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# Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME)

**Department of Defense**
**Department of Energy**
**Environmental Protection Agency**
**Nuclear Regulatory Commission**

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## DISCLAIMER

## ABSTRACT

The *Multi-Agency Radiation Survey and Assessment of Materials and Equipment* manual (MARSAME) is a supplement to the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) providing information on planning, conducting, evaluating, and documenting radiological disposition surveys for the assessment of materials and equipment. MARSAME is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). The objective of MARSAME is to provide a multi-agency approach for planning, performing, and assessing disposition surveys of materials and equipment, while at the same time encouraging an effective use of resources.

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# ACKNOWLEDGEMENTS

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AL | action level |
| ALARA | as low as reasonably achievable |
| ANSI | American National Standards Institute |
| ASTM | American Society for Testing and Materials |
| BKGD | background |
| CERCLA | Comprehensive Environmental Response Compensation and Liability Act |
| CFR | Code of Federal Regulations |
| cpm | counts per minute |
| cps | counts per second |
| CSM | conceptual site model |
| CSU | combined standard uncertainty |
| CZT | cadmium zinc telluride |
| DAC | derived air concentration |
| DCGL | derived concentration guideline level |
| DL | discrimination limit |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DOT | Department of Transportation |
| dpm | disintegrations per minute |
| DQA | data quality assessment |
| DQO | data quality objective |
| EMC | elevated measurement comparison |
| EPA | Environmental Protection Agency |
| EPRI | Electric Power Research Institute |
| EU | European Union |
| EZ | exclusion zone |
| FIDLER | field instrument for the detection of low-energy radiation |
| FRER | fluence rate to exposure rate |
| GM | Geiger Mueller |
| HASP | health and safety plan |
| HEU | high-enriched uranium |
| HPGe | high-purity germanium |
| HPS | Health Physics Society |
| HSA | Historical Site Assessment |
| HPSR | Health Physics Society Report |
| HWP | hazard work permit |
| IA | initial assessment |
| IAEA | International Atomic Energy Agency |
| IEEE | Institute of Electrical & Electronics Engineers |
| ISGS | in situ gamma spectroscopy |
| ISO | International Organization for Standardization |

| | |
|---|---|
| JSA | job safety analysis |
| LBGR | lower bound of the gray region |
| LEU | low-enriched uranium |
| LSA | low specific activity |
| LSC | liquid scintillation cocktail |
| M&E | materials and equipment |
| MARLAP | Multi-Agency Radiological Laboratory Analytical Protocols manual |
| MARSAME | Multi-Agency Radiation Survey and Assessment of Materials and Equipment manual |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual |
| MCA | multi-channel analyzer |
| MDC | minimum detectable concentration |
| MDCR | minimum detectable count rate |
| $MDCR_{surveyor}$ | MDCR by a less than ideal surveyor |
| MDER | minimum detectable exposure rate |
| MQC | minimum quantifiable concentration |
| MQO | measurement quality objective |
| NARM | naturally occurring and accelerator-produced radioactive material |
| NCRP | National Council on Radiation Protection and Measurements |
| NIST | National Institute of Science and Technology |
| NJBER | New Jersey Bureau of Environmental Radiation |
| NORM | naturally occurring radioactive material |
| NRC | Nuclear Regulatory Commission |
| NUREG | Nuclear Regulatory Commission technical report prepared by NRC staff |
| NUREG/CR | Nuclear Regulatory Commission technical report prepared by NRC contractor |
| ORISE | Oak Ridge Institute for Science and Education |
| OSHA | Occupational Safety and Health Administration |
| OSWER | EPA Office of Solid Waste and Emergency Response |
| PCB | polychlorinated biphenyl |
| pH | hydrogen ion concentration (acidity or basicity) |
| PIC | pressurized ion chamber |
| PPE | personal protective equipment |
| PVC | polyvinylchloride |
| QA | quality assurance |
| QAPP | quality assurance project plan |
| QC | quality control |
| RCA | radiological control area |
| RCRA | Resource Conservation and Recovery Act |
| RCSU | relative combined standard uncertainty |
| RDR | relative detector response |
| RESRAD | RESidual RADioactivity computer code (exposure pathway model) |
| ROC | radionuclide of concern |
| RTG | Radioisotopic Thermoelectric Generator |

| | |
|---|---|
| RWP | radiation work permit |
| SCO | surface-contaminated object |
| SI | International System of Units (Système International d'Unités) |
| SOP | standard operating procedure |
| TEDE | total effective dose equivalent |
| TENORM | technologically enhanced naturally occurring radioactive material |
| TRU | transuranic |
| UBGR | upper bound of the gray region |
| UCL | upper confidence limit |
| UMTRCA | Uranium Mill Tailings Radiation Control Act |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |
| USEPA | United States Environmental Protection Agency |
| U.S. | United States |
| WRS | Wilcoxon Rank Sum |

## SYMBOLS, NOMENCLATURE, AND NOTATIONS

| | |
|---|---|
| $<$ | less than |
| $>$ | greater than |
| $\leq$ | less than or equal to |
| $\geq$ | greater than or equal to |
| ° | degrees (angle or temperature) |
| % | percent |
| $1-\beta$ | statistical power of a hypothesis test |
| $\alpha$ | Type I decision-error rate |
| $\alpha_Q$ | quantile test ($\alpha_Q = \alpha/2$) |
| $a$ | half-width of a rectangular or triangular probability distribution |
| A | area |
| $A$ | overall sensitivity of a measurement |
| Ac | actinium (isotope listed: $^{228}$Ac) |
| $AL_i$ | action level value an individual radionuclide ($i$ = 1, 2, …, $n$) |
| $AL_{meas,mod}$ | modified action level for the radionuclide being measured when it is used as a surrogate for other radionuclide(s) |
| $AL_{meas}$ | action level for the radionuclide being measured |
| $AL_{infer}$ | action level for the inferred radionuclide (in surrogate measurements) |
| Am | americium (isotope listed: $^{241}$Am) |
| $\beta$ | Type II decision-error rate |
| $b$ | background count rate |
| $b_i$ | the average number of counts in the background interval (scanning) |
| Be | beryllium (isotope listed: $^{7}$Be) |
| Bi | bismuth (isotopes listed: $^{210}$Bi, $^{212}$Bi, $^{214}$Bi) |
| Bq | becquerel |
| C | carbon (isotope listed: $^{14}$C) |
| $C$ | radionuclide concentration or activity |
| Ci | curie |
| $C_i$ | concentration value an individual radionuclide ($i$ = 1, 2, …, $n$) |
| $c_i$ | sensitivity coefficient |
| $c_i\mu(x_i)$ | component of the uncertainty in $y$ due to $x_i$ |
| $C_{infer}/C_{meas}$ | ratio of amount of the inferred radionuclide to that of the measured surrogate radionuclide |
| °C | degrees Celsius |
| cm | centimeter |
| $cm^2$ | square centimeter |
| $cm^3$ | cubic centimeter |
| Cd | cadmium (isotope listed: $^{109}$Cd) |
| Co | cobalt (isotopes listed: $^{57}$Co, $^{60}$Co) |
| Cs | cesium (isotope listed: $^{137}$Cs) |
| CsI(Tl) | cesium iodide (thallium activated) |
| $\Delta$ | shift (width of the gray region, UBGR–LBGR) |

| | |
|---|---|
| $\Delta/\sigma$ | relative shift |
| $d$ | parameter in the Stapleton Equation for the critical net signal |
| $d'$ | detectability index (scanning) |
| $\varepsilon_i$ | instrument efficiency |
| $\varepsilon_s$ | surface efficiency for surveyed media |
| eV | electron-volt |
| $E_\gamma$ | energy of a gamma photon of concern in kiloelectron-volts (keV) |
| $E_i$ | energy of a photon of interest |
| °F | degrees Fahrenheit |
| $f_i$ | relative fraction of activity contributed by radionuclide *i* to the total |
| ft | foot (feet) |
| $ft^3$ | cubic foot (feet) |
| Fe | iron (isotope listed: $^{55}Fe$) |
| g | gram |
| GBq | gigabecquerel ($1\times10^9$ becquerels) |
| $GG_{AL}$ | gross gamma action level |
| h | hour |
| H | hydrogen (isotope listed: $^3H$ [tritium]) |
| $H_0$ | null hypothesis |
| $H_1$ | alternative hypothesis |
| $i$ | observation time interval length (scanning) |
| I | iodine (isotopes listed: $^{123}I$, $^{125}I$, $^{131}I$) |
| in | inch |
| Ir | iridium (isotope listed: $^{192}Ir$) |
| $k$ | coverage factor for the expanded uncertainty, *U* |
| K | potassium (isotope listed: $^{40}K$) |
| kBq | kilobecquerel ($1\times10^3$ becquerels) |
| keV | kiloelectron-volt ($1\times10^3$ electron-volts) |
| kg | kilogram |
| $k_Q$ | multiple of the standard deviation defining $y_Q$, usually chosen to be 10 |
| $L$ | grid size spacing |
| L | liter |
| lb | pound |
| µ | micro ($10^{-6}$) |
| $\mu$ | theoretical mean of a population distribution |
| $(\mu_{en}/\rho)_{\mathrm{air}}$ | mass energy absorption coefficient in air centimeters squared per gram ($cm^2/g$) |
| µR | microroentgen ($1\times10^{-6}$ roentgen) |
| $m$ | number of reference measurements (WRS test or Quantile test) |
| m | meter |
| $m^2$ | square meter |
| MeV | megaelectron-volt ($1\times10^6$ electron-volt) |
| mrem | millirem ($1\times10^{-3}$ rem) |

| | |
|---|---|
| mSv | milliseivert ($1\times10^{-3}$ Sv) |
| $n$ | number of survey unit measurements (WRS test or Quantile test) |
| $N$ | sample size, i.e. number of data points (or samples) for the Sign test |
| $n_{EA}$ | survey unit area divided by the maximum area corresponding to the area factor, which yields the number of measurements needed so the scan MDC is adequate |
| Na | sodium (isotope listed: $^{22}$Na) |
| NaI(Tl) | sodium iodide (thallium activated) |
| Ni | nickel (isotope listed: $^{63}$Ni) |
| Np | neptunium (isotope listed: $^{237}$Np) |
| $\xi_B$ | non-Poisson variance component of the background count rate correction |
| $p$ | coverage probability for expanded uncertainty, also used for efficiency of a less than ideal surveyor (scanning) |
| $P$ | probability of interaction between radiation and a detector |
| Pa | protactinium (isotopes listed: $^{234}$Pa, $^{234m}$Pa) |
| PA | probe area |
| Pb | lead (isotopes listed: $^{212}$Pb, $^{214}$Pb) |
| PC | personal computer |
| pCi | picocurie ($1\times10^{-12}$ curies) |
| Pm | promethium (isotope listed: $^{147}$Pm) |
| Po | polonium (isotopes listed: $^{210}$Po, $^{212}$Po, $^{214}$Po, $^{216}$Po) |
| Pu | plutonium (isotopes listed: $^{238}$P, $^{239}$Pu, $^{240}$Pu, $^{241}$Pu) |
| $q$ | critical value for statistical tests (Table A.3, Table A.4) |
| ρ | density |
| $\rho(X_i,X_j)$ | correlation coefficient for two input quantities, $X_i$ and $X_j$ |
| $R$ | ratio |
| R | roentgen (exposure rate) |
| Ra | radium (isotopes listed: $^{224}$Ra, $^{226}$Ra, $^{228}$Ra) |
| $R_B$ | mean background count rate |
| $R_I$ | mean interference count rate |
| Rn | radon (isotopes listed: $^{220}$Rn, $^{222}$Rn) |
| $r(x_i,x_j)$ | correlation coefficient for two input estimates, $x_\mathrm{i}$ and $x_\mathrm{j}$ |
| σ | theoretical total standard deviation of the population distribution being sampled |
| $\sigma_M$ | theoretical measurement standard deviation of the population distribution being sampled, estimated by the combined standard uncertainty of the measurement |
| $\sigma_M{}^2$ | theoretical measurement variance of the population distribution being sampled |
| $\sigma_{MR}$ | required measurement method standard deviation (upper limit) |
| $\sigma_S$ | theoretical sampling standard deviation of the population distribution being sampled |
| $\sigma_S{}^2$ | theoretical sampling variance of the population distribution being sampled |
| $\sigma(\hat{R}_I)$ | standard deviation of the measured interference count rate |
| $\sigma\left(y \middle| Y = y_Q\right)$ | variance of the estimator y given the true concentration $Y$ equals $y_Q$ |
| $\sigma(X_i, X_j)$ | covariance for two input quantities, $X_i$ and $X_j$ |

| | |
|---|---|
| $S+$ | Sign test statistic |
| $s(x)$ | sample standard deviation of the input estimate, $x_i$ |
| $S_C$ | critical value of the net instrument signal |
| $S_D$ | mean value of the net signal that gives a specified probability, $1-\beta$, of yielding an observed signal greater than its critical value $S_C$ |
| $s_i$ | minimum detectable number of net source counts in the observation interval (scanning) |
| $s_{i,surveyor}$ | minimum detectable number of net source counts in the observation interval by a less than ideal surveyor (scanning) |
| Sr | strontium (isotope listed: $^{90}$Sr) |
| Sv | seivert |
| Tc | techicium (isotopes listed: $^{99}$Tc, $^{99m}$Tc) |
| Th | thorium (isotopes listed: $^{228}$Th: $^{230}$Th, $^{232}$Th, $^{234}$Th) |
| Tl | thalium (isotopes listed: $^{201}$Tl, $^{208}$Tl) |
| $t_B$ | count time for the background |
| $t_S$ | count time for the source |
| $U$ | expanded uncertainty |
| U | uranium (isotopes listed: $^{234}$U, $^{235}$U, $^{238}$U) |
| $u(x_i)$ | standard uncertainty of the input estimate, $x_i$ |
| $u(x_i)/\mid x_i \mid$ | relative standard uncertainty of $x_i$ |
| $u(x_i,x_j)$ | covariance of two input estimates, $x_i$ and $x_j$ |
| $u_c(y)$ | combined standard uncertainty of y |
| $u_c(y)/y$ | relative combined standard uncertainty of the output quantity for a particular measurement |
| $u_c^2(y)$ | combined variance of $y$ |
| $u_i(y)$ | component of the combined standard uncertainty, $u_c(y)$, generated by the standard uncertainty of the input estimate $x_i$, $u(x_i)$, multiplied by the sensitivity coefficient, $c_i$ |
| $u_M$ | measurement method uncertainty |
| $u_{MR}$ | required measurement method uncertainty |
| $\varphi_{MR}$ | required relative measurement method uncertainty |
| $\phi_{\hat{A}}^2$ | relative variance of the measured sensitivity |
| $\varphi(x_i)$ | relative standard uncertainty of a nonzero input estimate, $x_i$, for a particular measurement. $\varphi(x_i) = u(x_i)/x_i$ |
| $\Phi(z)$ | cumulative normal distribution function |
| $W_r$ | sum of the ranks of the (adjusted) reference measurements (WRS test) |
| $W_s$ | sum of the ranks of the (adjusted) sample measurements (WRS test) |
| $WS$ | weighted instrument sensitivity |
| $x$ | estimate of the input quantity, $X$ |
| $X_i$ | an input quantity |
| $x_C$ | the critical value of the response variable, $x$ |
| $x_Q$ | minimum quantifiable value of the response variable, $x$ |
| y | year |

| | |
|---|---|
| $y$ | estimate of the output quantity for a particular measurement, $Y$ |
| $Y$ | output quantity, measurand |
| $y_C$ | critical value of the concentration |
| $y_D$ | minimum detectable concentration (MDC) |
| $y_Q$ | minimum quantifiable concentration (MQC) |
| yd | yard |
| $yd^3$ | cubic yard |
| Z | atomic number |
| $z_{1-\alpha}$ | $(1-\alpha)$-quantile of the standard normal distribution |
| $z_{1-\beta}$ | $(1-\beta)$-quantile of the standard normal distribution |
| ZnS(Ag) | zinc sulfide (silver activated) |

## CONVERSION FACTORS

| To Convert From | To | Multiply "From" Quantity By | To Convert From | To | Multiply By |
|---|---|---|---|---|---|
| acre | hectare | 0.405 | meter (m) | inch | 39.4 |
| | sq. meter ($m^2$) | 4,050 | | mile | 0.000621 |
| | sq. feet ($ft^2$) | 43,600 | sq. meter ($m^2$) | acre | 0.000247 |
| becquerel (Bq) | curie (Ci) | $2.7\times10^{-11}$ | | hectare | 0.0001 |
| | dps | 1 | | sq. feet ($ft^2$) | 10.8 |
| | pCi | 27 | | sq. mile | $3.86\times10^{-7}$ |
| Bq/kg | pCi/g | 0.027 | $m^3$ | liter | 1,000 |
| Bq/$m^2$ | dpm/100 $cm^2$ | 0.60 | mrem | mSv | 0.01 |
| Bq/$m^3$ | Bq/L | 0.001 | mrem/y | mSv/y | 0.01 |
| | pCi/L | 0.027 | mSv | mrem | 100 |
| centimeter (cm) | inch | 0.394 | mSv/y | mrem/y | 100 |
| Ci | Bq | $3.70\times10^{10}$ | ounce (oz) | liter (L) | 0.0296 |
| | pCi | $1\times10^{12}$ | pCi | Bq | 0.037 |
| dps | dpm | 60 | | dpm | 2.22 |
| | pCi | 27 | pCi/g | Bq/kg | 37 |
| dpm | dps | 0.0167 | pCi/L | Bq/$m^3$ | 37 |
| | pCi | 0.451 | rad | Gy | 0.01 |
| dpm/100 $cm^2$ | Bq/$m^2$ | 1.67 | rem | mrem | 1,000 |
| gray (Gy) | rad | 100 | | mSv | 10 |
| hectare | acre | 2.47 | | Sv | 0.01 |
| liter (L) | $cm^3$ | 1000 | seivert (Sv) | mrem | 100,000 |
| | $m^3$ | 0.001 | | mSv | 1,000 |
| | ounce (fluid) | 33.8 | | rem | 100 |