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United States Nuclear Regulatory Commission

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241 Survey approaches (discussed in Section 5) were determined using the DQO Process, giving due
242 consideration to two major requirements. Specifically, (1) the survey result must be able to demonstrate
243 that clearance criteria have been met within predetermined confidence levels, and (2) the survey unit size
244 must be sufficiently evaluated to develop a technically defensible approach for area or volume averaging.

245 The general release survey approaches identified in Section 5 include (1) surveys using conventional
246 instruments that incorporate both scanning and statistical designs for determining sample sizes;
247 (2) automated scanning surveys (conveyorized survey monitors); (3) *in toto* surveys performed using
248 gamma spectrometers, bag monitors, tool monitors, and portal monitors; and (4) analytical methods and
249 laboratory analyses on representative samples based on statistical sampling designs. Section 6 provides
250 guidance on reducing survey data, demonstrating compliance with clearance release criteria, and
251 documenting results. Appendix B provides additional information on advancements in general radiation
252 detectors and survey instruments that utilize new detection materials and software.

If there is no specific clearance criteria other than "no detectable above background", is this NUREG a moot point?

Various areas in this doc, "material" is spelled "materiel."

Throughout, various symbols did not format correctly and show up as •, or ?, or etc...

Such as ϵ , Δ , ...

1273 For situations in which multiple radionuclides with their own DCGLs are present, a gross activity DCGL_C
 1274 can be developed. This approach enables field measurement of gross activity (using static direct
 1275 measurements or scans), rather than determination of individual radionuclide activity, for comparison to
 1276 the DCGL_C. The gross activity DCGL for surfaces with multiple radionuclides is calculated as follows:

- 1277 (1) Determine the relative fraction (*f*) of the total activity contributed by the radionuclide.
- 1278 (2) Obtain the DCGL_C for each radionuclide present.
- 1279 (3) Substitute the values of *f* and DCGL_C in the following equation.

$$\text{Gross Activity DCGL}_C = \frac{1}{\left(\frac{f_1}{\text{DCGL}_1} + \frac{f_2}{\text{DCGL}_2} + \dots + \frac{f_n}{\text{DCGL}_n} \right)}$$

1280 For example, assume that 40 percent of the total surface activity was contributed by a radionuclide with a
 1281 DCGL_C of 1.4 Bq/cm² (8,300 dpm/100 cm²); 40 percent by a radionuclide with a DCGL_C of 0.3 Bq/cm²
 1282 (1,700 dpm/100 cm²); and 20 percent by a radionuclide with a DCGL_C of 0.1 Bq/cm² (830 dpm/100 cm²).
 1283 Using the above equation,

$$\text{Gross Activity DCGL}_C = \frac{1}{\frac{0.40}{1.4} + \frac{0.40}{0.3} + \frac{0.20}{0.1}}$$

1284

OK ✓ = 0.3 Bq/cm² (1,907 dpm/100 cm²)
 1277

1285 Note that the above equation may not work for sites that exhibit surface contamination from multiple
 1286 radionuclides having unknown or highly variable concentrations of radionuclides throughout the site.
 1287 In these situations, the best approach may be to select the most conservative surface activity DCGL from
 1288 the mixture of radionuclides present. If the mixture contains radionuclides that cannot be measured using
 1289 field survey equipment, such as ³H or ⁵⁵Fe, laboratory analyses of solid materials may be necessary.

1290 Meeting with surface activity DCGLs for radionuclides of a decay series (e.g., radium, thorium, and
 1291 uranium) that emit both alpha and beta radiation may be demonstrated by assessing alpha, beta, or both
 1292 radiations. However, relying on the use of alpha surface activity measurements often proves problematic
 1293 because of the highly variable level of alpha attenuation by rough, porous, and dusty surfaces. Beta
 1294 measurements typically provide a more accurate assessment of thorium and uranium contamination on
 1295 most building surfaces because surface conditions cause significantly less attenuation of beta particles
 1296 than alpha particles. Beta measurements, therefore, may provide a more accurate determination of
 1297 surface activity than alpha measurements.
 1298

1338 DCGLs.

1339 The unity rule, represented in the following expression, is satisfied when radionuclide mixtures yield a
1340 combined fractional concentration limit that is less than or equal to one:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots + \frac{C_n}{DCGL_n} \leq 1$$

1341 where

1342 C = concentration

1343 DCGL = clearance guideline value for each individual radionuclide (1, 2, ... n)

1344 For the clearance of solid materials that have potential contamination with multiple radionuclides, it may
1345 be possible to measure just one of the radionuclides and still demonstrate compliance for all of the other
1346 radionuclides present through the use of surrogate measurements. In the use of surrogates, it is often
1347 difficult to establish a "consistent" ratio between two or more radionuclides. Rather than follow
1348 prescriptive guidance on acceptable levels of variability for the surrogate ratio, a more reasonable
1349 approach may be to review the data collected to establish the ratio and to use the DQO Process to select
1350 an appropriate ratio from that data. The DCGL_C must be modified to account for the fact that one
1351 radionuclide is being used to account for one or more other radionuclides.

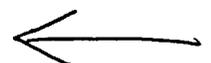
Ref. 10CFR61 scaling factors

1352 The following equation illustrates how the DCGL for the measured radionuclide is modified
1353 (DCGL_{meas,mod}) to account for the inferred radionuclide:

1354 where

= ??

$$DCGL_{meas,mod} = DCGL_{meas} \left(\frac{(DCGL_{infer})}{\left(\frac{C_{infer}}{C_{meas}} \right) DCGL_{meas} + DCGL_{infer}} \right)$$



1355 C_{infer}/C_{meas} = surrogate ratio for the inferred to the measured radionuclide

1356 When it is necessary for the measured radionuclide to be used as a surrogate for more than one
1357 radionuclide, Equation I-14 on MARSSIM page I-32 can be used to calculate the modified DCGL for the
1358 measured radionuclide:

= ?

$$DCGL_{meas,mod} = \frac{1}{\left(\frac{1}{D_1} + \frac{R_2}{D_2} + \frac{R_3}{D_3} + \dots + \frac{R_n}{D_n} \right)}$$

1359 where D₁ is the DCGL_C for the measured radionuclide by itself, D₂ is the DCGL_C for the second
1360 radionuclide (or first radionuclide being inferred) that is being inferred by the measured radionuclide.

1403 4.6.1 Static MDCs

1404 The measurement of contamination during clearance surveys often involves measuring contamination at
1405 near-background levels. Thus, it is essential to determine the minimum amount of radioactivity that may
1406 be detected using a given survey instrument and measurement procedure. In general, the MDC is the
1407 minimum activity concentration on a surface, or within a material volume, that an instrument is expected
1408 to detect (e.g., activity expected to be detected with 95-percent confidence). It is important to note,
1409 however, that this activity concentration, or MDC, is determined a priori (that is, before survey
1410 measurements are conducted).

1411 The MDC corresponds to the smallest activity concentration measurement that is practically achievable
1412 with a given instrument and type of measurement procedure. That is, the MDC depends on the particular
1413 instrument characteristics (efficiency, background, integration time, etc.), as well as the factors involved
1414 in the survey measurement process, which include surface type, source-to-detector distance, source
1415 geometry, and surface efficiency (backscatter and self-absorption). More information on detectability,
1416 detection limits, and formulas to compute MDCs is available in the literature (Currie 1968, NRC 1984,
1417 Brodsky 1992 and 1993, Chambless 1992, ANSI 1996, ISO 2000a and b).

1418 The methodology to determine an MDC for a given instrument, radionuclide, matrix or surface, and
1419 measurement protocol is based on the specific formulation of the MDC for the application in question.
1420 For example, the formula for calculating the MDC for a technician scanning copper tubing for alpha
1421 contamination would be different than the formula for calculating the MDC for ¹³⁷Cs in soil using a
1422 shielded gamma-ray spectrometer. However, all forms of the MDC equation do have the following
1423 structure (NCRP 1985):

$$MDC = \frac{\overline{d}}{k} \frac{\text{detection limit}}{\text{efficiency} \times \text{sample size}} \quad (4-1)$$

1424 where k is a unit conversion (from instrument response to activity and the desired units).

1425 The detection limit considers both the instrument background and backgrounds from other sources, such
1426 as interfering radiations from the environment (both natural and anthropogenic), in determining the
1427 response of the instrument that is statistically different from background. This detection limit is
1428 determined using a statistical hypothesis test with a specified gray region and Type I and Type II errors.
1429 The overall uncertainty of the measurement process when measuring a blank sample is a key parameter
1430 for determining realistic detection limits.

1431 The efficiency term includes the efficiency associated with the detector (instrument or intrinsic
1432 efficiency), geometrical efficiency, surface or sample efficiency, absorption efficiency, and, in some
1433 applications, surveyor efficiency (see Section 4.6.2). The surface efficiency accounts for field conditions
1434 such as rusty metal, damp surfaces, or scabbled concrete.

1435 The sample size term takes on different values depending on the type of measurement. For field survey
1436 instruments, this is usually well-defined as the physical probe area of the detector. For laboratory
1437 measurements, it is again a well-defined quantity defined as a measured amount of the sample. However,
1438 in the case of an *in situ* or *in toto* measurement, the sample size is a function of the detector's field-of-
1439 view, which is usually not well-defined (or difficult to define accurately). Section 5.4 further addresses
1440 MDC issues for the *in situ* gamma spectrometer used to release materials.

1441 The following equation is used to calculate the MDC for surface activity assessments using conventional
1442 survey instrumentation (NRC 1998a):

$$MDC = \frac{3 + 4.65 \sqrt{C_B}}{KT} \quad (4-2)$$

1443 where C_B is the background count in time, T , for paired observations of the sample and blank. The
1444 quantities encompassed by the proportionality constant, K , include the instrument efficiency, surface
1445 efficiency, and probe geometry. Based on the radionuclides of concern, specific instrument and surface
1446 efficiencies are used to calculate the static MDC for surface activity measurements. The MDC is also a
1447 function of the surface material background level and, therefore, varies with the nature of the surfaces
1448 being surveyed.

1449 The detection and detectability of contamination when using other than the conventional survey approach
1450 must also be considered. Tritium (^3H) and ^{14}C create a significant challenge for detection (because of the
1451 associated low instrument efficiency). They each emit a low-energy β radiation, and they are not
1452 amenable to the surrogate approach. Similarly, ^{63}Ni and ^{99}Tc are somewhat difficult to detect because
1453 they too have primary radiations of low-energy betas. Conversely, ^{60}Co , Cs-134, and ^{137}Cs (via Ba-
1454 ^{137}m) are easily detected because of their intense and rather energetic gamma-rays and readily-
1455 measured beta radiations. The evaluation of detectability for these seven radionuclides is more or less
1456 independent of the matrix and nature of the contamination. In general, all of the radionuclides (with the
1457 exception of ^3H) can be detected with hand-held devices using standard survey methods. The issue is
1458 whether hand-held devices and standard survey methods can detect these radionuclides, separately or in
1459 combination, at the levels established for release. *→ which is nothing above background at present*

1460 Therefore, the recipe to calculate the MDC for any measurement method (such as for an *in toto*
1461 technique or laboratory analysis) is to determine the detection limit, relevant efficiencies, and sample size
1462 for the given instrument and measurement protocol. For some of the more common (conventional)
1463 techniques of measuring radionuclides and materials, these quantities have been either measured,
1464 calculated, or estimated and MDCs are available in the literature (ANSI 1999, MARSSIM 1997, NRC
1465 1998a, EC 1998, and Goles *et al.* 1991). The reader should note, however, that the MDC provided in
1466 these references apply only to the situation described and must not be construed to be a universal MDC
1467 for a particular instrument or protocol. Rather, they should be viewed only as a general measure of the
1468 capability of the instruments for the application described.

On Page 6-43 of the MARSSIM, the equation for Scan MDC includes an area correction term:

probe area
100cm² in the denominator

1502 The scan MDC for structure surfaces may be calculated as

$$\text{scan MDC} = \frac{\text{MDCR}}{\sqrt{p e_i e_s}} \quad (4-3)$$

1503 where the minimum detectable count rate (MDCR), in counts per minute, can be written as

$$\text{MDCR} = d' \sqrt{b_i} (60/i) \quad (4-4)$$

should be attached to this doc instead of branching to another.

- 1504 where d' = detectability index (the value can be obtained from Table 6.5 in the MARSSIM),
- 1505 b_i = background counts in the observation interval,
- 1506 i = observational interval (in seconds), based on the scan speed and areal extent of the contamination
- 1507 (usually taken to be 100 cm²),
- 1508 e_i is the instrument or detector efficiency (unitless),
- 1509 e_s is the surface efficiency (unitless); and
- 1510 p is the surveyor efficiency (usually taken to be 0.5).

1511 Consider an example that involves determining the gas proportional scan MDC for the GDP mixture on
 1512 concrete slabs. The scan MDC will be determined for a background level of 400 cpm and a 1-second
 1513 observation interval. For a specified level of performance at the first scanning stage of 95-percent "true
 1514 positive" rate and 25-percent "false positive" rate, d' equals 2.32 (from Table 6.5 in the MARSSIM), and
 1515 the MDCR is calculated as follows:

1516 $S_i = \text{minimum detectable \# of net source counts in the interval}$ $b_i = (400 \text{ cpm})(1 \text{ s})(1 \text{ min}/60 \text{ s}) = 6.67 \text{ counts}$ $S_i = d' \sqrt{b_i}$

1517 $S_i = (2.32)(6.67)^{1/2} = 6.0 \text{ counts}$, and

1518 $\text{MDCR} = (6.0 \text{ counts})[(60 \text{ s/min})/(1 \text{ s})] = 360 \text{ cpm}$
 $= S_i (60/i)$

1519 Using a surveyor efficiency of 0.5 and the total weighted efficiency determined in Table 4.4 (0.11), the
 1520 scan MDC is calculated as

$$\text{scan MDC} = \frac{360}{\sqrt{0.5 (0.11)}} = 4,600 \text{ dpm}/100 \text{ cm}^2 \quad (0.77 \text{ Bq}/\text{cm}^2)$$

1521 A Geiger-Mueller (GM) detector is often used to scan material surfaces that are difficult (or impossible)
 1522 to access using the larger gas proportional detector. The efficiency of a GM detector in scanning this
 1523 radionuclide mixture can be determined in a manner similar to that used in Table 4.4. It is important to
 1524 note, however, that the scan MDC calculations usually require the assumption that the instrument
 1525 efficiencies are determined relative to a 100-cm² calibration source to yield the appropriate units (dpm/100

If $\neq 100 \text{ cm}^2$, area correction factor
 $\frac{A}{100}$

1526
1527
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cm²). This is in contrast to the static MDC equation, which uses a physical probe area correction in the calculation of surface activity.

Table 4.5 provides instrument efficiencies that correspond to a 100-cm² calibration source, without reducing the 2π emission rate for the smaller area subtended by the GM detector. [Note: This is precisely what would be performed for static measurements of surface activity.] In other words, as long as 100 cm² is used as the size of the postulated small, elevated area, and the instrument efficiency is calculated for the same area, there is no need for a probe area correction in the scan MDC equation.

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Table 4.5: Detector efficiency when scanning for GDP-enriched uranium (1.2%) and ⁹⁹Tc using a GM detector

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Radionuclide	Radiation/Average Energy (MeV)	Activity Fraction	ϵ_i	ϵ_i	Weighted Efficiency
⁹⁹ Tc	Beta/0.085	0.7082	0.05	0.25	8.9×10^{-3}
²³⁸ U	Alpha/4.2	0.1077	0.02	0.25	5.4×10^{-4}
²³⁴ Th	Beta/0.0435	0.1077	0.025	0.25	6.7×10^{-4}
^{234m} Pa	Beta/0.819	0.1077	0.12	0.50	6.5×10^{-3}
²³⁴ U	Alpha/4.7	0.1728	0.02	0.25	8.6×10^{-4}
²³⁵ U	Alpha/4.4	0.0084	0.02	0.25	4.2×10^{-5}
²³¹ Th	Beta/0.0764	0.0084	0.045	0.25	1.8×10^{-5}
Total Weighted Efficiency					0.018

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1545
1546
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1548

As an example, consider evaluating the scanning-based MDC for the gaseous diffusion plant (GDP) mixture on stainless-steel materials. The scanning-based MDC will be determined for a background level of 70 cpm and a 1-second interval using a GM detector. For a specified level of performance at the first scanning stage of 95-percent true positive rate and 25-percent false positive rate, d^* equals 2.32 (from Table 6.5 in the MARSSIM), and the MDCR is calculated as follows:

1549
1550
1551

$$b_i = (70 \text{ cpm})(1 \text{ s})(1 \text{ min}/60 \text{ s}) = 1.2 \text{ counts},$$

$$s_i = (2.32)(1.2)^{1/2} = 2.5 \text{ counts, and}$$

$$MDCR = (2.5 \text{ counts})[(60 \text{ s}/\text{min})/(1 \text{ s})] = 150 \text{ cpm.}$$

1552
1553

Using a surveyor efficiency of 0.5 and the total weighted efficiency determined in Table 4.5 (0.018), the scan MDC is calculated as

$$\text{scan MDC} = \frac{150}{\sqrt{0.5} (0.018)} = 12,000 \text{ dpm/100 cm}^2 \text{ (2 Bq/cm}^2\text{)}$$

1554 **4.6.2.2 Conveyor Survey Monitor Scan MDCs**

1555 The scan MDC for a CSM can be estimated using Equation 4-1, with some modification to account for
 1556 the automated nature of a CSM. That is, the parameters that impact the CSM scan MDC include the
 1557 detection limit, efficiency, and sample size. The detection limit is based on the background counts
 1558 obtained over the counting interval and the acceptable rate of true (correct detection) and false positives.
 1559 The background level depends on the nature of the material, while the counting interval is a function of
 1560 both the detector's field-of-view and the system belt speed (i.e., it establishes the length of time that the
 1561 detector(s) can respond to a fixed length of material). Basically, the MDCR can be calculated for the
 1562 CSM in much the same manner as it is for conventional scans, with the primary difference being that
 1563 automated systems interpret the signal stream (data) using a computer-based analysis algorithm rather
 1564 than by calculation (Equation 4-4).

1565 Sample or survey unit size is a function of the belt geometry, speed (which establishes the observation
 1566 interval), and the detector's field-of view and, therefore, has a fundamental impact on the scanning
 1567 detection limit (cpm) and MDC (Bq/g) of a CSM. The detection efficiency for a CSM depends on the
 1568 detector characteristics, nature of the contamination, the material being surveyed, and source-to-detector
 1569 geometry. Modeling was performed to support the determination of beta detection efficiencies for
 1570 automated scanning systems, as further discussed in Section 5.3.

1571 **4.6.2.3 Empirical Determinations of Scanning-Based MDCs**

1572 Empirical determination of scanning-based MDCs can serve as an alternative to calculation. That is, it is
 1573 possible to design experiments to assess (and empirically determine) the scanning-based MDCs for
 1574 particular survey instruments and scan procedures. A number of researchers, as well as R&D
 1575 professionals, have developed mockups of surfaces with contamination to determine scanning-based
 1576 MDCs. For instance, in a study by Goles *et al.* (1991), empirical results included MDCRs as a function
 1577 of background levels: 305 net cpm detected in 50-cpm background level, 310 cpm in 250-cpm
 1578 background, and 450 cpm in 500-cpm background. It is important to note that these MDCRs were quoted
 1579 for detection frequencies of 67 percent (compared to the usual 95 percent). Empirical assessments of
 1580 scanning-based MDC can also be valuable for determining the scanning capabilities of specific survey
 1581 technicians.

1582 The uncertainty in the scanning-based MDCs calculated using the approaches described in this section
 1583 should be viewed in the context of their use. That is, scanning-based MDCs are used to help design the
 1584 clearance survey approach, and should represent a "reasonable estimate" of the activity concentration
 1585 that can be detected when scanning. In other words, while the scanning-based MDC should be carefully
 1586 assessed, it is important to remember that such MDCs are inherently subject to uncertainties (e.g., human
 1587 factors, unknown characteristics of contamination prior to survey, variable background levels, etc.).
 1588 Recognizing this uncertainty in the scanning-based MDCs, it is worthwhile to consider additional means of
 1589 evaluating these values.

1590 Empirical evaluation of scanning-based MDCs can also be an important validation tool. This validation is

1632 pile. In this case, some of the scrap metal surfaces are considered to be inaccessible because they do not
1633 directly contribute to the detector's response. However, provided that a sufficient fraction of gamma
1634 radiation from the contamination is detected, *in situ* gamma spectrometry might provide a reasonable
1635 clearance technique for scrap metal piles. (Refer to Section 5.4 for a discussion of this survey approach.)

1636 4.7.2 Making an Inaccessible Area Accessible

1637 As previously indicated, one strategy that can be considered when dealing with materials that have
1638 inaccessible areas is to make the inaccessible areas accessible. For example, this can be accomplished
1639 by dismantling scrap equipment or by excavating buried or embedded pipes. Inaccessible areas that might
1640 require disassembly include small pumps, motors, hand tools, power tools, and electrical control panels.

1641 These materials are assumed to require some amount of disassembly to allow access to their interior
1642 surfaces. The dismantling might be deliberate to ensure that the item is still functional following the
1643 efforts to gain access to internal surfaces. Conversely, cutting techniques can be employed to expedite
1644 the process if reuse is not an option.

1645 Another technique that may be considered is the use of thermoluminescent dosimeters (TLDs) or small
1646 detectors to measure surface activity levels within buried and embedded piping systems. TLDs can be
1647 deployed for some period of time within small bore piping or conduit to respond to the contamination levels
1648 on the interior surfaces. An important aspect of this application is the calibration of the TLDs to surface
1649 activity in the given pipe geometries. Small detectors, such as miniature GM detectors, and other "pipe-
1650 crawling" detector systems have been used to assess surface contamination in pipe systems.

1651 Nondestructive assay (NDA) is any quantitative technique that does not require sampling or sample
1652 preparation, and will not alter the physical or chemical state of the object being measured. NDA
1653 techniques have been developed and used on nuclear fuel materials, transuranic waste, soils, and scrap
1654 metal. The two basic approaches to NDA involve passive and active techniques. A passive technique
1655 involves directly measuring the spontaneous decay of nuclear material, while an active technique attempts
1656 to excite atoms and molecules to emit characteristic radiation that can be measured and used for
1657 identification and quantification. With the exception of nuclear activation analysis, active techniques
1658 cannot distinguish between nuclear isotopes like some passive techniques. However, active techniques
1659 are potentially more sensitive than passive techniques associated with decay counting. In general, NDA
1660 techniques are less sensitive than laboratory techniques.

There will still be some inaccessible surfaces (windings,
removal of parts that will void calibration, etc).

There are many items which would never be
totally dismantled for unconditional release survey.

1852 One-Sample Statistical Test (Sign Test)

1853 The Sign test is designed to detect whether there is contamination in the material survey unit in excess of
1854 the DCGL_C. This test does not assume that the data follow any particular distribution, such as normal or
1855 log-normal. If any measurement exceeds this DCGL_C, additional investigation is recommended, at least
1856 locally, to determine the actual areal extent of the elevated concentration.

1857 The following formal null and alternative hypotheses are tested by the Sign test under Scenario A:

1858 Null Hypothesis

1859 H₀: The median concentration of contamination in the material survey unit is greater than the DCGL_C

1860 *versus*

1861 Alternative Hypothesis

1862 H_a: The median concentration of contamination in the material survey unit is less than the DCGL_C

1863 The null hypothesis is assumed to be true unless the statistical test indicates that it should be rejected in
1864 favor of the alternative hypothesis. The null hypothesis states that the probability of a measurement less
1865 than the DCGL_C is less than one-half (i.e., the 50th percentile, or median, is greater than the DCGL_C).
1866 Note that some individual survey unit measurements may exceed the DCGL_C even when the survey unit
1867 as a whole meets the release criteria. In fact, a survey unit average that is close to the DCGL_C might
1868 have almost half of its individual measurements greater than the DCGL_C. Such a material survey unit
1869 may still not exceed the release criteria.

1870 The assumption is that the survey unit measurements are independent random samples from a symmetric
1871 distribution. If the distribution of measurements is symmetric, the median and the mean are the same. To
1872 the extent that the mean may be larger than the median, there should be some areas of larger
1873 concentration that cause the distribution to be skew. When that is the case, they will be identified by
1874 scanning, and will trigger appropriate investigation levels as described in Section 6. This is the reason for
1875 combining direct measurements with scans in the survey design.

1876 The hypothesis specifies a release criterion in terms of a DCGL_C. The test should have sufficient power
1877 (1-β, as specified in the DQO Process) to detect residual radioactivity concentrations at the lower bound
1878 of the gray region (LBGR). The LBGR should be set at the expected mean contamination level for the
1879 material survey unit. If σ is the standard deviation of the measurements in the material survey unit, then
1880 Δ/σ expresses the size of the shift (i.e., Δ = DCGL_C - LBGR) as the number of standard deviations that
1881 would be considered "large" for the distribution of measurements in the survey unit. Table 5.5 in the
1882 MARSSIM provides sample sizes for the Sign test as a function of relative shift and Type I and II
1883 decision errors.

Δ ??
 $\Delta/\sigma = \text{relative shift}$
usually between 1 + 3

$\Delta = \text{shift}$
= width of gray region
Upper bound of gray region
= ~~DCGL_C~~ DCGL_C

1884 If the criterion specified for controlling the release of material is that there must be no contamination, the
1885 clearance survey requires a different approach, similar to Scenario B described in NUREG-1505. The
1886 following formal null and alternative hypotheses are tested by the Sign test under Scenario B:

1887 Null Hypothesis

1888 H_0 : The median concentration of contamination in the material survey unit is zero.

1889 *versus*

1890 Alternative Hypothesis

1891 H_1 : The median concentration of contamination in the material survey unit is greater than the upper
1892 bound of the gray region (UBGR).

1893 As in Scenario A, in order to design a survey to test the null hypothesis for Scenario B, it is necessary to
1894 specify a gray region. Since no contamination is the criterion, the LBGR is zero, but it is still necessary to
1895 specify the UBGR. This is essential for determining an appropriate sample size, and for specifying the
1896 needed measurement sensitivity (i.e., MDC, as discussed in Section 9.1). The width of the gray region Δ
1897 = UBGR - LBGR = UBGR - 0 = UBGR. If s is the standard deviation of repeated "blank" Δ/s
1898 measurements (i.e., measurements on material that is known to contain no contamination), Δ/s expresses
1899 the width of the gray region as a relative shift. Table 5.5 in the MARSSIM shows that when this relative
1900 shift falls below 1, the sample size required for the test increases dramatically. For example, if $\Delta/s = 1$,
1901 and the DQOs for the Type I and Type II error rates, $\alpha = \beta = 0.05$, 29 measurements are required. If Δ/s
1902 = 0.5, 89 measurements are required. If Δ/s falls as low as 0.1, more than 2,000 measurements are
1903 required. Thus, it is generally recommended that the relative shift Δ/s be between 1 and 3. Increasing
1904 the relative shift much above 3 does not appreciably reduce the required number of measurements.

1905 There is a direct connection between the UBGR and the MDC. For every instrument and procedure,
1906 there is an associated MDC, which is usually defined to be the concentration that will be detected with a
1907 95-percent probability when it is present, while limiting to 5 percent the probability that a detection
1908 decision will be made when there is actually no contamination. (Refer to Section 4.6.) This decision is
1909 made separately for each measurement. It is a test of the hypothesis that there is no contamination at
1910 that single location on the material. The detection decision is based on whether the instrument signal is
1911 above a critical level corresponding to a concentration equal to about one-half the MDC. The MDC is
1912 usually 3 to 4 times the measurement uncertainty, s . Since the MDC should not exceed the UBGR, the
1913 smallest practical value of the UBGR occurs when it equals the MDC. Thus, an essential part of the
1914 DQO process for this case is setting the required MDC. This ultimately defines the gray region, the
1915 sample size, and the effort that should be expended to find any contamination that might be present.
1916 When the UBGR = MDC, Δ/s is about 3. Table 5.5 in the MARSSIM then indicates that between 8 and
1917 20 samples must be taken, depending on the Type I and Type II error rates that are set.

1918 In practice, the very use of the Sign test implies that radionuclide-specific measurements are being made
1919 to detect radionuclides that do not appear in background. Thus, any *unambiguously* detected positive
1920 concentration measured anywhere on the material obviously shows that it does not meet the criterion of
1921 no contamination, even though the *median* added concentration may be zero. This is analogous to the
1922 procedure used in the MARSSIM, namely, if the average concentration exceeds the release criterion,
1923 the survey unit may not be released regardless of the result of the statistical test.

1960 Note that some or all of the material survey unit measurements may be larger than some reference
1961 material measurements, while still meeting the release criterion. Indeed, some survey unit measurements
1962 may exceed some reference material measurements by more than the $DCGL_C$. The result of the
1963 hypothesis test determines whether or not the material survey unit as a whole is deemed to meet the
1964 release criterion. Individual measurements exceeding the $DCGL_C$ are further investigated to the extent
1965 necessary to ensure that the overall average in the survey unit does not exceed the $DCGL_C$. Additionally,
1966 the test should consider whether any smaller areas with elevated levels of contamination may exceed a
1967 separate criterion set for such areas.

1968 The test should have sufficient power ($1-\beta$, as specified in the DQO Process) to detect residual
1969 radioactivity concentrations at the lower bound of the gray region (LBGR). The LBGR should be set at
1970 the expected mean residual contamination level in the material survey unit. The larger of the two values
1971 of s estimated from the reference material and material survey unit should be used for the WRS test
1972 sample determination. As described in the MARSSIM, the relative shift, Δ/s , where $\Delta = DCGL_C -$
1973 LBGR, is calculated. Table 5.3 in the MARSSIM provides sample sizes for the WRS test as a function
1974 of relative shift and Type I and II decision errors.

1975 If the criterion specified for controlling the release of material is that there must be no contamination, the
1976 clearance survey requires an approach similar to Scenario B described in. The following formal null and
1977 alternative hypotheses are tested by the WRS test under Scenario B:

1978 Null Hypothesis
1979 H_0 : The median concentration in the material survey unit does not exceed that in the reference
1980 material (i.e., there is no contamination).

1981 *versus*

1982 Alternative Hypothesis
1983 H_a : The median concentration in the material survey unit exceeds that in the reference material by
1984 more than the upper bound of the gray region (UBGR).

1985 For this test, the lower bound of the gray region is set at zero contamination. As for the Sign test using
1986 Scenario B, it is again necessary to specify a UBGR. It is essential for determining an appropriate sample
1987 size and the needed measurement sensitivity. The width of the gray region, $\Delta = UBGR - LBGR = UBGR$
1988 $- 0 = UBGR$. If s is the standard deviation of repeated "background" measurements (i.e., measurements
1989 on material known to contain no contamination), Δ/s expresses the width of the gray region as a relative
1990 shift. Table 5.3 in the MARSSIM shows that when this relative shift falls below 1, the sample size
1991 required for the test increases dramatically. For example, if $\Delta/s = 1$, and the DQOs for the Type I and
1992 Type II error rates, $\alpha = \beta = 0.05$, 32 measurements are required on both the survey material and on the
1993 background reference material. If $\Delta/s = 0.5$, 114 measurements are required on each. If Δ/s falls as
1994 low as 0.1, more than 2,700 measurements are required on each. Thus, it is generally recommended that
1995 the relative shift Δ/s be between 1 and 3. Increasing the relative shift much above 3 does not appreciably
1996 reduce the required number of samples.

1997 There is a direct connection between the UBGR and the required measurement sensitivity. To distinguish
1998 between a measurement of background on the reference material and a measurement equal to
1999 background plus the UBGR, the instrument or procedure must be able to reliably detect the difference
2000 (i.e., the UBGR). Unless the uncertainty of a typical background measurement (S_M) is less than the
2001 UBGR, the relative shift (S_M/s) = UBGR/s will fall below 1, even if there is no spatial variability contributing
2002 to (S_M). Conversely, setting the UBGR to be less than (S_M) will cause the number of measurements required
2003 to achieve the DQOs to rise dramatically. Thus, an essential part of the DQO Process for this case is
2004 in setting the UBGR, recognizing the implicit demand on the required relative measurement
2005 uncertainty at near-background levels.

$$S_M = \sigma_M ?$$

2006 Application to Surface Activity Measurements

2007 Either the Sign test or WRS test can also be used for surface activity measurements. Given that many
2008 material survey units are composed of the same material types, using the WRS test should be relatively
2009 straightforward (i.e., same as described in the MARSSIM). In some cases however, the number of
2010 materials present in a batch may make it impractical to use the WRS test. In such cases, it is possible to
2011 perform the Sign test on the difference of paired measurements on similar materials, one from the survey
2012 unit and one from a reference material, as outlined in Section 12 of NUREG-1505 (NRC, 1998b).

2013 When surface activity measurements are performed using non-radionuclide-specific (gross) survey
2014 instruments (e.g., GM and gas proportional detectors), a commonly used procedure is to subtract an
2015 "appropriate average background" from each gross measurement on the solid material, and then analyze
2016 the resulting data using a one-sample statistical test, such as the Sign test. Before doing so, however, the
2017 surveyor should recognize that the WRS test may be more advantageous for the following reasons:

- 2018 (1) The number of samples taken to compute an appropriate background average is left purely to
2019 judgment. When the WRS test is used, the appropriate number of background measurements has a
2020 statistical basis.
- 2021 (2) The Sign test will generally not be as powerful as the WRS test (more important as the expected
2022 contamination level approaches the DCGL_C).
- 2023 (3) The same data that are used to calculate the average background can always be used in the WRS
2024 test as well.

2025 The Sign test offers no real savings (compared to the WRS test), with the possible exception of the time
2026 needed to perform the calculations. However, when the material survey unit is very clean, the maximum
2027 survey unit measurement and minimum reference area measurement will likely not exceed the DCGL,
2028 and the survey unit will pass the WRS test without any need for calculations. When the material is
2029 contaminated above the DCGL, a simple comparison of the averages will likely show that the material
2030 cannot be released. It is only in cases where the contamination is near the DCGL that the extra
2031 computations involved in the WRS test will be necessary; however, it is precisely in those cases that the
2032 higher statistical power of the WRS test makes its use more desirable.

2475 was performed at the midpoint of each side of the pallet for 10 minutes, for a total of 40 minutes of count
 2476 time. The process was repeated for nine additional measurement sets with the ¹³⁷Cs sources placed
 2477 randomly each time. The ⁶⁰Co measurements were independently performed in the same manner. No
 2478 shielding or collimation was used, and the detector was placed 1 meter (vertically) from the floor, and
 2479 generally as close as possible to the pallet of steel conduit.

2480 The efficiency, ϵ , for the region-of-interest (ROI) corresponding to the appropriate total absorption peak
 2481 (TAP) for ⁶⁰Co or ¹³⁷Cs was calculated. First, the net counts in the TAP ROI were calculated by
 2482 subtracting the Compton continuum counts in the ROI from the gross counts in the TAP ROI. Next, the
 2483 net counts for the TAP ROI were divided by the total activity of the particular source, and the count time
 2484 in minutes to determine efficiency in net counts per minute per kBq. The minimum detectable activity
 2485 (MDA), in kBq, for the TAP ROI was calculated by the equation below, using the experimentally
 2486 determined efficiency, where the BKG values, or continuum counts, were determined by the gross peak
 2487 counts minus the net peak counts.

2488
$$MDA [kBq] = \frac{3 + 4.65 \sqrt{BKG [counts]}}{T [min] \epsilon [net\ peak\ counts\ per\ min\ per\ kBq]}$$

2489 Table 5.3 below summarizes the results of the ISGS measurements of the steel conduit pallet.

2490 **Table 5.3: Efficiency and MDA summary for ISGS measurements of scrap steel pallet**
 2491 **(10-minute count time)**

2492 Radionuclide 2493 (keV)	Efficiency (Standard Deviation) ^a [net counts min ⁻¹ kBq ⁻¹] 1) ^b	Efficiency 2-Sigma Range (net counts min ⁻¹ kBq ⁻¹)	MDA (kBq) ^c	MDA 2-Sigma Range (kBq)
2494 ¹³⁷ Cs (662)	0.41 (0.09)	0.23 – 0.59	11	7 – 19
2495 ⁶⁰ Co (1173)	0.33 (0.07)	0.19 – 0.47	11	7 – 22
2496 ⁶⁰ Co (1332)	0.30 (0.06)	0.18 – 0.42	11	7 – 15

2497 ^aTotal propagated uncertainty.

2498 ^bTo convert to units of net counts min⁻¹ μCi⁻¹, multiply by 37.

2499 ^cTo convert to units of μCi, divide by 37.

2500 Multiple sets of measurements with randomly placed sources (in a non-uniform geometry) were
 2501 performed to calculate an unbiased range of efficiencies for this particular geometry. Using the lower
 2502 5-percent confidence interval on the 2-sigma range of the efficiency from Table 5.3 allows the MDA to
 2503 be conservatively reported for comparison to potential dose limits.

2504 Table 5.3 shows that at an alternative dose criterion of 10 μSv/y (1 mrem/y), ISGS is a viable technology
 2505 for 1 metric ton of 5-inch diameter steel conduit released from a nuclear facility. The upper range MDA
 2506 for ¹³⁷Cs at 19 kBq (0.5 μCi) is below the total activity of 38 kBq (1.0 μCi) required to produce 10 μSv/y
 2507 (1 mrem/y). The upper range MDA for ⁶⁰Co at 22 kBq (0.6 μCi) is below the total activity of 40 kBq
 2508 (1.1 μCi) required to produce 10 μSv/y (1 mrem/y). However, if the more-restrictive dose limit of 1 μSv/y
 2509 (0.1 mrem/y) is assumed, ISGS would lack the necessary sensitivity to detect 3.8 kBq (0.1 μCi) of either

2510 ⁶⁰Co or ¹³⁷Cs.

2511 With the same ¹³⁷Cs and ⁶⁰Co sources used with the steel conduit experiment, a second experimental
 2512 configuration consisting of a pallet of 148 insulated copper wires with a total weight of 490 kg
 2513 (1,080 pounds) was set up. The only difference between the steel and copper experiment was that the
 2514 count time was increased from 10 to 30 minutes per measurement to allow for the increased attenuation
 2515 of the gamma-rays by the copper. Table 5.4 shows the dose calculation results.

2516 **Table 5.4: Calculated total activity for selected radionuclides**
 2517 **using mass-based, critical-group dose factors for copper (4.9x10⁵ g)**

Radionuclide	Key Gamma(s) (keV)	Mean Dose Factor ($\mu\text{Sv y}^{-1} \text{Bq}^{-1} \text{g}^{\text{a}}$)	Total Activity for 10 $\mu\text{Sv y}^{-1}$ (kBq) ^b
¹³⁷ Cs	662	62	78
⁶⁰ Co	1173, 1332	250	19

2521 ^a To convert to units of mrem y⁻¹ pCi⁻¹ g, multiply by 3.7x10⁻³.

2522 ^b To convert to units of μCi , divide by 37.

2523 Table 5.5 shows that for an alternative dose criterion of 10 $\mu\text{Sv/y}$ (1 mrem/y) and for the given
 2524 experimental conditions, ISGS may not be a viable technology for a typical volume of copper released
 2525 from a nuclear facility. The upper range MDA for ¹³⁷Cs at 89 kBq (2.4 μCi) is above the total activity of
 2526 78 kBq (2.1 μCi) required to produce 10 $\mu\text{Sv/y}$ (1 mrem/y). The upper range MDA for ⁶⁰Co at 59 kBq
 2527 (1.6 μCi) is above the total activity of 19 kBq (0.5 μCi) required to produce 10 $\mu\text{Sv/y}$ (1 mrem/y).
 2528 However, if the less-restrictive dose limit of 100 $\mu\text{Sv/y}$ (10 mrem/y) were adopted, ISGS would have the
 2529 necessary sensitivity to detect 780 kBq (21 μCi) of ¹³⁷Cs or 190 kBq (5 μCi) of ⁶⁰Co in this copper matrix.

2530 **Table 5.5: Efficiency and MDA summary for ISGS measurements of scrap copper pallet**
 2531 **(30-minute count time)**

Radionuclide (keV)	Efficiency (Standard Deviation ^a) [net counts min ⁻¹ kBq ⁻¹] 1 σ	Efficiency 2-Sigma Range (net counts min ⁻¹ kBq ⁻¹)	MDA ^c (kBq) ^d	MDA 2-Sigma Range (kBq)
¹³⁷ Cs (662)	0.13 (0.04)	0.05 – 0.21	33	22 – 89
⁶⁰ Co (1173)	0.11 (0.03)	0.05 – 0.17	37	22 – 85
⁶⁰ Co (1332)	0.09 (0.02)	0.05 – 0.13	30	22 – 59

2537 ^a Total propagated uncertainty.

2538 ^b To convert to units of net counts min⁻¹ μCi^{-1} , multiply by 37.

2539 ^c MDA values calculated for a 10 minute count.

2540 ^d To convert to units of μCi , divide by 37.

2541 **5.4.1.5 ISGS Measurement Considerations**

2542 The average contamination in the material determined by the ISGS system should be representative of the
2543 true average for comparison to the volumetric guidelines. For materials with uniform or near-uniform
2544 contamination, only one measurement, from any orientation, may sufficiently determine the average
2545 contamination. For materials that do not have uniform contamination, different ISGS measurement
2546 approaches may be necessary to determine a more accurate average contamination level. For instance,
2547 for Class 1 materials that potentially contain small elevated areas of radioactivity, the ISGS calibration
2548 should address the impact that these small elevated areas of radioactivity have on the efficiency of this
2549 survey technique, so that an accurate average contamination level is determined.

2550 One approach is to perform multiple measurements at different angles around the material, such as all
2551 four sides, and then average the measurement results. Another approach, which is commonly used in
2552 drum counters, is to rotate the material during the measurement time. However, rotating a pallet of pipes
2553 or wire can be unwieldy, if not impossible, so to effectively rotate the material, one might perform part of
2554 one measurement at each location around the material. For example, suppose a count time of 40 minutes
2555 was required to meet the required sensitivity and the material was to be measured from all four sides.
2556 The first 10 minutes of the single measurement would be performed, and then the acquisition would be
2557 paused while the detector was moved to the second measurement location, and then the acquisition would
2558 continue for another 10 minutes. This process would be repeated for the remaining two positions.

2559 5.4.2 Volume Counters

2561 Various designs of volume counters can be used to quantify surface activity or total activity. Volume
2562 counters, while generally designed for specific counting applications, have common characteristics.
2563 These include a counting chamber, array of detectors, and electronic package for analysis.

2564 The counting chambers are designed specifically for the measurement application. The size determines
2565 what type of materials or containers the system is capable of measuring. Volumes range from small
2566 items to large shipping containers. A variety of detectors, including gas proportional, plastic and NaI
2567 scintillators, HPGe semiconductors, and long-range alpha detection configurations, are used in volume
2568 counters, depending on the application. Many designs focus on detecting specific waste streams (e.g.,
2569 transuranic waste, with a high throughput). Systems designed to quantify alpha and/or beta surface
2570 activity use gas proportional and plastic scintillator detectors or long-range alpha detection. Plastic and
2571 NaI scintillators and HPGe semiconductor detectors are used for volumetric gamma radioactivity.

2572 Calibrations are usually performed with standard packages or suitable geometries containing sources of
2573 known activity. Shielded configurations are frequently used to reduce the background, thereby increasing
2574 the signal-to-noise ratio. In many systems, the shielded configuration completely surrounds the material to
2575 be measured (i.e., 4 π counting geometry). An example of this configuration is the drum counter, in which
2576 a conveyor belt typically moves the drum into the counting chamber, where the drum is usually rotated
2577 during the measurement to obtain a more representative average. After the count, the drum is then
2578 moved out and another drum counted.

2579 Considerations for applying volume counters do not vary significantly from the individual application of
2580 each of the mentioned detectors. For example, gas proportional detectors need to be calibrated to a
2581 calibration source representative of the radioactivity, and the considerations listed for ISGS apply for
2582 systems using HPGe detectors for volume counting.

2583 5.4.3 Portal Monitors

2734 5.7 Clearance Survey Examples

2735 The clearance survey examples presented on the following pages illustrate possible clearance survey
2736 approaches for pipe sections being released from a power reactor facility. The flow diagram for
2737 clearance of solid materials (Section 2) served as a guide for developing these examples; the letters in the
2738 examples correspond to the steps in Figure 2.1.

2739 Example 1 Clearance of small-bore pipes from nuclear power reactor

2740 a. Evaluate the physical description of the solid material.

2741 The solid material being considered for release is small-bore pipe (steel). The material survey unit
2742 consists of approximately 60 sections of pipe and conduit, each of which is 1.2 to 1.8 m in length.
2743 The diameter of each pipe section is less than 6 cm, with a total interior surface area of 17 m² and a
2744 weight of 2 tons. The pipe interiors are considered to be inaccessible with conventional hand-held
2745 detectors.

2746 b. Evaluate and document process knowledge and characterization of the solid material.

2747 The small-bore pipes are from a nuclear power plant. Process knowledge indicates that the pipes were
2748 used to transport radioactive liquids from the nuclear laundry. The radionuclide mixture for the nuclear
2749 power reactor consists of a number of radionuclides, including fission products, activation products, and
2750 even trace quantities of transuranics.

2751 During characterization, three samples of pipe residue were collected and analyzed from the total pipe
2752 population. The radionuclide mixture was as follows:

2753	⁶⁰ Co	15%
2754	¹³⁷ Cs	27%
2755	⁹⁰ Sr(⁹⁰ Y)	8%
2756	¹⁴ C	13%
2757	⁵⁵ Fe	11%
2758	⁶³ Ni	6%
2759	³ H	20%
		<u>100%</u>

2760 Therefore, the radionuclide mixture from characterization confirms the process knowledge that fission and
2761 activation products comprise the contamination. The mixture includes radionuclides that are readily-
2762 detected (⁶⁰Co, ¹³⁷Cs, ⁹⁰Sr(⁹⁰Y)), as well as those that are hard-to-detect (³H, ⁶³Ni, and ⁵⁵Fe).

2763 c. Is the material impacted?

2764 Yes, these small-bore pipe sections are certainly impacted, given that they were used to transport
2765 radioactive liquids.

2766 d. Specify release criteria and conditions for the solid material.

2767 For this example, Regulatory Guide 1.86 will be used. The surface activity guideline for all radionuclides
2768 (except ⁹⁰Sr(⁹⁰Y)) is 5,000 dpm/100 cm² averaged over 1 m². The guideline for ⁹⁰Sr(⁹⁰Y) is 1,000

2769 dpm/100 cm².

2770 e. Classify the material.

2771 The small-bore pipe sections are Class 1. This classification is based on the fact that the material was
2772 designed to be in contact with radioactivity, as further supported by the characterization results.

2773 f. Is clearance an option?

2774 Yes, the licensee in this example has decided to perform a clearance survey.

2775 g. Consider the survey approach based on the nature of the material and contamination.

2776 Given that the interior of the pipe sections is potentially contaminated, it will be necessary to cut the pipes
2777 along their lengths (resulting in semi-cylindrical sections). The nature of the radioactivity suggests that
2778 beta-sensitive detectors would work well.

2779 h. Can scanning be used to release the material?

2780 Yes, the proposed clearance survey approach is to scan the interior of the semi-cylindrical pipe sections
2781 using GM detectors. Before this approach can be implemented, it is necessary to demonstrate that the
2782 scan MDC is less than the DCGL_C.

2783 i. Application of DCGLs.

2784 To demonstrate compliance with the clearance release criteria, the clearance survey will consist of
2785 surface scans with a GM detector. Given the radioactive decay emissions from these radionuclides, the
2786 GM will respond to gross beta radiation. Therefore, it is necessary to calculate the gross activity DCGL_C
2787 for surface activity using the following equation:

$$\text{Gross Activity DCGL}_C = \frac{1}{\left(\frac{f_1}{\text{DCGL}_1} + \frac{f_2}{\text{DCGL}_2} + \dots + \frac{f_n}{\text{DCGL}_n} \right)} \quad (14)$$

2788 where f₁, f₂, etc. are the fractional amounts of each radionuclide present.

$$\left(\frac{0.92}{5000} + \frac{0.08}{1000} \right)^{-1} = \sim 3800$$

2789 A simplifying observation is that 92 percent of the radionuclide mixture consists of radionuclides for which
2790 the surface activity guideline is 5,000 dpm/100 cm², while ⁹⁰Sr(⁹⁰Y) makes up 8 percent with a guideline
2791 of 1000 dpm/100 cm². Substituting into the above equation, the gross activity DCGL is 3,800 dpm/100
2792 cm².

2793 j. Determine background.

2794 Measurements were performed on similar, non-impacted pipe sections to determine the GM background;

2795 this resulted in a background level of approximately 60 cpm.

2796 k. Determine scan MDC.

2797 Scan MDCs are determined from the MDCR by applying conversion factors to obtain results in terms of
2798 measurable surface activities. The scan MDC for a material surface can be expressed as

$$\text{scan MDC} = \frac{\text{MDCR}}{\sqrt{p} e_i e_s}$$

2799 where the minimum detectable count rate (MDCR), in counts per minute, can be written

$$\text{MDCR} = d' \cdot \sqrt{b_i} \cdot (60/i)$$

2800 d' = detectability index (the value can be obtained from MARSSIM Table 6.5),

2801 b_i = background counts in the observation interval,

2802 i = observational interval (in seconds), based on the scan speed and areal extent of the contamination
2803 (usually taken to be 100 cm²),

2804 e_i is the instrument or detector efficiency (unitless),

2805 e_s is the surface efficiency (unitless), and

2806 p is the surveyor efficiency (usually taken to be 0.5).

2807 The scan MDC is determined for a background level of 60 cpm and a 2-second observation interval using

2808 a GM detector ($b_i = 2$ counts). For a specified level of performance at the first scanning stage of 95-

2809 percent true positive rate and 25-percent false positive rate, d' equals 2.32 and the MDCR is 98 cpm.

2810 Before the scan MDC can be calculated, it is necessary to determine the total efficiency for the
2811 radionuclide mixture.

	e_i	e_s	Radionuclide Fraction	Weighted Efficiency
2812	0.05	0.25	0.15	1.88×10^{-3}
2813	0.08	0.5	0.27	1.08×10^{-2}
2814	0.12	0.5	0.08	4.80×10^{-3}
2815	0.03	0.25	0.13	9.75×10^{-4}
2816	0	0.25	0.11	0
2817	0.01	0.25	0.06	1.50×10^{-4}
2818	0	0	0.2	0
2819	Total Weighted Efficiency			1.9×10^{-2}

2820 Using a surveyor efficiency of 0.5 and the total weighted efficiency of 1.9×10^{-2} , the scan MDC is
2821 calculated as

$$\text{Scan MDC} = \frac{98}{\sqrt{0.5 (1.9E-2)}} = 7,400 \text{ dpm}/100 \text{ cm}^2 \quad (1.2 \text{ Bq}/\text{cm}^2)$$

2822 l. Is the scan MDC less than the DCGL_C ?

2823 No, the scan MDC of 7,400 dpm/100 cm² (1.2 Bq/cm²) is not less than 3,800 dpm/100 cm² (0.6 Bq/cm²).

2824 m. Can the scan MDC be reduced?

2825 It is not likely that modifying the scanning parameters will lower the scan MDC to a value less than the
2826 DCGL_C . (Note: If the scan MDC could be sufficiently reduced below the DCGL_C , the next step is to
2827 evaluate the instrument's ability to automatically document scan results (step o).)⁴

2828 n. Is another clearance survey design feasible?

2829 Since the scan MDC is not sufficiently sensitive, the next step is to determine whether conventional static
2830 measurements are feasible. Example 2 provides the details of the design.

2831 Example 2 Clearance of small-bore pipes from nuclear power reactor (using statistical design for
2832 static direct measurements)

2833 Based on the information obtained in Example 1, step h in the flow diagram of Figure 2.1 results in the
2834 decision that scanning with a GM detector cannot be used to release the pipe sections. This example
2835 continues from step n in Example 1 (now at the right side of Figure 2.1).

2836 i. Application of DCGLs.

2837 To demonstrate compliance with the clearance release criteria, the clearance survey will consist of static

⁴ o. Can scanning instrument automatically document results? (Note: This step, as well as step p, is not possible in this example because the scan MDC is not less than the DCGL_C ; it is covered in this footnote for illustration only).

p. If the scanning instrument can automatically document results, the material survey unit is scanned and the results are automatically logged. Since it is a Class 1 survey unit, 100 percent of the pipe sections are scanned. However, if the scanning instrument cannot automatically document results, it is necessary to collect a number of static direct measurements to serve as scan documentation, in addition to scanning 100 percent of the Class 1 material survey unit. The number of these measurements should be determined using the DQO Process, and may be determined using a statistically based sampling design.

2838 direct measurements of surface activity using a GM detector. The gross activity DCGL_C for surface
 2839 activity determined in Example 1 is the same for this example (i.e., the gross activity DCGL_C is
 2840 3,800 dpm/100 cm²).

2841 j. Determine background.

2842 Fifteen measurements, as determined based on the WRS test (step p), were performed on non-impacted
 2843 pipe sections to determine the GM background. The mean background was 60 cpm, with a standard
 2844 deviation of 8 cpm.

2845 k. Determine the static MDC.

2846 The static MDC for the GM detector can be calculated as

$$MDC = \frac{3 + 4.65 \sqrt{C_B}}{e_i e_s T \frac{\text{probe area}}{100 \text{ cm}^2}}$$

2847 where C_B is the background count in time, T, for paired observations of the sample and blank, e_i is the
 2848 instrument efficiency, and e_s is the surface efficiency. However, before the static MDC can be
 2849 calculated, it is necessary to determine the total efficiency for the radionuclide mixture. [Note: The
 2850 instrument efficiencies for the GM detector used for static measurements (based on the detector's
 2851 response to a source area equal to its physical probe area of 20 cm²) are higher than instrument
 2852 efficiencies for the GM detector used for scanning (based on the detector's response to a source area of
 2853 100 cm²), by a factor of 5.]

	e _i	e _s	Radionuclide Fraction	Weighted Efficiency	
2854	⁶⁰ Co	0.25	0.25	0.15	9.40x10 ⁻³
2855	¹³⁷ Cs	0.40	0.5	0.27	5.40x10 ⁻²
2856	⁹⁰ Sr	0.60	0.5	0.08	2.40x10 ⁻²
2857	¹⁴ C	0.15	0.25	0.13	4.88x10 ⁻³
2858	⁵⁵ Fe	0	0.25	0.11	0
2859	⁶³ Ni	0.05	0.25	0.06	7.50x10 ⁻⁴
2860	³ H	0	0	0.2	0
2861	Total Weighted Efficiency				9.3x10 ⁻²

2862 Therefore, the static MDC for the GM for 1-minute counts is

$$MDC = \frac{3 + 4.65 \sqrt{60}}{9.3E-2 (1 \text{ min}) \frac{20 \text{ cm}^2}{100 \text{ cm}^2}} = 2,100 \text{ dpm}/100 \text{ cm}^2$$

2863 l. Is the static MDC less than the DCGL_C?

2864 Yes, the static MDC of 2,100 dpm/100 cm² is less than the DCGL_C of 3,800 dpm/100 cm².

2865 p. Perform clearance survey based on statistical sampling design for the number of direct measurements
2866 of surface activity.

2867 The WRS test can be used to determine the number of surface activity measurements needed for the
2868 clearance survey. The number of data points necessary for this material survey unit is determined
2869 through the DQO Process. Specifically, the sample size is based on the DCGL_C, the expected standard
2870 deviation of the radionuclides in the pipe sections, and the acceptable probability of making Type I and
2871 Type II decision errors.

2872 • The gross activity DCGL_C is 3,800 dpm/100 cm².

2873 • Process knowledge, coupled with results from characterization surveys, was used to estimate the
2874 contamination on the pipe sections. The contamination, as measured in gross cpm with a GM detector,
2875 averaged 82 cpm, with a standard deviation of 18 cpm.

2876 • Other DQO inputs include the LBGR set at the expected contamination level on the pipe sections
2877 (82 • 60 cpm, or 22 cpm), and Type I and II errors of 0.05 and 0.01 respectively.

2878 The DCGL_C, and the expected standard deviation of the material survey unit and background
2879 measurements are used to estimate the relative shift, Δ/σ

2880 First, it is necessary to convert the DCGL_C into the same units as the standard deviation:

$$\text{gross activity DCGL}_C = (3,800 \text{ dpm}/100 \text{ cm}^2) (9.3E-2) 20/100 = 70.7 \text{ cpm}$$

2881

$$\Delta = DCGL_C - LBGR$$

2882 The larger of the values of the estimated measurement standard deviations from the survey unit and the
2883 reference area should be used. Since the estimated standard deviation in the survey unit is 18 and that for
2884 the reference area is 8, the survey unit value of $\sigma=18$ will be used to calculate the relative shift.

2885 The relative shift can now be calculated: $(70.7 - 22)/18 = 2.7$.

2886 Table 5.3 in MARSSIM (1997) provides a list of the number of data points to demonstrate compliance
2887 using the WRS test for various values of Type I and II errors and Δ/σ . For $\alpha = 0.05$ and $\beta = 0.01$, the
2888 required sample size is about 15 direct measurements for this material survey unit and 15 measurements

2921 It is necessary to convert the surface activity guidelines (from RG 1.86) to total activity limits. This is
 2922 performed for each radionuclide by multiplying the surface activity guideline by the total surface area of
 2923 the pipes in the material survey unit (17 m²). For example, the total dpm that corresponds to 5,000
 2924 dpm/100 cm² can be calculated as

2925
$$(5,000 \text{ dpm}/100 \text{ cm}^2) \times (17 \text{ m}^2) \times (10,000 \text{ cm}^2/1 \text{ m}^2) = 8.5\text{E}6 \text{ dpm}$$

2926 Each of the radionuclides, with the exception of ⁹⁰Sr(⁹⁰Y), has a surface activity guideline of
 2927 5,000 dpm/100 cm². The total activity limit for ⁹⁰Sr(⁹⁰Y), based on its 1,000 dpm/100 cm² guideline,
 2928 is 1.7x10⁶ dpm.

2929 Returning to the use of ⁶⁰Co and ¹³⁷Cs as surrogates, it is necessary to modify the DCGL_C for these two
 2930 radionuclides to account for all of the other radionuclides. First, note that the limit for both ⁶⁰Co and ¹³⁷Cs
 2931 is 8.5x10⁶ dpm; therefore, when both are measured, the sum of both radionuclides should not exceed
 2932 8.5x10⁶ dpm (when they are the only radionuclides present). Equation I-14 on page I-32 of the
 2933 MARSSIM can be used to calculate the modified DCGL_C for Co+Cs:

$$DCGL_{Co+Cs,mod} = \frac{1}{\left(\frac{1}{D_1} + \frac{R_2}{D_2} + \dots + \frac{R_n}{D_n}\right)}$$

2934 where D₁ is the DCGL_C for the sum of ⁶⁰Co and ¹³⁷Cs (8.5x10⁶ dpm), D₂ is the DCGL_C for the first
 2935 radionuclide (⁹⁰Sr(⁹⁰Y)) that is being inferred by ⁶⁰Co and ¹³⁷Cs. R₂ is the ratio of concentration of the
 2936 ⁹⁰Sr(⁹⁰Y) to that of the sum of ⁶⁰Co and ¹³⁷Cs (8% divided by 42%, or 0.19), and R₃ is the ratio of the
 2937 concentration of ¹⁴C to that of the sum of ⁶⁰Co and ¹³⁷Cs (or 0.31). Therefore, DCGL_{Co+Cs,mod} can be
 2938 calculated for the mixture as follows:

$$DCGL_{Co+Cs,mod} = \frac{1}{\left(\frac{1}{8.5\text{E}6} + \frac{0.19}{1.7\text{E}6} + \frac{0.31}{8.5\text{E}6} + \frac{0.26}{8.5\text{E}6} + \frac{0.14}{8.5\text{E}6} + \frac{0.476}{8.5\text{E}6}\right)} = 2.7\text{E}6 \text{ dpm}$$

2939 Therefore, to demonstrate compliance, the ISGS result should be less than 2.7x10⁶ dpm (1.22 μCi) for the
 2940 sum of ⁶⁰Co and ¹³⁷Cs.

2941 j. Determine background.

2942 Since neither ⁶⁰Co nor ¹³⁷Cs is present naturally in the material (pipe sections), the background value (i.e.,
 2943 Compton continuum) for each radionuclide's region of interest (ROI) was determined from an ambient
 2944 count at the location where the pipe section clearance measurements will be performed. The count time
 2945 should be long enough to result in sufficiently sensitive MDC.

2946 k. Determine static MDC.

2947 The static MDC for the *in situ* gamma spectrometer can be calculated as

$$MDC = \frac{3 + 4.65 \sqrt{BKG}}{e T}$$

2948 where BKG is the background continuum counts determined in time T, and e is the efficiency in net peak
2949 counts per minute per activity (μCi or Bq). This MDC is the general MDC for the measurement process,
2950 rather than an individual MDC for each measurement.

2951 The measurement protocol consisted of four 10-minute measurements at the midpoint of each side of the
2952 material survey unit. The efficiency for a particular distribution of radioactivity within the pipe sections
2953 was determined by randomly positioning a known quantity of ^{60}Co and ^{137}Cs radionuclide sources within a
2954 non-impacted geometry of pipe sections. The efficiencies for the ^{60}Co (1,173 keV) ranged from 7.2 to
2955 17.3 net counts per minute per μCi , while the efficiencies for the ^{137}Cs ranged from 8.8 to 21.8 net counts
2956 per minute per μCi . To be conservative, the MDCs for both ^{60}Co and ^{137}Cs were calculated for the
2957 lowest efficiencies observed. The MDCs for ^{60}Co and ^{137}Cs were 0.6 and 0.5 μCi , respectively.

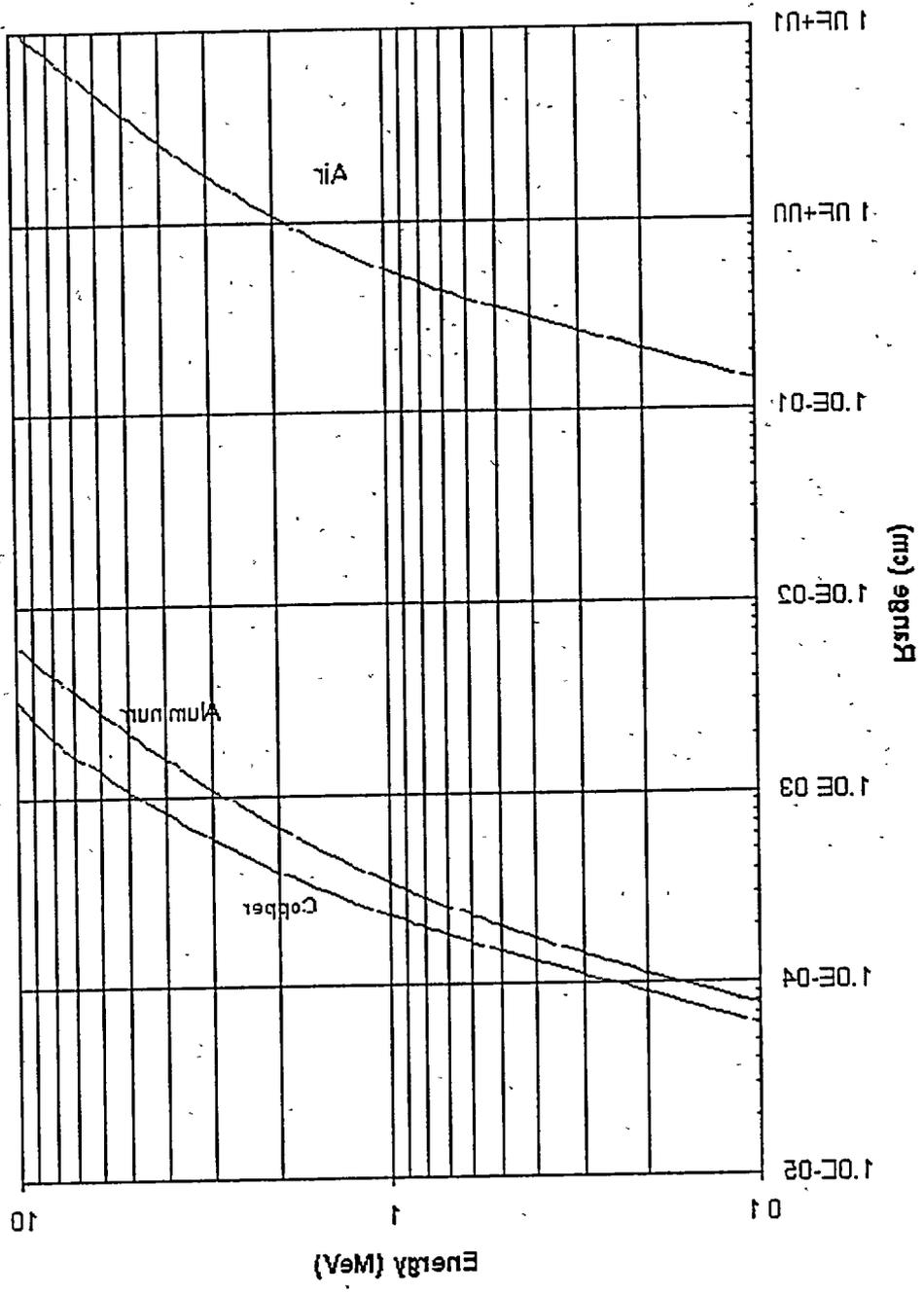
2958 l. Is the static MDC less than the DCGL_c ?

2959 Yes, the static MDCs for ^{60}Co and ^{137}Cs are less than the DCGL_c of 1.22 μCi . If either of the MDCs
2960 were greater than the DCGL_c of 1.22 μCi , step m would be performed to determine whether the MDCs
2961 could be reduced (e.g., by using longer count times).

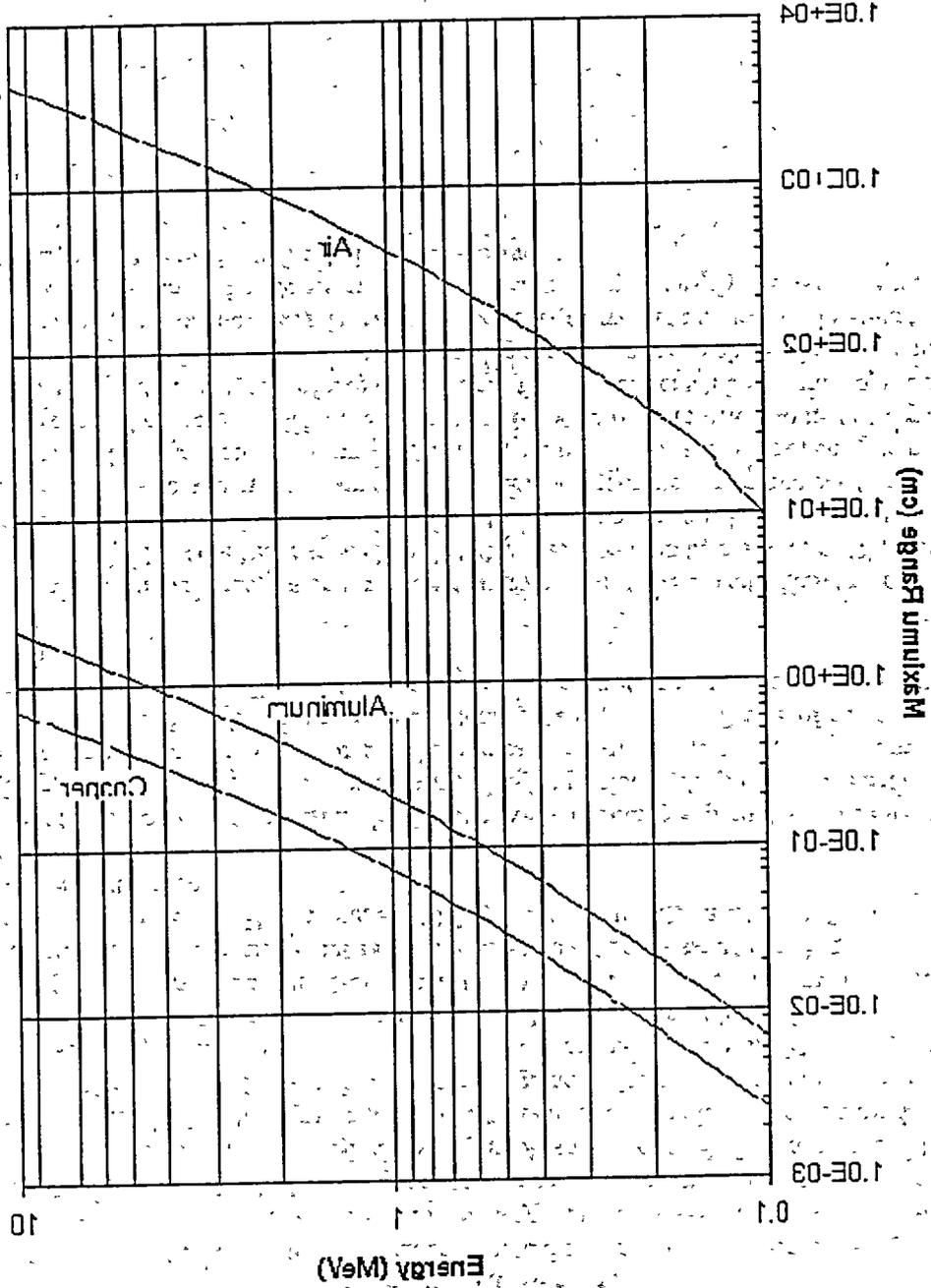
2962 p. Perform *in toto* survey.

2963 Perform clearance survey based on ISGS measurements for ^{60}Co and ^{137}Cs . Each measurement consists
2964 of four 10-minute measurements at the midpoint of each side of the material survey unit. The total
2965 activity for both ^{60}Co and ^{137}Cs is summed, and then compared to the DCGL_c of 1.22 μCi . Survey results
2966 are documented.

What is the time ^{and \$} comparison between
basically performing a MARSSIM final status
release survey on several pipes (or pumps, meters,
computer monitor, etc.) vs. disposal?



Nice MacKewards graph



Nice backwards graph