4.3 Hazards.

a. Identified safety hazards are those associated with testing using radioactive materials (internal and external dose hazards), simulants (chemical toxicity), and hazardous decontaminant chemicals (e.g., oxidizers, acids, bases) at temperature and pressure. Chemical safety guidelines can be found in Occupational Safety and Health Administration (OSHA) Laboratory Safety Guidance (3404-11R 2011[8]), and the OSHA Occupational Chemical Database, and 10 Code of Federal Regulations (CFR) Part 851[9]. Nuclear and radiological safety guidelines can be found in the U.S. Nuclear Regulatory Commission (NRC) Regulation 10 CFR Part 20[10] Standards for Protection Against Radiation.

b. A test plan must be developed with a safety section (which may include a composite risk management) identifying and addressing all safety concerns for each test conducted using these methods IAW Army Regulation (AR) 385-10[11]. The safety section of the test plan will be coordinated with the test site’s safety office.

4.4 Calibration of Chemical Analytical Equipment and Standards.

General chemical analytical calibration guidelines are found in best laboratory practices (e.g., practices in ISO 17025[12]). These guidelines can be used for calibrating most chemical analytical equipment (e.g., gas chromatographs, liquid chromatographs, ICP) and must be used whenever possible. Refer to TOP 08-2-061A[13] for building calibration curves using standard chemical reference materials.

4.5 Calibrations of Radiation Counting Equipment and Standards.

a. General radiological calibration guidelines are found in best laboratory practices ASTM D3648-14 Standard Practices for the Measurement of Radioactivity[14], which provides a thorough overview of considerations in calibrating various detection systems for radioisotopes. Other guidelines include Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) NUREG-1576[15] chapters 15 and 20; American National Standards Institute (ANSI) Standard N42.14 Calibration and Use of Germanium Detectors for the Measurement of Gamma-Ray Emission Rates of Radionuclides[16]; ISO 9696:2017 Water Quality - Gross Alpha Activity - Test Method Using Thick Source[17]; ISO 9697:2018 Water Quality - Gross Beta Activity - Test Method Using Thick Source [18]; ISO 9698: 2019 Water quality - Tritium - Test Method Using Liquid Scintillation Counting [19]; ISO 10703:2007 Determination of the Activity Concentration of Radionuclides By High Resolution Gamma-Ray Spectrometry[20].

b. Calibration. Each instrument should be calibrated at a frequency in accordance with the organizations and/or manufacturers procedures and response-checked with a source following calibration. Calibration procedures of survey instruments that might be included in the test plan can be taken from Environmental Implementation Guide for Radiological Survey Procedures - 1997[21], and is further discussed below. Recalibration of field instruments is also required following maintenance that could affect the validity of the *a priori* calibration. The calibration interval may be longer if the manufacturer can document that the extended frequency adequately ensures the validity of the data obtained with the equipment. Calibrations should be traceable to the National Institute of Standards and Technology (NIST). Where NIST-traceable standards are not available, standards of an industry-recognized organization (e.g., the New Brunswick Laboratory for various uranium standards) may be used. The user may decide to perform calibrations following industry recognized procedures (ANSI N323A-1997[22], Department of Energy (DOE) Order 5484.1[23], National Council on Radiation Protection (NCRP) Report 57 - 1978[24], NCRP Report 58 - 1985[25]) or may choose to obtain calibration by an outside service, such as a major instrument manufacturer or a health physics services organization. Calibration for surface activity should be performed such that a direct instrument response can be accurately converted to the 4π (total) emission rate from the source, and should be consistent with the following where necessary:

(1) Calibrations for point and large-area source geometries may differ, and both may be necessary if areas of activity smaller than the probe area and regions of activity larger than the probe area are present.

(2) Calibration should be performed with the reference source for the appropriate type of radiation.

(3) Conversion factors developed during the calibration process should be for the same counting geometry to be used during the actual use of the detector[21].

(4) Response Check. Periodic checks of instrument response are necessary to ensure that the calibration has not changed. Following calibration, the response of each instrument to a check source is determined, and an acceptable response range is established.

(a) For readout (count rate) instruments, a variation of ± 20 percent is considered acceptable (References 22 through 25). Instrumentation that integrates events and displays the total on a digital readout typically provides an acceptable average response range of two or three standard deviations. This is achieved by performing a series of repetitive measurements (10 or more is suggested, but the actual number will depend on the nature of the tested radionuclides and articles tested) of the check source response and determining the average and standard deviation of those measurements. From a practical standpoint, a maximum deviation of ± 20 percent is usually adequate when compared with other uncertainties associated with the use of the equipment.

(b) The amount of uncertainty allowed in the response checks should be consistent with the level of uncertainty allowed in the final data.

(c) It is ultimately up to the investigator and the stakeholders to determine what level of uncertainty is acceptable. Instrument response, meaning both the background and source check response of the instrument, is tested and recorded at a frequency which ensures that the data collected with the equipment is reliable.

(d) For most portable radiation survey equipment, a response check should be performed at a minimum of twice daily - typically before beginning the day’s measurements and again following the conclusion of measurements on that same day.

(e) If the instrument response does not fall within the established range, the instrument is removed from use until the reason for the deviation can be resolved and acceptable response again demonstrated. If the instrument fails the post-survey source check, then all data collected during that time period must be carefully reviewed and possibly discarded, depending on the cause of the failure.

(f) Ultimately, the frequency of response checks must be balanced with the stability of the equipment being used under field conditions and the quantity of data being collected. For example, if the instrument experiences a sudden failure during the course of the day’s work because of physical harm, such as a punctured probe, then the data collected up until that point may be kept unless there is reason to suspect the integrity of the calibration (e.g., outlying data points) since a post-use performance check cannot be performed.

(g) Likewise, if no obvious failure occurred but the instrument failed the post-use response check, then the data collected with that instrument since the last response check should be viewed with great skepticism and possibly recollected or randomly checked with a different instrument. If recalibration is necessary, acceptable response ranges must be re-established and documented.

4.6 Receipt Inspection.

a. Test articles may consist of coupons, panels, or equipment items of various sizes (see Appendix A for more information).

(1) Coupons are generally small materials or subsections of a material that are suitable for replicate analysis. Coupons are generally small enough that they can be accurately counted in the detector volume or appropriately scanned as a single object without moving the coupon relative to the detector.

(2) Panels are larger materials, subsections of a material, or the entire section of a material. Panels tend to be flat or curved in geometry but are too large to be accurately counted in the detector volume or appropriately scanned as a single object without moving the coupon relative to the detector.

(3) Equipment items are entire pieces of equipment or an assemblage of pieces of equipment that may range in size from small (coupon size) to large (panel size or larger) and can be of complex geometry.

(4) The test articles will be subjected to a visual receipt inspection after arrival at the test site. Evidence of damage or irregularities in the test articles will be recorded in the laboratory record keeping system and will be documented by still photographs. Damage and irregularities to be considered will include, but are not limited to, the following (if applicable):

(a) Corrosion.

(b) Broken connections.

(c) Cracked or deteriorated surfaces.

(d) Contamination with foreign material.

(e) Discoloration.

(f) Evidence of deterioration or illegible markings.

(g) Incorrect number of items.

(h) Missing components, instructions, or manuals.

(i) Determine if the test article can be operated and/or is operational.

b. Each test article's model, serial number, nomenclature, identifier, manufacturer, lot number, and other pertinent information/indicators, if applicable, will be recorded in the laboratory record keeping system. Assignment of a Test Item Control Number (TICN) to the test article is mandatory for identification and tracking. The TICN will be marked on small items of equipment in a location that will not interfere with test procedures or on the reverse side. The TICN and other pertinent information about the test article will be linked in the laboratory record keeping system. The tests must be conducted as to not remove the TICN or there must be procedures established to maintain the identity of the TICN if removed by a test (e.g., relabeling the test item after test completion).

c. If any items are determined to be not fit for testing, they will be rejected and the customer will provide replacements that are in suitable condition for testing.

4.7 Trial Preparation Tasks.

a. Test personnel will ensure that all necessary equipment, materials, reagents, and analytical capabilities are available for the test.

b. Any data analysis calculations required will be identified to ensure the necessary data are collected.

c. Use active ingredients and reagents for preparation of decontaminant formulations as received. Purity will be established based on supplied purity documents and will be selected to be appropriate for the tests to be performed. Chemicals used as solvents will be purchased in the purity sufficient for the test from the manufacturer or distributor. Simulants will be purchased in the purity sufficient for the test from the manufacturer or distributor.

d. Prepare decontaminants IAW the manufacturer's instructions. Perform quality checks as necessary by routine analytical methods (such as pH (Hydrogen ion concentration) measurement, titration, etc.).

e. Test fixtures will be powered on and allowed to equilibrate at the specified test conditions. Test personnel will confirm that all equipment is operational before the start of the test.

f. Test personnel will complete the test setup, labeling of vials, trays, jars, etc., and other associated pretest tasks.

g. Test articles may require cleaning before testing to remove cutting oils or other preparation contaminants. TICN-labeled test articles or small equipment articles will be stored in a secure, environmentally-controlled location. The test articles will be protected from unrelated environmental contaminants and degradation.

h. Test personnel will ensure that all calibrated instrumentation have a current calibration.

4.8 Radioisotope Contamination.

a. General. Radiological isotopes will be utilized to conduct decontaminant testing. This would ensure that the relevant chemical and physical properties of the contamination are being represented during testing.

b. Simulants. The use of an alternative radioactive or non-radioactive isotope as a simulant may be advantageous to reduce radiation or health hazards, to reduce costs, to facilitate procurement of materials, to facilitate waste disposal, to facilitate measurements, etc. Isotopes will differ in terms of half-life so test personnel shall ensure that the half-life of the simulant isotope is sufficiently long to complete the tests or provide the procedure for accounting for decay during testing in the test plan. Example radionuclides and their recommended alternatives are given in Table 1. Substitutes shall be documented in the test plan with justification.

TABLE 1. RADIONUCLIDES AND THEIR RECOMMENDED RADIOACTIVE ISOTOPES

RADIONUCLIDE	PHYSICAL FORM	RADIOACTIVE ISOTOPE	NON-RADIOACTIVE ALTERNATIVES
Cesium (Cs) ^{134}Cs, ^{137}Cs	Cesium Chloride (CsCl) or other highly soluble salts of cesium.	^{134}Cs, ^{137}Cs, Rubidium (Rb) ^{85}Rb.	Natural Cs, Na, Potassium (K)
	Cs Alumino-Silicate or other inert[a] particulate.	Any radionuclide-tagged, inert particulate of representative particle size range and density (e.g., Lanthanum (La) ^{140}La-*tagged silica*).	Any particulate of representative particle size range and density.
Strontium (Sr) ^{90}Sr	Strontium Fluoride (SrF_2) or other highly soluble salts of Sr.	^{85}Sr, ^{89}Sr.	Natural Sr.
	Sr titanate or other inert particulate.	Any radionuclide-tagged, inert particulate of representative particle size range and density (e.g., ^{140}La-*tagged silica*).	Any particulate of representative particle size range and density.
Iridium (Ir) ^{292}Ir	Metal alloy	Any radionuclide-tagged metal or metal fragments that represent the expected contamination.	Natural Ir metal alloy.

TABLE 1. CONTINUED

RADIONUCLIDE	PHYSICAL FORM	RADIOACTIVE ISOTOPES	NON-RADIOACTIVE SIMULANT
Americium (Am) ^{241}Am	Americum Oxide (Am_2O_3), Americium Dioxide (AmO_2)	Europium (Eu) ^{152}Eu, ^{154}Eu, ^{140}La, other lanthanide gamma-emitters.	Any natural lanthanide series element (e.g., Eu).
	Soluble salt of Am.	Soluble salt of ^{152}Eu, ^{154}Eu, ^{140}La, other lanthanide gamma emitter.	
Cobalt (Co) ^{60}Co	Co metal or metal alloy.	Any radionuclide-tagged metal or metal fragments that represent the expected contamination.	Natural Co. Any metal or metal fragments of representative particle size range and density.
	Soluble or insoluble salts of Co.	^{58}Co, Nickel (Ni) ^{65}Ni.	Natural Co.
Plutonium (Pu) ^{239}Pu Uranium (U) ^{235}U, ^{238}U	Oxides.	Cerium (Ce) ^{141}Ce, ^{144}Ce, Thorium (Th) ^{232}Th.	Natural Ce, Natural Th.
	Soluble salt of U and Pu.	^{141}Ce, ^{144}Ce, ^{232}Th as soluble salt.	
Tritium (^{3}H)	Water (H_20) $^{3}H_2O$.	$^{3}H_2O$.	H_2O or deuterated water (*HDO* or D_2O).
Nuclear fallout	Particulate.	Any radionuclide-tagged, inert particulate of representative particle size range (e.g., ^{140}*La-tagged silica*).	Any inert particulate of representative particle size range.
Tartar or contaminated mud[b]		^{140}*La carbonates*.	Zinc Sulfide (ZnS).

NOTES: [a] Inert is used to describe radioactivity that is fixed to a solid particulate and neither it nor the particulate can be dissolved into water or the decontaminant.
[b] Referenced from AEP-7 Edition 5, Table 6-1.

4.9 Application of the Contaminant.

a. General. The choice of approach for application of contamination should be appropriate for the physico-chemical properties of the contaminant, as discussed in paragraph 4.8. In addition, it should be appropriate for the physical type of contamination that is expected from a release and also properties of the expected radionuclide contamination that will be encountered. These two factors are discussed below. The test plan should describe the contamination that is to be tested and also provide a justification for the choice of physical contamination type to be used in testing the decontamination efficacy.

b. Physical Type of Contamination Applied to the Test Article.

(1) Particulate Contamination. The method (see Paragraph 4.9.b(2)(e) for examples) of contaminating test surfaces with particulate contaminations should mimic the physical properties of the particulate contamination that will be encountered (see Appendix D for brief description of particle size considerations for contaminants). It is important to note that when mixing dried particles containing radioactivity, the user must ensure proper safety practices are followed to avoid the production of inhalable radioactive dust that may result from mixing and handling the particles.

(a) Warming[26] describes a method of tagging silica-based sand of different mesh size with radioactive lanthanum-140 as a surrogate for solid, inert fallout particles at different distances from a nuclear detonation. The La-140 was added into solution of liquid glass (sodium silicate) and added as a liquid to dry sand, mixed thoroughly to homogenize the sample, and dried. The sand was spread in a controlled and reproducible manner with a broadcast spreader to cover large, paved test areas. Particles from other types of contamination events that may be encountered may differ in size range, density, and morphology. For smaller areas, EPA used a similar approach to prepare the particles, which were then loaded into a salt shaker for a higher level of control during deposition[27].

(b) Defense Research and Development Canada-Ottawa (DRDCO) described the manufacture of simulated nuclear weapon fall-out material with radioactive contamination using a method of labeling common sand with liquid samples containing radioactive liquid and then homogenizing the samples and then drying the resultant for use in evaluating dry methods of decontamination[28]. A related report[29] describes a method for preparation of simulated fallout for Sr-85, Na-24, and La-140 where sand is contaminated with liquid radioactive solution, homogenized, and dried for use in experiments for decontamination by vacuuming.

(c) Radioactive powder can be distributed onto a surface to mimic a powder-type contamination. The test article surface is pressed lightly into a container of the powder under a weighted plate for a specified period of time. Afterward, the test sample is removed from the powder and tapped lightly several times on a hard surface to remove loosely bound particles.

(d) The contaminated powder is spread across the test sample surface using an appropriate spreader such as a sifter or sieve. Afterward, the test sample is removed and tapped lightly several times on a hard surface to remove loosely bound particles.

(e) Contamination may be dissolved into an appropriate volatile, dry solvent (e.g., methanol) (see EPA/600/R-12/068[30]) and spread across the test surface using an appropriate method (e.g., by Droplet Method or Aerosol Method).

(f) Particle contamination should be applied in a manner that is reproducible. The reproducibility of the method will be documented and tested periodically to ensure the expected activity and physical form of the contamination is consistent between test samples.

(2) Liquid Contamination. The liquid contaminations should mimic the chemical properties of the liquid contamination that will be encountered. These include oxidation state of the radionuclide or surrogate, pH of the solution, redox potential of the solution, and

concentration of other chemicals. Deviations from the known properties of the liquid contamination that will be encountered shall be documented with justification.

(a) Liquid contamination should be applied in a manner that mimics the physico-chemical properties of the liquid contamination that will be encountered.

(b) Liquid contamination should be applied in a manner that is reproducible. The reproducibility of the method will be documented and tested periodically to ensure the expected activity and chemical form of the contamination is consistent between test samples.

(c) Liquid contamination may be applied by appropriately dispensing a liquid contaminant onto the test surface.

(d) Acceptable methods of dispensing the liquid contaminant include aspiration, spraying, or dripping a volume of solution and spreading the liquid across the surface.

(e) Methods for aspirating liquid contaminant with dissolved ^{137}CsCl onto small test coupons is described in EPA 600/R-13/001[31] and by Argonne National Laboratory[32].

1 Droplet Method. The test article surface is covered with droplets of a solution containing the contaminant, covering the surface as thoroughly as possible[32]. This can be accomplished using a dropper or pipette. Each set of test articles receive the same volume of solution. The solution is allowed to dry with an appropriate method such that the desired chemical form of the contaminant is unaltered. For example, if the salt of a contaminant (e.g., Uranium) is dried in an oven at high temperature, it is possible to convert from the salt to the oxide, which changes the chemical reactivity compared to its native salt form.

2 Aerosol Method. An aerosol delivery device can be purchased or constructed. Idaho National Laboratory developed a delivery device constructed of two syringes. The plunger and needle were removed from the first syringe and discarded, then a compressed air line was attached to the rear of the syringe. The second syringe contained the contaminant solution and was equipped with a 27 gauge needle, which penetrated through the plastic housing near the tip of the first syringe. Compressed air flowing at a rate of approximately 1-2 liters per minute created a turbulent flow through the first syringe. When the contaminant solution in the second syringe was introduced, the contaminant solution became nebulized by the turbulent air flow. A fine aerosol was ejected from the tip of the first syringe, creating a controlled and uniform spray of fine liquid droplets onto the coupon surface. The contaminant spray was applied all the way to the edges of the coupon, which were taped (after having previously been sealed with polyester resin) to ensure that the contaminant was applied only to the surfaces of the coupons (see EPA/600/R-12/068[30]).

3 Dry Aerosol Contamination. Dry aerosols may be appropriate, particularly when the solvent used for liquid contamination is expected to alter the interaction between the test article and the radionuclide of interest.

4 Dry aerosol contamination may be applied by appropriately dispensing an aerosol contaminant onto the test surface. The aerosol contaminant should be spread uniformly across the test surface. Dry aerosol contamination should be applied in a manner that is reproducible. The reproducibility of the method will be documented and tested periodically to ensure the expected activity and chemical form of the contamination is consistent between test samples.

(f) A method for appropriate dry aerosol contamination is reported in EPA/600/R-12/068[30], involving spreading an aerosol of contamination dissolved in a volatile solvent (e.g., methanol) to mimic a dry deposition of soluble radioactive contaminant. This aerosol was applied to coupons and the solvent allowed to evaporate leaving the dry, radioactive compound residue.

(g) Other Surrogate Forms of Contamination. While the above contamination approaches encompass a variety of scenarios in which a test article may become contaminated in the field, they are not comprehensive of all scenarios. It may be necessary to develop a contamination approach for a specific contaminant, release scenario, and test article. Any new method of preparing and dispensing radioactive contaminant or surrogate should be tested for physico-chemical similarity with the expected contaminant that will be encountered. Accordingly, the test plan will describe method development of the approach to contaminate the TICN, including justification for methods chosen.

(h) Radioactive contaminant encountered in the field may be in the form of a slurry (combination of water and solid).

(i) Radionuclide contamination within a jet engine may require a proper development protocol to produce a contamination that experiences the time, temperature, pressure environment that characterizes intake and transport through a jet engine. Such contaminations may take on forms that are unique and unexpected.

c. Concentration of Contaminants. The concentration of contaminants should represent the range of expected values. This may be expressed in terms of mass concentration (e,g, $\mu g/m^2$) or activity concentration (e.g., $\mu Ci/m^2$, Bq/m^2) normalized to surface area. The amount of radioactivity should be optimized to reduce the initial contamination required while still maintaining the desired level of contamination. For conditions where high levels of radioactive contamination are justified, the use of non-radioactive surrogates for the specific radionuclide may be justified in terms of safety.

NOTE: The starting challenge and residual levels of contaminants are established by the requirements office/program office. See Appendix E for summary discussion of reference values established under STANAG-2473[33].

4.10 Aging of the Contaminant.

a. General. Contaminated test articles should be aged to represent the potential field environment. Radioactivity does not age but decays. However, the radioactive material can chemically bond or otherwise weather in a way that can affect decontamination efficacy and hence is an important consideration. This may include maintaining a constant or variable temperature, RH, light intensity, etc. for a duration that represents the expected field conditions or that is needed to produce a desired effect. Aging is important to consider since the effects of aging can alter the chemical form of the native contamination (e.g., converting a salt into an oxide) or can cause or increase the rate of chemical bonding of the native contaminant to the surface (e.g., transport of cesium into the interlayers of clays ubiquitous on building materials).

b. Equilibrium. It is often desirable to allow the contamination to age on the surface of the test article material until an environmental equilibrium has been established. The exact aging time may require a separate test to determine the time to reach equilibrium.

c. Equilibrium Testing.

(1) Test articles are contaminated using the appropriate method (See paragraph 4.8).

(2) Replicate test articles (usually ≥ 3 or as needed to enable appropriate statistical interpretation of results) are placed in the appropriate environment (e.g., temperature, RH, irradiance) and removed at time steps until equilibrium is established.

(3) The time to reach equilibrium is used to age samples for subsequent Decontamination Efficacy tests.

d. Accelerating the Approach to Equilibrium. Many factors (temperature, redox potential, pH) may affect equilibrium kinetics, and the test plan shall describe the choice of method to induce accelerated aging and provide justification. For example, increased temperature may reduce equilibration times or accelerate slow reactions to represent the potential field contaminations. An example testing approach using temperature follows.

(1) Replicate test articles (≥ 3) are placed in the appropriate environment (e.g., RH, irradiance), with fixed temperature $T=T_1$, and removed at time steps until equilibrium is established.

(2) Replicate test articles (≥ 3) are placed in the appropriate environment (e.g., RH, irradiance), with fixed temperature $T=T_2$, and removed at time steps until equilibrium is established.

(3) This may be repeated as necessary to establish the relationship for the time to reach equilibrium as a function of temperature. The equilibrium time can be identified by plotting the observance of equilibrium (such as fraction of contaminant in a certain chemical form) versus time and determine when the observance of equilibrium has attained a steady value.

e. Method.

(1) Contaminated test articles are placed at the proper environmental conditions.

(2) Replicate test articles (≥ 3) are placed in the appropriate environment (e.g., temperature, RH, irradiance) and removed after the established aging time.

4.11 Decontamination Efficacy.

a. General. The DOE Environmental Implementation Guide for Radiological Survey Procedures[21] describes the instrumentation and methods for counting smears (loose contamination), solid samples, and water samples by gas-filled detector, liquid scintillation, gamma spectroscopy (scintillator and semiconductor). The values for surface contamination are generally expressed in Bq/cm². Methods for deriving surface contamination values are usually based on appropriate models and scenarios. Examples can be found in ANSI/Health Physics Society (HPS) N13.12-2013[34].

b. Absolute Measurement and Relative Measurements. Absolute measurements relate the measured activity to a concentration of radioisotope or its simulant on the material such as in µg/m², µCi/m², or Bq/m². This requires correlating the measured activity using a detector type to its absolute quantity (usually measured in terms of mass or activity) (see paragraph 4.4). For most measurements of radioactive contaminants, the relative counting method is preferred. In the relative counting method, the initial activity of the test sample (minus the appropriate background and test article blank values) is measured using a detector type, and the activity after decontamination or during the decontamination cycle is measured under identical analytical conditions (minus the appropriate background and test article blank values). The relative reduction in activity is recorded to quantify the percent removal of radioisotope and/or the Decontamination Factor (see Section 5).

c. Calculating Decontaminant Removal and the Decontamination Factor. The decontamination efficacy of the decontamination agent for each radionuclide is measured for each contaminated item in terms of percent removal (%R) and/or the Decontamination Factor (DF). Both of these measurements provide a means of representing the extent of decontamination accomplished by a technology. The %R gives the extent as a percent relative to the activity, and the DF is the ratio of the initial activity to the final activity or the factor by which the activity was decreased. These terms are defined by Equations 1 and 2. This procedure assumes the half-life of the chosen radioisotope is sufficiently long that there is insignificant change in activity because of its half-life. If short-lived isotopes are chosen, then the effect of decay may need to be computed, and the means to quantify such decay provided in the test plan (e.g., see Section 12.4 of ASTM E181 - 2017[35]).

$$\%R = \left(1 - \frac{A_f}{A_o}\right) \times 100\% \qquad \textit{(Equation 1)}$$

where:

A_f = the contaminant concentration on the surface of the test article after removal of the decontaminant.
A_o = the initial contaminant concentration on the surface of the test article.

$$DF = A_o/A_f \qquad \text{(Equation 2)}$$

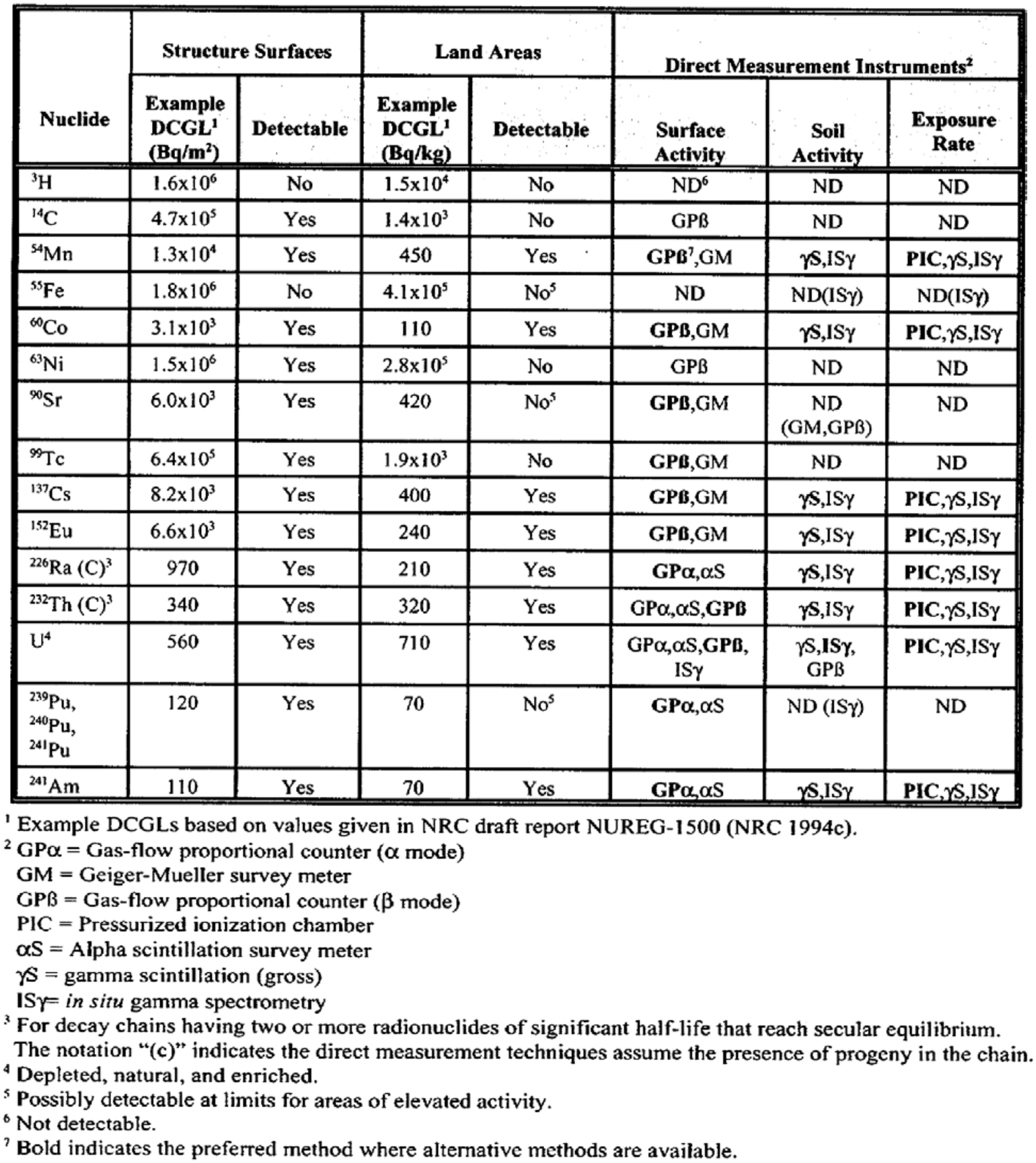
d. Measurement Methods.

(1) Selecting Instrument Type. The instrument and probe are selected based on the type of radiation to be detected (i.e., alpha, beta, gamma) and the required sensitivity range. Consult International Atomic Energy Agency (IAEA) Safety Reports Series 67[36] and Tables 2 and 3 for more information on choosing the correct instrument and probe.

(2) Minimum Detectable Concentration. For direct measurements and sample analyses, Minimum Detectable Concentrations (MDC) less than 10 percent of the Clearance Criteria Guidelines (CCG) are preferable while MDCs up to 50 percent of the CCG are acceptable (from EPA 402-R-97-016, Multi-Agency Radiation Survey and Site Investigation Manual[37] (MARSSIM)). MQL requirements will be different based on Immediate, Operational, Thorough, Clearance Levels for Field Decontamination Operations and for Radiological Clearance Criteria Guidelines. (These guidelines reference ANSI/HPS N13.12-2013, Surface and Volume Radioactivity Standards for Clearance (Reference 34). DOE Order 5400.5 (Reference 38) is the primary directive relating to the release of property subject to radiological contamination by Department of Energy operations. DOE 5400.5 will be replaced by 10 CFR Part 834 and its guidance will be adopted for Part 834 when it is issued.) Example of detection instruments and associated MDC that are recommended by MARSSIM are given in the Tables 2 and 3. Not all instruments are described in the tables, and may be thought of as being illustrative for capabilities of detection instruments in general.

TABLE 2. SELECTION OF DIRECT MEASUREMENT TECHNIQUES BASED ON EXPERIENCE

(extracted from Reference 37, Table 4.1. Derived Concentration Guideline Level (DCGL) is equivalent to Clearance Criteria Guidelines (CCG))



Nuclide	Structure Surfaces		Land Areas		Direct Measurement Instruments[2]		
	Example DCGL[1] (Bq/m^{2})	Detectable	Example DCGL[1] (Bq/kg)	Detectable	Surface Activity	Soil Activity	Exposure Rate
^{3}H	1.6x10^{6}	No	1.5x10^{4}	No	ND[6]	ND	ND
^{14}C	4.7x10^{5}	Yes	1.4x10^{3}	No	GPß	ND	ND
^{54}Mn	1.3x10^{4}	Yes	450	Yes	**GPß**[7],GM	**γS**,ISγ	**PIC**,γS,ISγ
^{55}Fe	1.8x10^{6}	No	4.1x10^{5}	No[5]	ND	ND(ISγ)	ND(ISγ)
^{60}Co	3.1x10^{3}	Yes	110	Yes	**GPß**,GM	**γS**,ISγ	**PIC**,γS,ISγ
^{63}Ni	1.5x10^{6}	Yes	2.8x10^{5}	No	GPß	ND	ND
^{90}Sr	6.0x10^{3}	Yes	420	No[5]	**GPß**,GM	ND (GM,GPß)	ND
^{99}Tc	6.4x10^{5}	Yes	1.9x10^{3}	No	**GPß**,GM	ND	ND
^{137}Cs	8.2x10^{3}	Yes	400	Yes	**GPß**,GM	**γS**,ISγ	**PIC**,γS,ISγ
^{152}Eu	6.6x10^{3}	Yes	240	Yes	**GPß**,GM	**γS**,ISγ	**PIC**,γS,ISγ
^{226}Ra (C)[3]	970	Yes	210	Yes	**GPα**,αS	**γS**,ISγ	**PIC**,γS,ISγ
^{232}Th (C)[3]	340	Yes	320	Yes	GPα,αS,**GPß**	**γS**,ISγ	**PIC**,γS,ISγ
U[4]	560	Yes	710	Yes	GPα,αS,**GPß**, ISγ	γS,**ISγ**, GPß	**PIC**,γS,ISγ
^{239}Pu, ^{240}Pu, ^{241}Pu	120	Yes	70	No[5]	**GPα**,αS	ND (ISγ)	ND
^{241}Am	110	Yes	70	Yes	**GPα**,αS	**γS**,ISγ	**PIC**,γS,ISγ

[1] Example DCGLs based on values given in NRC draft report NUREG-1500 (NRC 1994c).

[2] GPα = Gas-flow proportional counter (α mode)
GM = Geiger-Mueller survey meter
GPß = Gas-flow proportional counter (β mode)
PIC = Pressurized ionization chamber
αS = Alpha scintillation survey meter
γS = gamma scintillation (gross)
ISγ= *in situ* gamma spectrometry

[3] For decay chains having two or more radionuclides of significant half-life that reach secular equilibrium. The notation "(c)" indicates the direct measurement techniques assume the presence of progeny in the chain.

[4] Depleted, natural, and enriched.

[5] Possibly detectable at limits for areas of elevated activity.

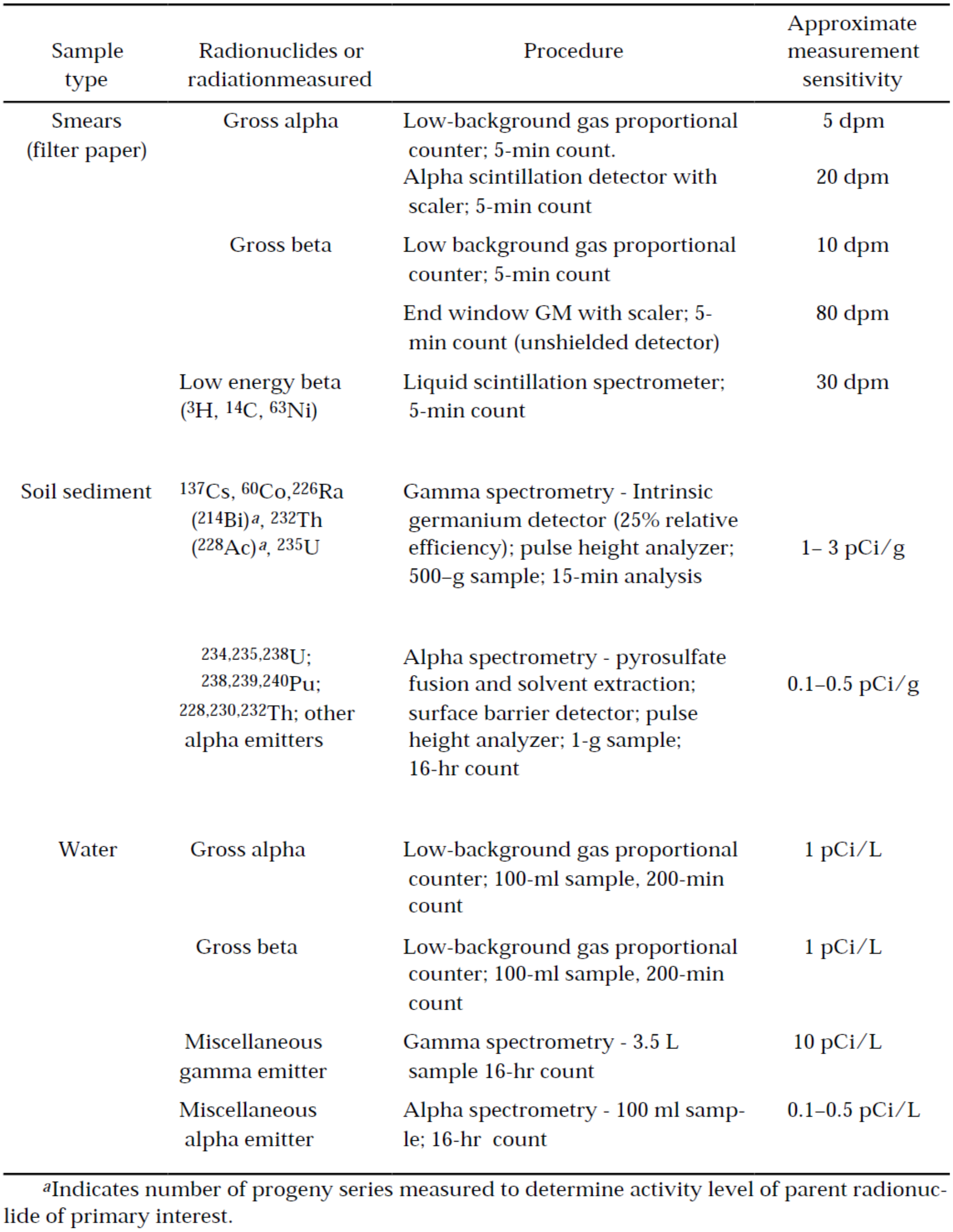
[6] Not detectable.

[7] Bold indicates the preferred method where alternative methods are available.

NOTE: Additional radionuclides and instruments are given in Appendix III of Reference 36, as well as Appendix B of this TOP.

TABLE 3. TYPICAL MEASUREMENT SENSITIVITIES FOR LABORATORY RADIOMETRIC PROCEDURES

(extracted from Reference 21, Table 6.1)



Sample type	Radionuclides or radiationmeasured	Procedure	Approximate measurement sensitivity
Smears (filter paper)	Gross alpha	Low-background gas proportional counter; 5-min count.	5 dpm
		Alpha scintillation detector with scaler; 5-min count	20 dpm
	Gross beta	Low background gas proportional counter; 5-min count	10 dpm
		End window GM with scaler; 5-min count (unshielded detector)	80 dpm
	Low energy beta (^{3}H, ^{14}C, ^{63}Ni)	Liquid scintillation spectrometer; 5-min count	30 dpm
Soil sediment	^{137}Cs, ^{60}Co,^{226}Ra (^{214}Bi)^{a}, ^{232}Th (^{228}Ac)^{a}, ^{235}U	Gamma spectrometry - Intrinsic germanium detector (25% relative efficiency); pulse height analyzer; 500–g sample; 15-min analysis	1– 3 pCi/g
	^{234,235,238}U; ^{238,239,240}Pu; ^{228,230,232}Th; other alpha emitters	Alpha spectrometry - pyrosulfate fusion and solvent extraction; surface barrier detector; pulse height analyzer; 1-g sample; 16-hr count	0.1–0.5 pCi/g
Water	Gross alpha	Low-background gas proportional counter; 100-ml sample, 200-min count	1 pCi/L
	Gross beta	Low-background gas proportional counter; 100-ml sample, 200-min count	1 pCi/L
	Miscellaneous gamma emitter	Gamma spectrometry - 3.5 L sample 16-hr count	10 pCi/L
	Miscellaneous alpha emitter	Alpha spectrometry - 100 ml sample; 16-hr count	0.1–0.5 pCi/L

^{a}Indicates number of progeny series measured to determine activity level of parent radionuclide of primary interest.

(3) Survey Plan.

(a) For small samples (i.e., coupons, small panels, small equipment) that can be measured in its entirety, the entire surface of the material shall be measured for contamination.

(b) For larger samples that cannot be measured in its entirety, a survey plan shall be developed to ensure statistical confidence in the outcome.

(4) Measurement Instruments.

(a) Instruments commonly used to assess surface contamination are given in Tables 2 and 3, and also addressed more recently and more thoroughly in IAEA Safety Series No. 67 and Appendix III therein[36]. See Table B.2 (Appendix B) of this TOP for an additional summary table.

(b) All detectors will be checked for correct functioning before any other testing. Results of function checks will be recorded as part of the test documentation.

e. Direct Measurement of Contaminated Material.

(1) General.

(a) Test articles may be composed of a non-porous or porous media that may affect the ability to reliably measure the surface contamination levels of alpha, beta, and low energy gamma radiation. **CAUTION:** For tests using alpha, beta, and low energy gamma radiation, this may result in a significant difference between activity measured on the surface when using counting meters and actual residual contaminant concentration. This discrepancy is because of the fact that alpha, beta, and low energy gamma radiation can be shielded by the test material itself, the air between the test specimen and the meter, and/or the protective shield covering the active region of the meter. Special attention must be made to the exact procedure for measuring initial and residual surface contamination when using such radiation (see Chapter 15 of Reference 15 for guidance on its measurement). The test plan must clearly describe the technique used to accurately measure such radiation. Consult relevant ISO standards (ISO-7503-1[39], ISO-7503-2[40], ISO-7503-3[41]) for example techniques. See Table B-1 (Appendix B) of this TOP for a brief discussion of general approaches used to monitor surface contamination. The methods described below apply to measurement of gamma-emitting contaminants only.

(b) Applies to gas-filled detectors, scintillators, and semiconductor detectors.

(c) Test size should optimize the need to safely handle the sample, ability to quantify contamination concentration, ability to accurately represent the variability in the material properties, and waste disposal costs.

(2) Method. Encapsulate each test article to protect against cross-contamination. Suitable encapsulating materials include Petri dishes, plastic wrap, and sealable plastic bags.

Place encapsulated test article in front of detector at the position identical to that used during calibrations (distance and positioned at the radial centerline to the active region of the detector).

f. Decontamination Methods.

(1) In most cases, the method will be delineated by the test sponsor or manufacturer of the decontaminant. The decontaminant must be applied in a controlled and reproducible manner. Follow test sponsor's or manufacturer's instructions for application of decontaminants. For novel decontamination agents or procedures, operating procedures may be provided by the developer.

(2) Physical Decontamination. Physical decontamination methods remove contaminant by physically removing particulates of the contaminant from the surface that is contaminated. These may include rinsing or washing, application and removal of peelable coatings, brushing and vacuuming, and scabbling and scouring.

(3) Chemical Decontamination. Chemical decontamination methods remove contaminant by chemically interacting with the contaminant or the contaminant surface to promote its removal into the decontaminant formulation.

(4) Combination Decontamination. Combination decontamination methods combine physical and chemical mechanisms to promote removal of contamination into the decontaminant formulation.

g. Decontaminant Test Rig.

(1) General. Decontaminant testing shall be performed on a test sample using an appropriate test rig (e.g., Petri dish, beaker, test stand) that exposes the contaminated sample to the decontaminant agent in a manner and for sufficient time that is consistent with sponsors, manufacturer's, or developer's instructions.

(2) Test Sample Orientation. Test samples may be placed horizontally or vertically during the application of the decontaminant. The test plan should describe the test sample orientation and justification for the choice of orientation.

(3) Kinetic Tests. Some decontaminants require a dwell time on the surface of the contaminated material to work effectively. It may be required to perform a kinetic test to determine the duration of subsequent tests.

(4) Sponsor's. Manufacturer's or Developer's Instructions. The test rig shall conform to the specifications set by the manufacturer or developer. For decontaminants with unspecified test format, the guidance in paragraphs (5), (6), and (7) can be used.

(5) Samples Soak Test. The intention of this test is to provide an upper-bound for the removal of radionuclides into a liquid decontaminant by providing a long residence time (contact time) between the contaminated surface and liquid decontaminant. For example, a Petri dish is

placed in a secondary container and onto the bottom is placed a Teflon grid or several glass beads[32]. The purpose of the grid or beads is to suspend the sample above the bottom surface of the Petri dish to avoid trapping air along the test surface. The open spaced grids or small beads do not interfere with access of the decontaminant to the test article surface. Test articles with contaminant applied to the surface are suspended on the grid or beads with the contaminated test surface facing down, and, before or after, a volume of decontaminant is injected in each dish. Test articles are covered to minimize evaporative losses of decontaminant. Test articles are removed from the decontaminant after the specified test time. The sample test article may be rinsed with a small volume of deionized water to remove residual decontaminant from the surface. Additional example methods can be found in ASTM G121-18[42].

(6) Flow Test. The intention of this test is to provide an upper bound for the removal of radionuclides into a decontamination solution by providing fresh reagents constantly for variable residence times between the contaminated surface and decontaminant. Samples, pitched at known angle, are placed in a test stand (see example test configuration published by Kaminski et al[32]. Water is introduced at the top of the test sample and allowed to flow down its surface to a collection vessel. The decontaminant should be introduced to the sample surface in a manner that provides complete coverage of the sample surface with flowing decontaminant.

(7) Vertical Test Stand. To evaluate the decontamination technologies on vertical surfaces (simulating walls), a test stand is constructed to hold the test articles vertically (see example test configuration published by Drake et al[43] and in EPA 600/R-13/001[31]). Sample replicates are attached to the test stand. The decontaminant is applied to the surface such that the entire surface is covered and removed according to procedure before analyzing the test samples.

h. Acceptability/Viability of Decontaminant. The acceptability/viability of the decontaminant shall be IAW manufacturer’s, developer’s, or test sponsor’s instructions.

4.12 <u>Decontaminant Pot Life Test</u>.

a. This test determines the useful life characteristics of the decontaminant under normal use conditions. This test is designed to measure any degradation in critical performance parameters from that of the decontaminant’s baseline performance resulting from changes in the decontaminant’s physical state or chemical composition after mixing constituents or after opening the container. The test duration shall be as required by the TEMP, or as otherwise specified by the test sponsor.

b. The test will be conducted at temperatures and RH as specified by the test plan.

c. Procedure.

(1) Properties or performance characteristics to be used to evaluate continued decontaminant efficacy will be identified in the test plan. A quantitative measure of the identified performance characteristics will be determined. The quantitative measure will be assigned a nominal value of 100 (representing 100 percent) for the level present when the

decontaminant is initially produced/opened. Examples of quantitative measures would be comparative decontamination efficacy measurements.

(2) This quantitative measure value may decrease as the decontaminant ages after mixing or opening. When the quantitative value decreases to levels less than a predetermined threshold (e.g., 50 may be a threshold minimum value compared with the initial nominal value of 100) the decontaminant will be considered ineffective. The time it takes for a decontaminant to decrease to this threshold level will be considered the decontaminant's pot life.

(3) Multiple samples of the decontaminant will be obtained from the original unopened containers. The number of samples will be determined based on a minimum of three replicates for the baseline decontaminant and three replicates for the decontaminant to be aged, which may mean three replicates for each sampling period. The decontaminant samples will be prepared IAW the manufacturer's instructions or standard procedures for field use of the decontaminant.

(4) One of the decontaminant samples will be evaluated for the quantitative measure as a baseline for comparison with the aged decontaminant. Both samples (baseline and the decontaminant to be aged) will be prepared at the specified test conditions (temperature and RH) identified in the test plan.

(5) The quantitative measure will be evaluated from the aged decontaminant samples at the intervals specified in the test plan (e.g., at 4, 8, 10, and 12 hours) until values decrease below the threshold level. The decontaminant's pot life will be estimated from these sampling results.

(6) The following data will be reported:

(a) Test environmental conditions (i.e., temperature and humidity (RH and AH)).

(b) Type, quantity, and concentration (if applicable) of decontaminant.

(c) Performance characteristic measurements.

(d) Estimated decontaminant pot life.

4.13 Decontaminant Shelf Life / Accelerated Aging Test.

a. General.

(1) This test determines the storage/shelf life characteristics of the decontaminant under normal storage conditions by accelerated aging of the decontaminant (e.g., by elevated temperature). This test is designed to measure any degradation caused by the accelerated aging on selective aspects of the decontaminant's performance from that of the decontaminant's baseline performance established by government or contractor test data or product specifications.

(2) Before the start of the accelerated aging test, decontaminant properties or performance characteristics to be used to evaluate the decontaminant will be identified in the test plan. A quantitative measure of the quality of the decontaminant (e.g., sorptive capacity) will be determined based on the identified characteristics. The quantitative measure will be assigned a nominal value of 100 when the decontaminant is initially produced or opened. This quantitative measure value will decrease as the decontaminant ages. When the quantitative measure value decreases below a predetermined threshold, the decontaminant will be considered out of compliance.

(3) The test plan shall specify the method for testing the shelf-life of the decontaminant or inducing an accelerated aging of the decontaminant. At the end of the aging period outlined in the test plan, the decontaminant will be opened and the decontaminant samples will be prepared IAW the manufacturer’s instructions or standard procedures for field use of the decontaminant. The aged decontaminant samples will be evaluated for the quantitative measure for comparison with the baseline decontaminant samples.

(b) The following data will be reported. Other data will be reported as specified in the test plan.

(1) Test environmental conditions (i.e., temperature and RH).

(2) Type, quantity, and concentration (if applicable). For multi-component decontaminants, the corresponding values for all components will be recorded.

(3) Performance characteristics used to calculate the decontaminant’s quantitative measure of quality.

(4) Quantitative measurement values for each baseline and post-aging sample collected during the test period.

(5) Estimated decontaminant shelf-life based on analysis of test data.

5. UNCERTAINTY MEASUREMENTS AND REPORTING.

a. General. Uncertainty shall be estimated according to internationally accepted guidance such as the Joint Committee for Guides in Metrology (JCGM) 100:2008[44] (see also Range Commander’s Council (RCC) Document 122-07[45]). Uncertainty estimates specific to radiation counting statistics is given in Chapter 20 of MARLAP[15] and by Knoll[46].

b. Uncertainty estimates shall be reported for all measured data.

6. DATA REQUIRED.

Data required are listed under the individual subtests in Section 4.

7. PRESENTATION OF DATA.

a. Photographs will be presented of any visible effect from contaminant or decontaminant on the test article.

b. Kinetic data versus time will be presented in tabular form.

c. Decontamination efficacy results will be presented by isotope in tabular form.

d. Decontamination efficacy data will be analyzed IAW the experimental design specified in the test plan.

e. Environmental data for each trial will be presented graphically (e.g., temperature and/or humidity (RH and AH) versus time).

f. Material compatibility subtest results will be presented in tabular form with photographs demonstrating significant effects.

g. Pot life results will be presented graphically versus time.

h. Shelf life results will be presented graphically versus time.

i. Data collected from these subtests will be presented in narrative form supplemented by drawings, photographs, charts, tables, graphs, or any other suitable means of displaying information. The report will describe whether or not the test item meets the criteria established in applicable specifications. Recommendations relative to further testing and methods to overcome malfunctions will also be included.

j. Data collected will include estimates of uncertainty.

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APPENDIX A. TEST ARTICLE MATERIALS.

A.1 MATERIAL SELECTION.

Test articles will be prepared of materials representing a range of surfaces inherent to the items undergoing decontamination operations (vehicles, weapons, etc.). The selection and prioritization of materials to meet the needs of each program of record will be coordinated between the test sponsor and operational test agencies. There are a wide variety of items comprising hundreds of potential materials that could be encountered during decontamination. A sample listing of highest-priority materials was compiled by materiel developers to condense the potential materials to a manageable number and facilitate a cost-effective test and evaluation program for a decontaminant. Factors considered are the expected impact of the material on mission/combat readiness, likelihood of the materials to be exposed to contamination, and the cost of the material to replace.

A.2 SAMPLE LISTING OF MATERIALS.

Test article materials are provided as a reference but selection of materials will be decided by requirements of the test program and are not limited to the following.

a. Chemical Agent-Resistant Coating (CARC) on steel (tactical vehicles).

b. Aircraft topcoat paint on aluminum (aircraft).

c. Low infrared paints on aluminum or steel (aircraft and ships).

d. Ship deck antiskid coating on steel.

e. Polyurethane, epoxy, and alkyd paints on metals (commercial vehicles).

f. Aluminum alloys, forged and cast (aircraft surfaces and structural members).

g. Aluminum, oxidized aluminum (vehicle substrate surface).

h. Stainless and high strength steel alloys (aircraft and engine structural members).

i. Nickel-based and other super-alloys (aircraft and engine structural members).

j. Carbon/stainless steels (vehicle, munitions substrate surface).

k. Brass/bronze/copper and nickel alloys (munitions substrate surface).

l. Composite and laminate materials (aircraft surface and structural members).

APPENDIX A. TEST ARTICLE MATERIALS.

m. Aircraft composites (aircraft).

n. Tire rubber (aircraft, vehicles).

o. Polycarbonates/Lexan® (SABIC Innovative Plastics, Pittsfield, Massachusetts) (aircraft canopy/window materials, tactical vehicles).

p. Glass (commercial vehicles, tactical vehicles).

q. Butyl rubber (mask, gloves/boots).

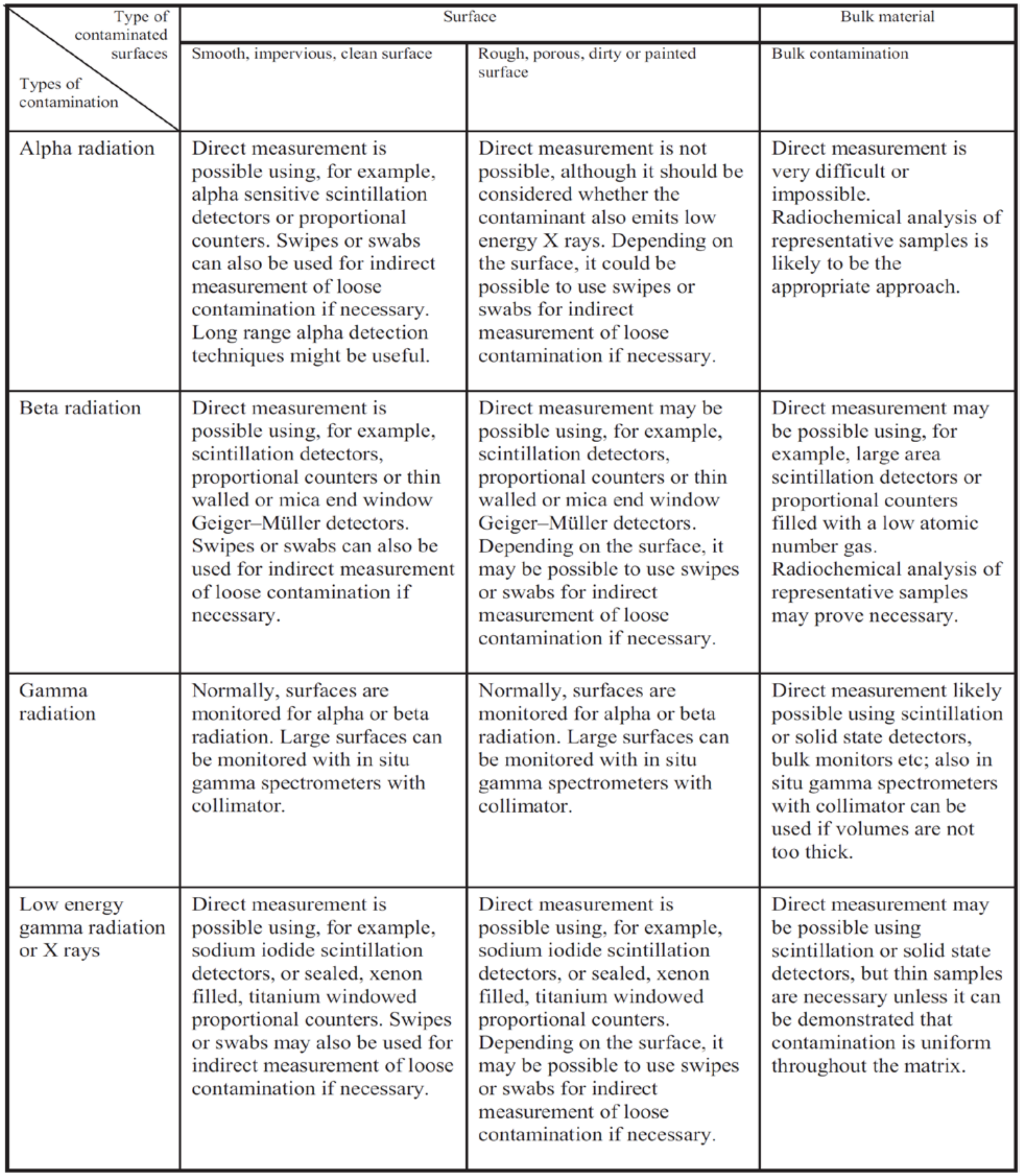
r. Silicon rubber (M40 mask).

APPENDIX B. APPROACHES FOR MONITORING SURFACE CONTAMINATION.

The IAEA Safety Series No. 67[36] includes a thorough summary of the approaches used to determine the appropriate measurement technique for a variety of radionuclide contamination on various surfaces. Table B-1 provides a general approach to monitoring alpha, beta, and gamma radiations. Table B-2 provides a more thorough summary of the various instruments available as a supplement to the information provided in Table 1 in paragraph 4.8

APPENDIX B. APPROACHES FOR MONITORING SURFACE CONTAMINATION.

TABLE B-1. GENERAL APPROACHES USED TO MONITOR FOR COMPLIANCE WITH CLEARANCE LEVELS FOR VARIOUS SURFACES OR BULK CONTAMINATION, AND VARIOUS TYPES OF RADIOACTIVE EMISSIONS.



Type of contaminated surfaces / Types of contamination	Surface		Bulk material
	Smooth, impervious, clean surface	Rough, porous, dirty or painted surface	Bulk contamination
Alpha radiation	Direct measurement is possible using, for example, alpha sensitive scintillation detectors or proportional counters. Swipes or swabs can also be used for indirect measurement of loose contamination if necessary. Long range alpha detection techniques might be useful.	Direct measurement is not possible, although it should be considered whether the contaminant also emits low energy X rays. Depending on the surface, it could be possible to use swipes or swabs for indirect measurement of loose contamination if necessary.	Direct measurement is very difficult or impossible. Radiochemical analysis of representative samples is likely to be the appropriate approach.
Beta radiation	Direct measurement is possible using, for example, scintillation detectors, proportional counters or thin walled or mica end window Geiger–Müller detectors. Swipes or swabs can also be used for indirect measurement of loose contamination if necessary.	Direct measurement may be possible using, for example, scintillation detectors, proportional counters or thin walled or mica end window Geiger–Müller detectors. Depending on the surface, it may be possible to use swipes or swabs for indirect measurement of loose contamination if necessary.	Direct measurement may be possible using, for example, large area scintillation detectors or proportional counters filled with a low atomic number gas. Radiochemical analysis of representative samples may prove necessary.
Gamma radiation	Normally, surfaces are monitored for alpha or beta radiation. Large surfaces can be monitored with in situ gamma spectrometers with collimator.	Normally, surfaces are monitored for alpha or beta radiation. Large surfaces can be monitored with in situ gamma spectrometers with collimator.	Direct measurement likely possible using scintillation or solid state detectors, bulk monitors etc; also in situ gamma spectrometers with collimator can be used if volumes are not too thick.
Low energy gamma radiation or X rays	Direct measurement is possible using, for example, sodium iodide scintillation detectors, or sealed, xenon filled, titanium windowed proportional counters. Swipes or swabs may also be used for indirect measurement of loose contamination if necessary.	Direct measurement is possible using, for example, sodium iodide scintillation detectors, or sealed, xenon filled, titanium windowed proportional counters. Depending on the surface, it may be possible to use swipes or swabs for indirect measurement of loose contamination if necessary.	Direct measurement may be possible using scintillation or solid state detectors, but thin samples are necessary unless it can be demonstrated that contamination is uniform throughout the matrix.

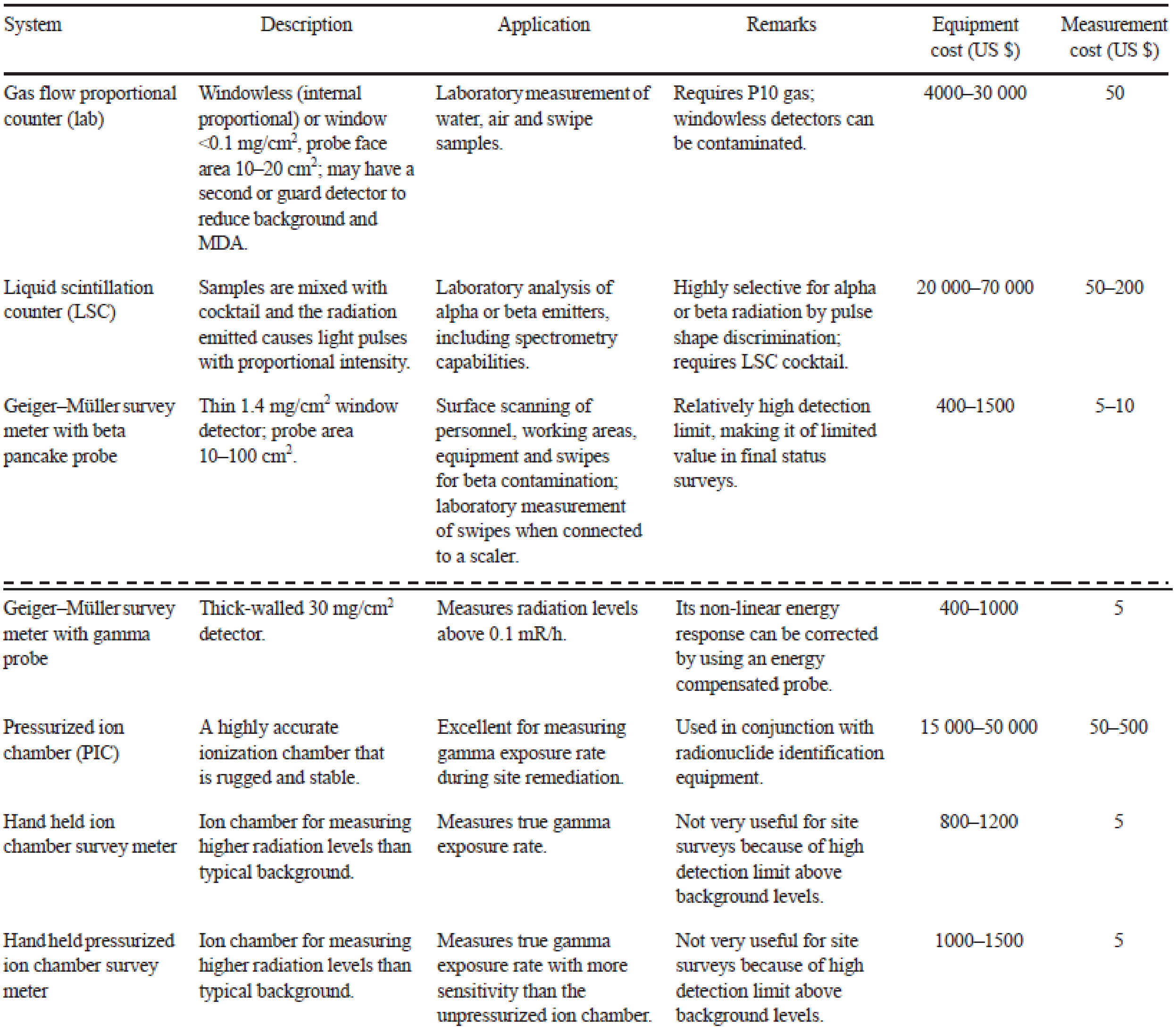
APPENDIX B. APPROACHES FOR MONITORING SURFACE CONTAMINATION.

TABLE B-2. PROPERTIES OF VARIOUS TYPES OF INSTRUMENTS
(extracted from IAEA Safety Series No. 67, Appendix III, Table 12)

System	Description	Application	Remarks	Equipment cost (US $)	Measurement cost (US $)
Alpha spectroscopy	A system using silicon diode surface barrier detectors for alpha energy identification and quantification.	Accurately identifies and measures the activity of multiple alpha radionuclides in a thin extracted sample of soil, water or air filters.	Sample requires radiochemical separation or other preparation before counting.	10 000–100 000	250–400
Alpha scintillation survey meter	<1 mg/cm^2 window; probe face area 50–100 cm^2.	Field measurement of presence or absence of alpha contamination on non-porous surfaces, swipes and air filters, or on irregular surfaces if the degree of surface shielding is known.	Minimum sensitivity is 10 counts/min, or 1 counts/min with headphones.	1000	5
Alpha track detector	Polycarbonate plastic sheet is placed in contact with a contaminated surface and kept in place.	Measures gross alpha surface contamination, soil activity level or the depth profile of contamination.	Alpha radiation produces holes that are enlarged chemically. Density of holes gives a measure of the radioactivity level.		5–25
Electret ion chamber	A charged Teflon disc in an open-faced ion chamber.	Measures alpha or beta contamination on surfaces and in soils, plus gamma radiation dose or radon concentration.	The type of radiation is determined by how the electret is employed, e.g. the unit is kept closed and bagged in plastic to measure gammas.	4000–5000	8–25
Long range alpha detector (LRAD)	1 m × 1 m detector measures ionization inside the box; attached to tractor for movement; has location finder and plots graph of contamination.	Measures surface contamination or soil concentration at grid points and plots curves of constant contamination; intended for large areas.	Alpha detection limit is 20–50 dpm/100 cm^2 or 0.4 Bq/g (10 pCi/g).	25 000	80
Gas-flow proportional counter (field)	A detector through which P10 gas flows and which measures alpha and beta radiation; <1–10 mg/cm^2 window; probe face area 50–100 cm^2 for hand held detectors; up to 600 cm^2 if cart mounted.	Surface scanning, surface activity measurement or field evaluation of swipes; serves as a screen to determine whether more radionuclide specific analyses are needed.	Natural radionuclides in samples can interfere with the detection of other contaminants; requires P10 gas, but can be disconnected.	2000–4000	2–10/m^2

APPENDIX B. APPROACHES FOR MONITORING SURFACE CONTAMINATION.

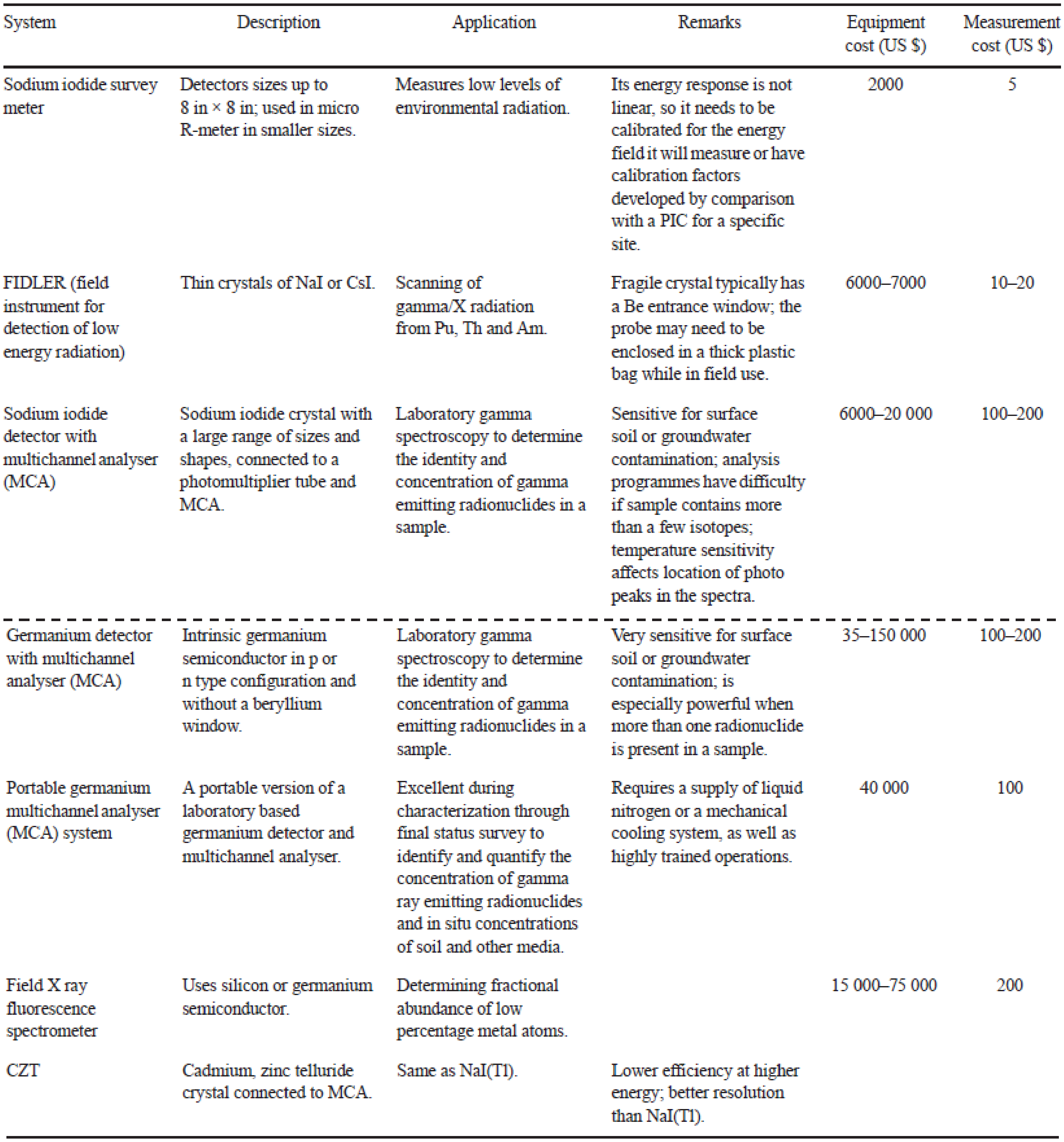
TABLE B-2. CONTINUED



System	Description	Application	Remarks	Equipment cost (US $)	Measurement cost (US $)
Gas flow proportional counter (lab)	Windowless (internal proportional) or window <0.1 mg/cm^2, probe face area 10–20 cm^2; may have a second or guard detector to reduce background and MDA.	Laboratory measurement of water, air and swipe samples.	Requires P10 gas; windowless detectors can be contaminated.	4000–30 000	50
Liquid scintillation counter (LSC)	Samples are mixed with cocktail and the radiation emitted causes light pulses with proportional intensity.	Laboratory analysis of alpha or beta emitters, including spectrometry capabilities.	Highly selective for alpha or beta radiation by pulse shape discrimination; requires LSC cocktail.	20 000–70 000	50–200
Geiger–Müller survey meter with beta pancake probe	Thin 1.4 mg/cm^2 window detector; probe area 10–100 cm^2.	Surface scanning of personnel, working areas, equipment and swipes for beta contamination; laboratory measurement of swipes when connected to a scaler.	Relatively high detection limit, making it of limited value in final status surveys.	400–1500	5–10
Geiger–Müller survey meter with gamma probe	Thick-walled 30 mg/cm^2 detector.	Measures radiation levels above 0.1 mR/h.	Its non-linear energy response can be corrected by using an energy compensated probe.	400–1000	5
Pressurized ion chamber (PIC)	A highly accurate ionization chamber that is rugged and stable.	Excellent for measuring gamma exposure rate during site remediation.	Used in conjunction with radionuclide identification equipment.	15 000–50 000	50–500
Hand held ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate.	Not very useful for site surveys because of high detection limit above background levels.	800–1200	5
Hand held pressurized ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate with more sensitivity than the unpressurized ion chamber.	Not very useful for site surveys because of high detection limit above background levels.	1000–1500	5

APPENDIX B. APPROACHES FOR MONITORING SURFACE CONTAMINATION.

TABLE B-2. CONTINUED



System	Description	Application	Remarks	Equipment cost (US $)	Measurement cost (US $)
Sodium iodide survey meter	Detectors sizes up to 8 in × 8 in; used in micro R-meter in smaller sizes.	Measures low levels of environmental radiation.	Its energy response is not linear, so it needs to be calibrated for the energy field it will measure or have calibration factors developed by comparison with a PIC for a specific site.	2000	5
FIDLER (field instrument for detection of low energy radiation)	Thin crystals of NaI or CsI.	Scanning of gamma/X radiation from Pu, Th and Am.	Fragile crystal typically has a Be entrance window; the probe may need to be enclosed in a thick plastic bag while in field use.	6000–7000	10–20
Sodium iodide detector with multichannel analyser (MCA)	Sodium iodide crystal with a large range of sizes and shapes, connected to a photomultiplier tube and MCA.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Sensitive for surface soil or groundwater contamination; analysis programmes have difficulty if sample contains more than a few isotopes; temperature sensitivity affects location of photo peaks in the spectra.	6000–20 000	100–200
Germanium detector with multichannel analyser (MCA)	Intrinsic germanium semiconductor in p or n type configuration and without a beryllium window.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Very sensitive for surface soil or groundwater contamination; is especially powerful when more than one radionuclide is present in a sample.	35–150 000	100–200
Portable germanium multichannel analyser (MCA) system	A portable version of a laboratory based germanium detector and multichannel analyser.	Excellent during characterization through final status survey to identify and quantify the concentration of gamma ray emitting radionuclides and in situ concentrations of soil and other media.	Requires a supply of liquid nitrogen or a mechanical cooling system, as well as highly trained operations.	40 000	100
Field X ray fluorescence spectrometer	Uses silicon or germanium semiconductor.	Determining fractional abundance of low percentage metal atoms.		15 000–75 000	200
CZT	Cadmium, zinc telluride crystal connected to MCA.	Same as NaI(Tl).	Lower efficiency at higher energy; better resolution than NaI(Tl).		

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APPENDIX C. CALCULATION EXAMPLE.

a. This is a calculation using the direct radioactive counting values from a mass of a radioactive material to determine an estimated particle number density.

b. In this example, uniform, spherical silica particles that are labelled with La-140 have been prepared. Using a calibrated hand-held radiation survey instrument, a total of 100 µCi of activity (A_{silica}) is measured in a mass (m_{silica}) = 1 gram sample of labeled silica. The density of the silica (ρ_{silica}) = 2.65 g/cm^3. To estimate the number of particles ($N_{particles}$) in that sample, we need an estimate of the diameter of the particles and its geometry. For particles of uniform, spherical size, this is straightforward as one will measure the diameter by microscopy, by light scattering measurement devices, or use information provided by the supplier. In our example, we assume that uniform silica spheres with a mean diameter (D_{silica}) = 1 µm or 10^{-4} cm and use Equation C-1.

$$N_{particles} = \frac{m_{silica}}{\frac{4}{3}\pi\left(\frac{D_{silica}}{2}\right)^3 \rho_{silica}} = \frac{1\text{g}}{\frac{4}{3}\pi\left(\frac{10^{-4}\text{cm}}{2}\right)^3 2.65\frac{\text{g}}{\text{cm}^3}} = 7.2 \times 10^{11} \quad \textit{(Equation C-1)}$$

c. Therefore, in a 1 gram sample there are 7.2x10^{11} particles providing a total activity of 100 µCi of activity. If, for example, a test with the 1 gram of starting mass is used and the total activity left on the sample using the calibrated meter registers as 50 µCi, then we conclude that 3.6x10^{11} particles remain on the sample.

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APPENDIX D. CONTAMINANT PARITCLE SIZE CONSIDERATIONS.

Per AEP-58[1], Section 0110.5, page 21: "Radioactive contaminations from nuclear fallout vary distinctly from those arising from RDDs or Nuclear Reactor failures (either accidental or intentional). While nuclear fallout consists generally of mainly insoluble larger (> 50 µm) particles (*compared to particles carried large distances in the plume cloud*), particles from RDDs may range down to micron and sub-micron size, their solubility depends on the isotope and the properties of the radioactive source. Particle size and solubility impact the effectiveness of decontamination operations. The levels of activity and the resulting dose rates in nuclear scenarios can be expected to be much higher than those of radiological contaminations."

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APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

a. For radiological/nuclear incidents, the location of the contaminant release, the nature/intended use of the contaminated items/areas, and to what extent the release impacts Department of Defense (DOD)/civilian populations can influence the selection of appropriate contaminant concentration reference values to use for a specific scenario. For example, if a release on a DOD installation migrates off the facility, multiple items/areas/populations may be affected; and for large releases, multiple geographical and political entities may be impacted. The choice of reference values can be influenced by a number of technical and policy factors related to the government(s) or jurisdiction(s) impacted by the release. The following two examples may be instructive in selecting reference values, although other reference values are possible.

b. The EPA Protective Action Guide (PAG) manual (https://www.epa.gov/radiation/protective-action-guides-pags) contains radiation dose guidelines that would trigger public safety measures, such as evacuation or staying indoors, to minimize or prevent radiation exposure during an emergency. EPA developed PAGs to help responders plan for radiation emergencies. These public safety measures may be applicable in some radiological/nuclear release and decontamination scenarios, e.g., domestic and/or other incidents to which the PAG manual applies by practice or by statute.

c. For some releases, for example those potentially impacting IAEA member states, the ANSI/HPS N13.12-2013[34] “Surface and Volume Radioactivity Standards for Clearance” established the dose criterion of 10 μSv/year (1 mrem/year) for the release of solid materials and is consistent with the IAEA guideline for clearance[47].

d. The guidelines presented in DOD Manual 3145.03 DOD Chemical, Biological, and Radiological (CBR) Clearance Guidance for Platforms and Materiel[48] is based on the standards identified in the ANSI/HPS N13.12-2013[34]. These clearance levels are shown in Table E-1.

APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

TABLE E-1. CLEARANCE SCREENING LEVELS FOR PLATFORMS AND MATERIEL
(extracted from DOD Manual 3145.03 [2019] [34])

Radionuclide Groups[a]	Screening Levels (S.I. units)[b] (Bq/cm^2 or Bq/g)[c]	Surface Screening (Conventional Units)[b] (Disintegrations per minute/100 cm^2)	Volume Screening (Conventional Units)[b] (pCi/g)
Group 1 High Energy gamma, radium, thorium, transuranics, and mobile beta-gamma emitters: ^{22}Na, ^{46}Sc, ^{54}Mn, ^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{129}Ic, ^{134}Cs, ^{56}Co, ^{60}Co, ^{65}Zn, ^{94}Nb, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{182}Ta, ^{207}Bi, ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{229}Th, ^{230}Th, ^{232}Th, ^{232}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{244}Pu, ^{241}Am, ^{243}Am, ^{245}Cm, ^{247}Cm, ^{248}Cm, ^{249}Cf, ^{251}Cf, ^{246}Cm, ^{254}Es and associated decay chains(d), and others(a)	0.1	600	3
Group 2 Uranium and selected beta-gamma emitters: ^{14}C, ^{36}Cl, ^{95}Zr, ^{105}Ag, ^{59}Fe, ^{57}Co, ^{58}Co, ^{75}Se, ^{85}Sr, ^{90}Sr, ^{99}Tc, ^{109}Cd, ^{113}Sn, ^{124}Sb, ^{123m}Te, ^{139}Ce, ^{140}Ba, ^{155}Eu, ^{160}Tb, ^{181}Hf, ^{185}Os, ^{204}Tl, ^{206}Bi, ^{234}U, ^{235}U, ^{190}Ir, ^{192}Ir, ^{233}U, ^{238}U, natural uranium(e) ^{237}Np, ^{236}Pu, ^{243}Cm, ^{244}Cm, ^{248}Cf, , ^{250}Cf, ^{252}Cf, ^{254}Cf, and associated decay chains(d) and others(a)	1	6,000	30

APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

TABLE E-1. CONTINUED

Radionuclide Groups[a]	Screening Levels (S.I. units)[b] (Bq/cm^2 or Bq/g)[c]	Surface Screening (Conventional Units)[b] (Disintegrations per minute/100 cm^2)	Volume Screening (Conventional Units)[b] (pCi/g)
Group 3 General beta-gamma emitters ^{7}Be, ^{74}As, ^{93}Mo, ^{93}Zr, ^{103}Ru, ^{114m}In, ^{125}Sn, ^{127}mTe, ^{93m}Nb, ^{97}Tc, ^{129}mTe, ^{131}I, ^{131}Ba, ^{144}Ce, ^{153}Gd, ^{181}W, ^{203}Hg, ^{202}Tl, ^{225}Ra, ^{230}Pa, ^{233}Pa, ^{236}U, ^{241}Pu, ^{242}Cm, ^{191}Os, ^{237}Pu, ^{249}Bk, ^{253}Cf, and others(a)	10	60,000	300
Group 4(f) Other beta-gamma emitters: ^{3}H, ^{35}S, ^{45}Ca, ^{51}Cr, ^{53}Mn, ^{97m}Tc, ^{115m}Cd, ^{115m}In, ^{125}I, ^{59}Ni, ^{63}Ni, ^{86}Rb, ^{91}Y, ^{135}Cs, ^{141}Ce, ^{147}Nd, ^{170}Tm, and others(a)	100	600,000	3,000
Group 5 Low-energy beta emitters: ^{55}Fe, ^{147}Pm, ^{151}Sm, ^{171}Tm, ^{185}W, and others(a)	100(surface)(f) 1,000 (volume)	600,000	30,000

NOTES: (a) To determine the specific group for radionuclides not shown, a comparison of the effective dose factors, by exposure pathway, listed in Table A.1 of National Council on Radiation Protection Report No. 123I for the radionuclides in question and the radionuclides in the general groups above should be performed and a determination of the proper group made, based on similarity of the factors. In instances where more than a single radionuclide is present, periodic reconfirmation of radioactivity levels may be required. (b) Rounded to one significant figure. Surface screening levels are total (fixed and removable) contamination. (c) The screening levels shown are used for either surface activity concentration (in units of Bq/cm2), or volume activity concentration (in units of Bq/g). These groupings were determined based on similarity of the scenario modeling results, as described in Annex B of ANSI/HPS N13.12-2013. (d) For decay chains, the screening levels represent the total activity present, such as activity of the parent plus the activity of all progeny. 235U.(e) Where the natural uranium activity equals 48.9 percent from 238U, plus 48.9 percent from 234U, plus 2.25 percent from (f) For radioactivity control considerations, surface radioactivity screening levels for Group 5 radionuclides are controlled to the Group 4 surface radioactivity screening levels. (g) The field probe efficiency and size need to be considered when converting corrected counts per minute into disintegrations per minute (dpm). To determine dpm per 100 cm2 from ccpm, use the following equations:

APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

probe size factor = (probe size in cm2) / 100 cm2 and
dpm/100 cm2 = (# ccpm)/(probe efficiency x probe size factor).

[d] For decay chains, the screening levels represent the total activity (i.e., the activity of the parent plus the activity of all progeny) present.

[e] Where the natural uranium activity equals ~48.9 percent from ^{238}U, plus ~48.9 percent from ^{234}U, plus -2.25 percent from ^{235}U.

[f] Radionuclides were assigned to groups that were protective of 1.0 millirem/year or less and were limited to 4 groups for ease of application, as discussed in Annex B of ANSI/HPS N13.12-2013[34].

[g] The field probe efficiency and size need to be considered when converting corrected counts per minute (ccpm) into disintegrations per minute (dpm). To determine dpm per 100 cm^2 from corrected ccpm; use the following equations: probe size factor =100 cm^2/(probe size in cm^2) and # dpm/100 cm^2 = (#ccpm)/(probe efficiency x probe size factor).

e. During radiological or nuclear operations, the operational commander may choose to select screening levels based on with Operational Exposure Guidance (OEG) levels. DOD Manual 3145.03 provides recommended screening levels based on command directed OEG levels. These are provided in Table E-2.

TABLE E-2. RECOMMENDED OPERATIONAL EXPOSURE GUIDANCE (OEG) LEVELS

ACCEPTABLE RISK LEVEL	MISSION IMPORTANCE		
	CRITICAL	PRIORITY	ROUTINE
Extremely High	125	75	25
High	75	25	5
Moderate	25	0.5	0.5
Low	5	0.5	0.5
Units of measure are centi-Sievert/mission (equivalent to rem/mission).			

f. To convert Clearance Screening Levels in Table E-1 to threshold levels consistent with a given OEG stipulated in Table E-2, one must multiply the screening levels by the respective multiplication factor given in Table E-3 and a mission factor based on time in a year divided by the mission length. For example when determining a threshold level for decontamination of Cesium 137 with a OEG of 0.5 centi-Sievert/mission, and a mission duration of 180 days, the screening level is 600 dpm/cm2, the multiplication factor is 500, and the mission factor is 365(days/year) / 180 (days/mission) = 2.078 (mission/year) gives us a threshold level of 600 (dpm/cm2)/(milli centiSievert /year) x 500 (milli-centiSievert /mission) x 2.028 (mission/year) = 6.084 x 105 dpm/cm2.

APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

TABLE E-3. MULTIPLICATION FACTORS TO CONVERT PLATFORM AND MATERIEL SCREENING LEVELS TO A RECOMMENDED DECONTAMINATION LEVEL FOR A GIVEN OEG

ACCEPTABLE RISK LEVEL	MISSION IMPORTANCE		
	CRITICAL	PRIORITY	ROUTINE
Extremely High	125,000	75,000	25,000
High	75,000	25,000	5,000
Moderate	25,000	5,000	500
Low	5,000	500	500

TABLE E-4. LOWEST CONTAMINATION LEVELS IN STANAG 2473[33]

Condition		Levels of High-Toxicity alpha emitters Contamination (Bq/cm^2)	Levels for Beta and Low-Toxicity alpha emitters (Bq/cm^2)
Radiological	Mission Time 7 days	5	50
	Mission Time 3 months	0.5	5
Nuclear		(maximum of 12 hour exposure)	
	Contaminants	0.1 cGy	
	Induced Activity	0.1 cGy	

TABLE E-5. INITIAL CONTAMINATION LEVELS IN STANAG 2473[33]

Level	Alpha (Bq/cm^2)	Beta/Gamma (Bq/cm^2)
High	50	500
Medium	5	50
Low	1	10

APPENDIX E. CONTAMINANT CONCENTRATION REFERENCE VALUES.

g. AEP-7[3] summarizes contamination levels for radiological contamination testing for survivability capability and corresponds to levels reported within STANAG 2473[33], which describes the contamination levels acceptable to NATO forces for different operation times with the lowest levels requiring some action shown in Table E-4. These contamination levels serve as guidance for commanders in the field for the level of action required when operating in a contaminated environment. From AEP-7, “unprotected personnel in the downwind area can inadvertently inhale or ingest radiological material deposited on the surface of an item. Therefore, the level of contamination for the testing and evaluation of items for their contamination survivability capability will be based on the contamination level values separated in three categories: high, medium, and low level” as seen in Table E-5.

h. AEP-7 discriminates between radiological and nuclear testing. For nuclear testing, contamination levels “will be equivalent to between 100 and 300 MBq/m^2 for plates and between 10 to 300 MBq/m^2 for a vehicle. Radiological material selected for nuclear testing can be for a nuclear explosion where two-thirds of the activity could be induced activity resulting from the neutrons of the initial blast and they are not to be considered in the test. The other one-third of the activity (to be determined in the test) would result from radioactive debris remaining on the item after nuclear fallout contamination. The unprotected users of the item would arrive at H+2 hours and remain one meter from the item for a period of time based on the item mission profile, not to exceed 12 hours”. The document continues with “For fallout after nuclear bursts, a contamination as high as 185 GBq/m^2 has to be taken into account. Knowing that decontamination to a level as low as reasonable achievable would be desirable, a decontaminability standard of 25 cGy dose per mission period is in line with guidance in STANAG 2083[504]. This amount of fallout contamination would result in a dose rate of approximately five (5) cGy/h at one (1) m distance from a typical large armoured vehicle. Using 75 cGy as a negligible risk dose (rd) which could come from exposure over a mission profile period (maximum of 12 hours) where two-thirds are from operational exposure, such as direct radiation from initial effects (or from fallout on the ground), and one-third from equipment contamination”.

APPENDIX F. ABBREVIATIONS.

%R	percent removal
ΔP	differential pressure
AEP	Allied Engineering Publication
AES	Atomic Emission Spectroscopy
Ag	Silver
AH	Absolute Humidity
Am	Americium
AmO_2	Americium Dioxide
Am_2O_3	Americium Oxide
ANSI	American National Standards Institute
API	American Petroleum Institute
AR	Army Regulation
ASTM	American Society of Testing and Materials
ATEC	U.S. Army Test and Evaluation Command
ATP	Allied Tactical Publication
Au	Gold
BET	Brunauer-Emmett-Teller
Bq	Becquerel
°C	degrees Celsius
C	Carbon
Ca	Calcium
CAPAT	Capability Area Process Action Team
CARC	Chemical Agent-Resistant Coating
CBDP	Chemical and Biological Defense Program
CBR	Chemical, Biological, and Radiological
CBRN	Chemical, Biological, Radiological, and Nuclear
CCG	Clearance Criteria Guidelines
ccpm	corrected counts per minute
Cd	Cadium
CDD	Capability Development Document
Ce	Cerium
CFR	Code of Federal Regulations
cGy	centiGray
Cl	Chlorine
Cm	Curium
Co	Cobalt
Cr	Chromium
Cs	Cesium
CsCl	Cesium Chloride
CZT	Cadmium, Zinc Telluride

APPENDIX F. ABBREVIATIONS.

DA	Department of the Army
DCGL	Derived Concentration Guideline Level
DF	Decontamination Factor
DOD	Department of Defense
DOE	Department of Energy
dpm	disintegrations per minute
DRDCO	Defense Research and Development Canada-Ottawa
EPA	Environmental Protection Agency
Eu	Europium
Fe	Iron
FIDLER	Field Instrument for Detection of Low Energy Radiation
GC	Gas Chromatograph
GBq	GigaBequerel
H	Hydrogen
^3H	Tritium
H_2O	Water
Hg	Mercury
HPS	Health Physics Society
I	Iodine
IAEA	International Atomic Energy Agency
IAW	in accordance with
ICP	Inductively-Coupled Plasma
In	Indium
Ir	Iridium
ISO	International Organization for Standardization
JCGM	Joint Committee for Guides in Metrology
K	Potassium
La	Lanthanum
LC	Liquid Chromatograph
LSC	Liquid Scintillation Counter
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual

APPENDIX F. ABBREVIATIONS.

MBq	Mega-Becquerel
MCA	Multi-Channel Analyser
MDC	Minimum Detectable Concentration
mm	millimeter
Mn	Manganese
MOU	Memorandum of Understanding
MQL	Minimum Quantification Limit
N_2	Dinitrogen
Na	Sodium
NATO	North Atlantic Treaty Organization
Nb	Niobium
NCRP	National Council on Radiation Protection
NEMI	National Environmental Methods Index
Ni	Nickel
NIST	National Institute of Standards and Technology
Np	Neptunium
NRC	Nuclear Regulatory Commission
OEG	Operational Exposure Guidance
OPSEC	Operations Security
OSHA	Occupational Safety and Health Administration
OTA	Operational Test Agency
P	Phosphorus
PAG	Protective Action Guide
PAM	Pamphlet
Pb	Lead
PIC	Pressurized Ion Chamber
Pm	Promethium
Po	Polonium
Pu	Plutonium
QA/QC	Quality Assurance/Quality Control
Ra	Radium
Rb	Rubidium
RCC	Range Commander’s Council
RDD	Radiological Dispersal Device
RDT&E	Research, Development, Test, and Evaluation
RH	Relative Humidity

APPENDIX F. ABBREVIATIONS.

RP	Recommended Practice
Ru	Ruthenium
S	Sulfur
Sb	Antimony
SCG	Security Classification Guide
SDS	Safety Data Sheet
SEP	Systems Engineering Plan
SNM	Special Nuclear Material
SOP	Standing Operating Procedure
Sr	Strontium
SrF_2	Strontium Fluoride
STANAG	Standardized Agreement
T&E IPT	Test and Evaluation Integrated Product Team
Tc	Technetium
TECMIPT	Test and Evaluation Capabilities and Methodologies Integrated Process Team
TEMP	Test and Evaluation Master Plan
Th	Thorium
TICN	Test Item Control Number
TIR	Test Incident Report
TO	Test Officer
TOP	Test Operations Procedure
U	Uranium
U.S.	United States
V&V	Verification and Validation
µCi	microCurie
µg	microgram
Zn	Zinc
ZnS	Zinc Sulfide

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APPENDIX H. APPROVAL AUTHORITY.

TECMIPT Test Operations Procedure (TTOP) 08-2-069 Radiological and Nuclear Decontamination Testing

Radiological and Nuclear and Decontamination Capability Area Process Action Teams (CAPATs):

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CAPAT Review & Concurrence: December 2018

Test and Evaluation Capabilities and Methodologies Integrated Process Team (TECMIPT) Participants:

DISTRIBUTION A. Approved for public release: distribution unlimited.

REFERENCES:
(a) *Chemical and Biological Defense Program (CBDP) Test and Evaluation (T&E) Standards Development Plan*, dated 19 July 2010.
(b) *Memorandum of Understanding (MOU) Among the Department of National Defence of Canada the Secretary of State for Defense of the United Kingdom of Great Britain and Northern Ireland and the Secretary of Defense on Behalf of the Department of Defense of the United State of America concerning the Research, Development and Acquisition of Chemical, Biological and Radiological Defense Materiel*, dated June 2000. Amendment One, dated August 2006.

APPENDIX H. APPROVAL AUTHORITY.

TECMIPT Test Operations Procedure (TTOP) 08-2-069 Radiological and Nuclear Decontamination Testing

The Radiological and Nuclear and Decontamination CAPAT recommends approval of the TECMIPT Test Operations Procedure (TTOP) 08-2-069 Radiological and Nuclear Decontamination Testing. If a representative non-concurs, a dissenting position paper will be attached.

Organization	Signature	Date
Deputy Under Secretary of the Army Test and Evaluation (DUSA-TE)	Sean O'Brien	2/7/2019
Joint Program Executive Office of Chemical Biological Radiological & Nuclear Defense (JPEO-CBRND) Test & Evaluation	Joseph Rybak	7/10/19
Joint Requirements Office for Chemical, Biological, Radiological and Nuclear Defense (JRO-CBRND)	MORISSETTE.GREGORY.A.1012347924 Digitally signed by MORISSETTE.GREGORY.A.1012347924 Date: 2018.12.07 09:25:13 -05'00' Lt Col Greg Morissette, USAF	
Joint Science and Technology Office (JSTO)	Thomas R Tom Yuzuik	7/10/19
US Army Evaluation Command (AEC)	YOST.EMILY.D.1245776124 Digitally signed by YOST.EMILY.D.1245776124 Date: 2019.02.19 11:15:05 -05'00' Emily Yost	
Operational Test and Evaluation Force (OPTEVFOR)	CAPT CAPT R. Ramirez	20 DEC 18
Air Force Operational Test and Evaluation Center (AFOTEC)	Col Matthew Magness, USAF	18 JAN 19
Marine Corps Operational Test & Evaluation Activity (MCOTEA)	WADLEY.MICHAEL.CRAIG.1130810841 Digitally signed by WADLEY.MICHAEL.CRAIG.1130810841 Date: 2019.02.27 11:16:23 -05'00' Michael Wadley, USMC	
Edgewood Chemical Biological Center	Roderick A. Fry Matthew Shue	29 Nov 2018
Naval Surface Warfare Center Dahlgren Division (NSWC-DD)	Mike Pompeii	12/3/18
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Decon CAPAT Co-Chair	THANDE-KAMIRU.MUMBI.J.1362900570 Digitally signed by THANDE-KAMIRU.MUMBI.J.1362900570 Date: 2019.02.19 10:30:21 -05'00' Mumbi Thande-Kamiru	
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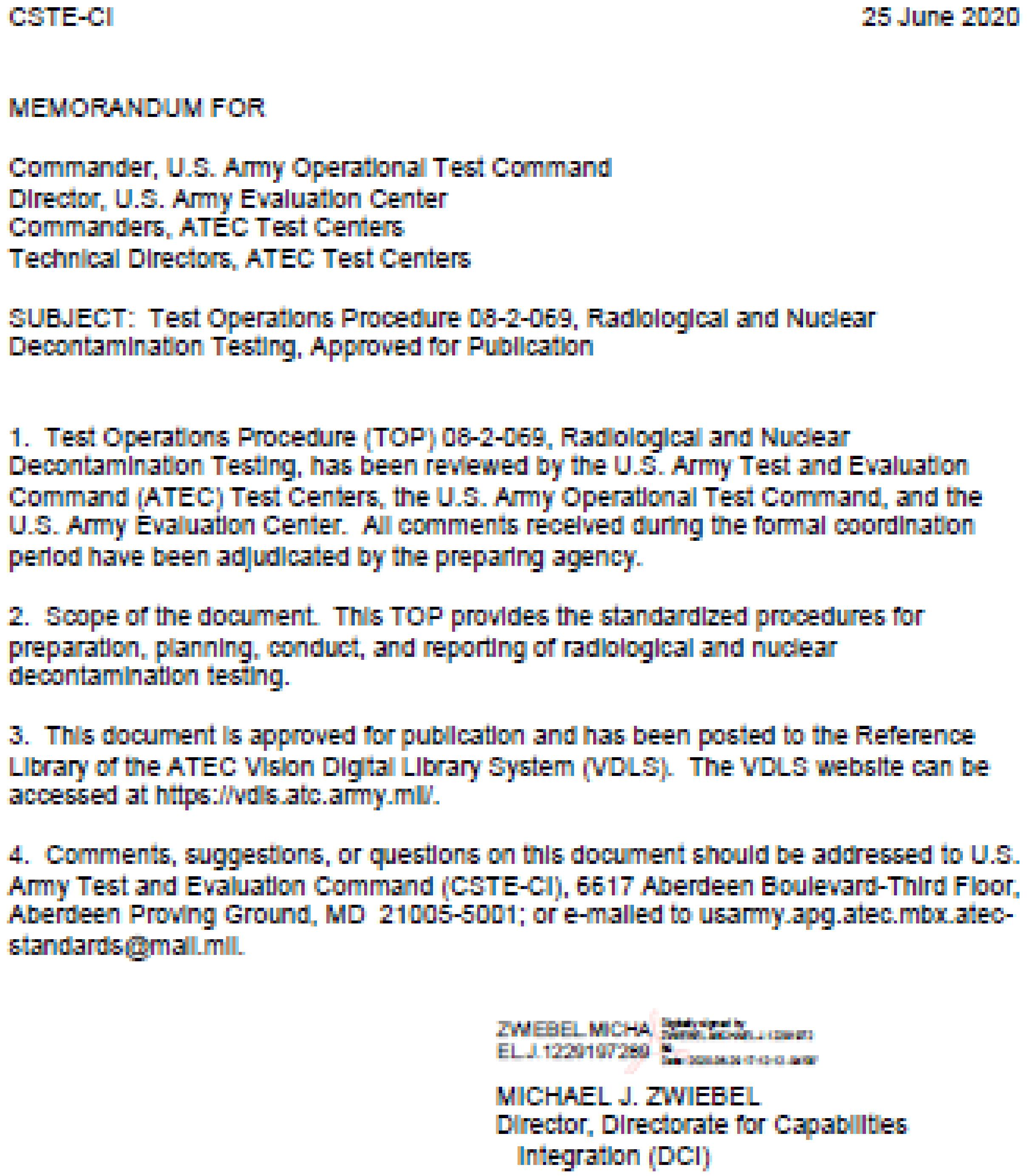
APPENDIX H. APPROVAL AUTHORITY.



CSTE-CI 25 June 2020

MEMORANDUM FOR

Commander, U.S. Army Operational Test Command
Director, U.S. Army Evaluation Center
Commanders, ATEC Test Centers
Technical Directors, ATEC Test Centers

SUBJECT: Test Operations Procedure 08-2-069, Radiological and Nuclear Decontamination Testing, Approved for Publication

1. Test Operations Procedure (TOP) 08-2-069, Radiological and Nuclear Decontamination Testing, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.

2. Scope of the document. This TOP provides the standardized procedures for preparation, planning, conduct, and reporting of radiological and nuclear decontamination testing.

3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-CI-P), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Commander, West Desert Test Center, US Army Dugway Proving Ground, ATTN: TEDT-DPW, Dugway, UT 84022-5000. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.