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**MULTI-AGENCY
RADIATION SURVEY
AND ASSESSMENT OF
MATERIALS AND
EQUIPMENT
MANUAL
(MARSAME)
DRAFT REPORT FOR COMMENT**



December 2006

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11

ABSTRACT

12 MARSAME is a supplement to MARSSIM providing information on planning, conducting,
13 evaluating, and documenting radiological disposition surveys for the assessment of materials and
14 equipment. MARSAME is a multi-agency consensus document that was developed
15 collaboratively by four Federal agencies having authority and control over radioactive materials:
16 Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency
17 (EPA), and Nuclear Regulatory Commission (NRC). The objective of MARSAME is to provide
18 a multi-agency approach for planning, performing, and assessing disposition surveys of materials
19 and equipment, while at the same time encouraging an effective use of resources.

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376 CAPT Colleen F. Petullo, U.S. Public Health Service, EPA, Chair

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406

LIST OF ACRONYMS AND ABBREVIATIONS

407	AL	action level
408	ALARA	as low as reasonably achievable
409	ANSI	American National Standards Institute
410	ASTM	American Society for Testing and Materials
411	BKGD	background
412	CFR	Code of Federal Regulations
413	cpm	counts per minute
414	cps	counts per second
415	CSM	conceptual site model
416	CSM	conveyorized survey monitoring
417	CSU	combined standard uncertainty
418	CZT	cadmium zinc telluride
419	DCGL	derived concentration guideline level
420	DL	discrimination limit
421	DOD	Department of Defense
422	DOE	Department of Energy
423	DOT	Department of Transportation
424	dpm	disintegrations per minute
425	DQA	data quality assessment
426	DQO	data quality objective
427	EMC	elevated measurement comparison
428	EPA	Environmental Protection Agency
429	EPRI	Electric Power Research Institute
430	EZ	exclusion zone
431	FIDLER	field instrument for the detection of low energy radiation
432	FRER	fluence rate to exposure rate
433	GM	Geiger Mueller

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LIST OF ACRONYMS AND ABBREVIATIONS

HASP	health and safety plan
HPGe	high-purity germanium
HPS	Health Physics Society
HSA	Historical Site Assessment
HPSR	Physics Committee Report
HWP	hazard work permit
IA	Initial Assessment
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
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
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

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LIST OF ACRONYMS AND ABBREVIATIONS

NIST	National Institute of Science and Technology
NJBER	New Jersey Bureau of Environmental Radiation
NORM	naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
NUREG	NRC <u>NU</u> clear <u>REG</u> ulatory Guide
NUREG/CR	NRC <u>NU</u> clear <u>REG</u> ulatory Guide 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
RCSU	relative combined standard uncertainty
RDR	relative detector response
RESRAD	<u>RES</u> idual <u>RAD</u> ioactivity computer code (exposure pathway model)
ROC	radionuclide of concern
RTG	Radioisotopic Thermoelectric Generator
RWP	radiation work permit
SI	International System of Units (Système international d'unités)
SOP	standard operating procedure

488

LIST OF ACRONYMS AND ABBREVIATIONS

489	TEDE	total effective dose equivalent
490	TENORM	technologically enhanced naturally occurring radioactive material
491	TRU	transuranic
492	UBGR	upper bound of the gray region
493	UCL	upper confidence limit
494	UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
495	USEPA	United States Environmental Protection Agency
496	U.S.	United States
497	WRS	Wilcoxon Rank Sum

498

SYMBOLS, NOMENCLATURE, AND NOTATIONS

499	<	less than
500	>	greater than
501	\leq	less than or equal to
502	\geq	greater than or equal to
503	%	percent
504	$1-\beta$	power
505	a	half-width of a bounded probability distribution
506	α	alpha
507	α	maximum type I decision error rate
508	α_Q	Quantile test ($\alpha_Q = \alpha/2$)
509	A	area
510	A	overall sensitivity of the measurement
511	Ac	actinium (isotope listed: ^{228}Ac)
512	Al_i	action level value for each individual radionuclide ($i = 1, 2, \dots, n$)
513	$AL_{\text{meas,mod}}$	modified action level for the radionuclide being measured
514	AL_{meas}	action level for the radionuclide being measured
515	AL_{infer}	action level for the inferred radionuclide (i.e., not measured)
516		action level for radionuclide i
517	Am	americium (isotope listed: ^{241}Am)
518	β	beta
519	β	maximum type II decision error rate
520	b	background count rate
521	b_i	the average number of counts in the background interval
522	Be	beryllium ((isotope listed: ^7Be)
523	Bi	bismuth (isotopes listed: ^{210}Bi , ^{212}Bi , ^{214}Bi)
524	Bq	becquerel
525	C	carbon (isotope listed: ^{14}C)
526	C	radionuclide concentration or activity
527	C_i	concentration value for each individual radionuclide ($i = 1, 2, \dots, n$)

528

SYMBOLS, NOMENCLATURE, AND NOTATIONS

529	C_i	sensitivity coefficient
530	$C_i\mu(x_i)$	component of the uncertainty in y due to x_i
531	C_{infer}/C_{meas}	surrogate ratio of the inferred to the measured radionuclide
532	$^{\circ}\text{C}$	degrees Celsius
533	cm	centimeter
534	cm^2	square centimeter
535	cm^3	cubic centimeter
536	Cd	cadmium (isotope listed: ^{109}Cd)
537	Co	cobalt (isotopes listed: ^{57}Co , ^{60}Co)
538	Cs	cesium (isotope listed: ^{137}Cs)
539	CsI	cesium iodide
540	CsI(Tl)	cesium iodide (thallium activated)
541	γ	gamma
542	d'	detectability index
543	D	action level for radionuclide
544	Δ	shift (width of the gray region, UBGR-LBGR)
545	Δ/σ	relative shift
546	eV	electron volt
547	E_{γ}	energy of the gamma photon of concern kiloelectron volts (keV)
548	E_i	energy of the photon of interest
549	ε	epsilon
550	ε_i	instrument efficiency
551	ε_s	surface efficiency for the surveyed media
552	ζ_B	non-Poisson variance component of the background count rate correction
553	$^{\circ}\text{F}$	degrees Fahrenheit
554	f	relative fraction
555	Fe	iron (isotope listed: ^{55}Fe)

556 **SYMBOLS, NOMENCLATURE, AND NOTATIONS**

557	ft	foot (feet)
558	ft ³	cubic foot (feet)
559	g	gram
560	h	hour
561	H	hydrogen (isotope listed: ³ H (tritium))
562	H ₀	null hypothesis
563	H ₁	alternative hypothesis
564	<i>i</i>	the observation interval length
565	in	inch
566	I	iodine (isotopes listed: ¹²³ I, ¹²⁵ I, ¹³¹ I)
567	Ir	iridium ((isotope listed: ¹⁹² Ir)
568	K	potassium (isotope listed: ⁴⁰ K)
569	<i>k</i>	coverage factor for expanded uncertainty
570	k	critical value (Sign Test)
571	keV	kiloelectron volt (1×10 ³ electron volt)
572	kg	kilogram
573	<i>k_Q</i>	Multiple of the standard deviation defining <i>y_Q</i> , usually chosen to be 10
574	<i>k_Q</i>	standard deviation for the MQC
575	L	grid size spacing
576	λ	lambda
577	lb	pound
578	m	reference material measurements (Quantile test)
579	m	adjusted reference sample measurements (WRS test)
580	m	meter
581	m ²	square meter
582	MeV	megaelectron volt (1×10 ⁶ electron volt)
583	/ m-r /	probability

584

SYMBOLS, NOMENCLATURE, AND NOTATIONS

585	mrem	millirem (1×10^{-3} rem)
586	μ	micro (10^{-6})
587	μ	mean
588	μ	expanded uncertainty
589	$\mu(x_i)$	standard uncertainty
590	$\mu(x_i)$	type A or B standard uncertainty of the input estimate x_i
591	$\mu(x_i)/x_i$	relative standard uncertainty of x_i
592	$\mu(x_i)/x_i$	relative standard uncertainty of a nonzero input estimate x_i for a particular
593		measurement
594	$\mu(x_i, x_j)$	covariance of two input estimates, x_i and x_j ,
595	$\mu_c(y)$	combined standard uncertainty of y
596	$\mu_c(y)/y$	relative combined standard uncertainty of the output quantity for a particular
597		measurement
598	$\mu_c^2(y)$	combined variance of y
599	$\mu_i(y)$	component of the combined standard uncertainty $u_c(y)$ generated by the standard
600		uncertainty of the input estimate x_i , $u(x_i)$
601	$(\mu_{en}/\rho)_{air}$	mass energy absorption coefficient in air centimeters squared per gram (cm^2/g)
602	μ_m	measurement method uncertainty
603	μ_{MR}	required measurement method uncertainty
604	μ_p	expanded uncertainty for a specified coverage probability p
605	μ_x	overall uncertainty
606	$\mu_c(y)$	Combined standard uncertainty of y
607	μR	microroentgen (1×10^{-6} roentgen)
608	μ/ρ	mass absorption coefficient
609	n	adjusted survey unit measurement (Quantile test)
610	n	sample measurement (WRS Test)
611	n	sample location
612	n	positive number
613	n	number of results

614

SYMBOLS, NOMENCLATURE, AND NOTATIONS

615	N	number of data points (or samples)
616	N	sample size
617	n_{EA}	survey unit area divided by the maximum area corresponding to the area factor
618	Na	sodium (isotope listed: ^{22}Na)
619	NaI	sodium iodide
620	NaI(Tl)	sodium iodide (thallium activated)
621	Ni	nickel (isotope listed: ^{63}Ni)
622	Np	neptunium ((isotope listed: ^{237}Np)
623	p	coverage probability for expanded uncertainty
624	p	efficiency of a less than ideal surveyor
625	P	probability of interaction
626	Pa	protactinium (isotopes listed: ^{234}Pa , ^{234m}Pa)
627	PA	probe area
628	Pb	lead (isotopes listed: ^{212}Pb , ^{214}Pb)
629	PC	personal computer
630	pCi	picocurie (1×10^{-12} curies)
631	Pm	promethium (isotope listed: ^{137}Pm)
632	Po	polonium (isotopes listed: ^{210}Po , ^{212}Po , ^{214}Po , ^{216}Po)
633	Pu	plutonium (isotopes listed: ^{238}P , ^{239}Pu , ^{240}Pu , ^{241}Pu)
634	π	pi
635	q	critical value for statistical tests (Table A.3, Table A.4, Table A.5)
636	r	random number(Chap 6, line 385)
637	R	ratio
638	R	roentgen (exposure rate)
639	Ra	radium (isotopes listed: ^{224}Ra , ^{226}Ra , ^{228}Ra)
640	R_B	mean background count rate
641	R_I	mean interference count rate
642	Rn	radon (isotopes listed: ^{220}Rn , ^{222}Rn)
643	$r(x_i, x_j)$	correlation coefficient for two input estimates, x_i and x_j ,

644

SYMBOLS, NOMENCLATURE, AND NOTATIONS

645	ρ	density
646	$\rho(X_i, X_j)$	correlation coefficient for two input quantities, X_i and X_j ,
647	S_+	Sign test statistic
648	$s(X_i)$	sample standard deviation of the input estimate x_i
649	S_C	critical net signal
650	S_C	critical value
651	S_D	mean value of the net signal that gives a specified probability, $1-\beta$, of yielding an
652		observed signal greater than its critical value S_C
653	S_D	minimum detectable value of the net instrument signal (discrimination limit)
654	s_i	minimum detectable number of net source counts in the observation interval
655	$s_{i, \text{surveyor}}$	minimum detectable number of net source counts in the observation interval by a
656		less than ideal surveyor
657	Sr	strontium (isotope listed: ^{90}Sr)
658	σ	sigma
659	σ	standard deviation, standard deviation of the population data, or overall
660		uncertainty
661	σ_M	standard deviation of the measurement process (measurement standard deviation)
662		– estimated by the combined standard uncertainty
663	σ_M^2	measurement variance
664	σ_s	standard deviation of the sampled population data (sampling standard deviation)
665	σ_s	spatial variability in radioactivity concentration
666	σ_s^2	variance of sampled population
667	$\sigma(\hat{R}_I)$	standard deviation of the measured interference count rate
668	$\sigma(y Y = q_0)$	variance of the estimator y given the true concentration Y equals y_0
669	$\sigma(X_i, X_j)$	covariance for two input quantities, X_i and X_j ,
670	t	less than value (WRS test)
671	Tc	technetium (isotopes listed: ^{99}Tc , ^{99m}Tc)
672	Th	thorium (isotopes listed: ^{228}Th , ^{230}Th , ^{232}Th , ^{234}Th)
673	Tl	thallium (isotopes listed: ^{201}Tl , ^{208}Tl)

674 **SYMBOLS, NOMENCLATURE, AND NOTATIONS**

675	t_B	background count time
676	t_B	count time for the background
677	t_S	count time for the test source
678	U	uranium (isotopes listed: ^{234}U , ^{235}U , and ^{238}U)
679	W_r	adjusted reference measurement (WRS test)
680	W_s	sum of the ranks of the sample measurements (WRS test)
681	WS	weighted instrument sensitivity
682	ϕ_A^2	relative variance of the measured sensitivity
683	ϕ_{MR}	relative required method uncertainty above the UBGR or AL
684	$\Phi(z)$	cumulative normal distribution function
685	x	estimate of the input quantity X
686	X_i	input quantity
687	X	concentration or level of radioactivity
688	x_C	the critical value of the response variable
689	X_N	input quantity
690	x_Q	minimum quantifiable concentration
691	y	year
692	y	estimate of the output quantity for a particular measurement
693	y	estimate of the output quantity Y
694	Y	output quantity
695	Y	measurand
696	y_C	critical value of the concentration
697	y_D	minimum detectable concentration (MDC)
698	y_Q	minimum quantifiable concentration (MQC)
699	yd	yard
700	yd^3	cubic yard

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SYMBOLS, NOMENCLATURE, AND NOTATIONS

702	Z	atomic number
703	Z	adjusted reference material measurement (WRS test)
704	Z	adjusted survey unit measurement (Quantile test)
705	$z_{1-\alpha}$	(1 - α)-quantile of the standard normal distribution
706	$z_{1-\beta}$	(1 - β)-quantile of the standard normal distribution
707	ZnS	zinc sulfide
708	ZnS(Ag)	zinc sulfide (silver activated)

CONVERSION FACTORS

To Convert From	To	Multiply 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
becquerel (Bq)	curie (Ci)	2.7x10 ⁻¹¹	m ³	hectare	0.0001
	dps	1		sq. feet (ft ²)	10.8
	pCi	27		sq. mile	3.86x10 ⁻⁷
Bq/kg	pCi/g	0.027	mrem	liter	1,000
Bq/m ²	dpm/100 cm ²	0.60	mrem/y	mSv	0.01
Bq/m ³	Bq/L	0.001	mSv	mSv/y	0.01
	pCi/L	0.027	mSv	mrem	100
centimeter (cm)	inch	0.394	mSv/y	mrem/y	100
Ci	Bq	3.70x10 ¹⁰	ounce (oz)	liter (L)	0.0296
	pCi	1x10 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

1 **ROADMAP**

2 **Introduction to MARSAME**

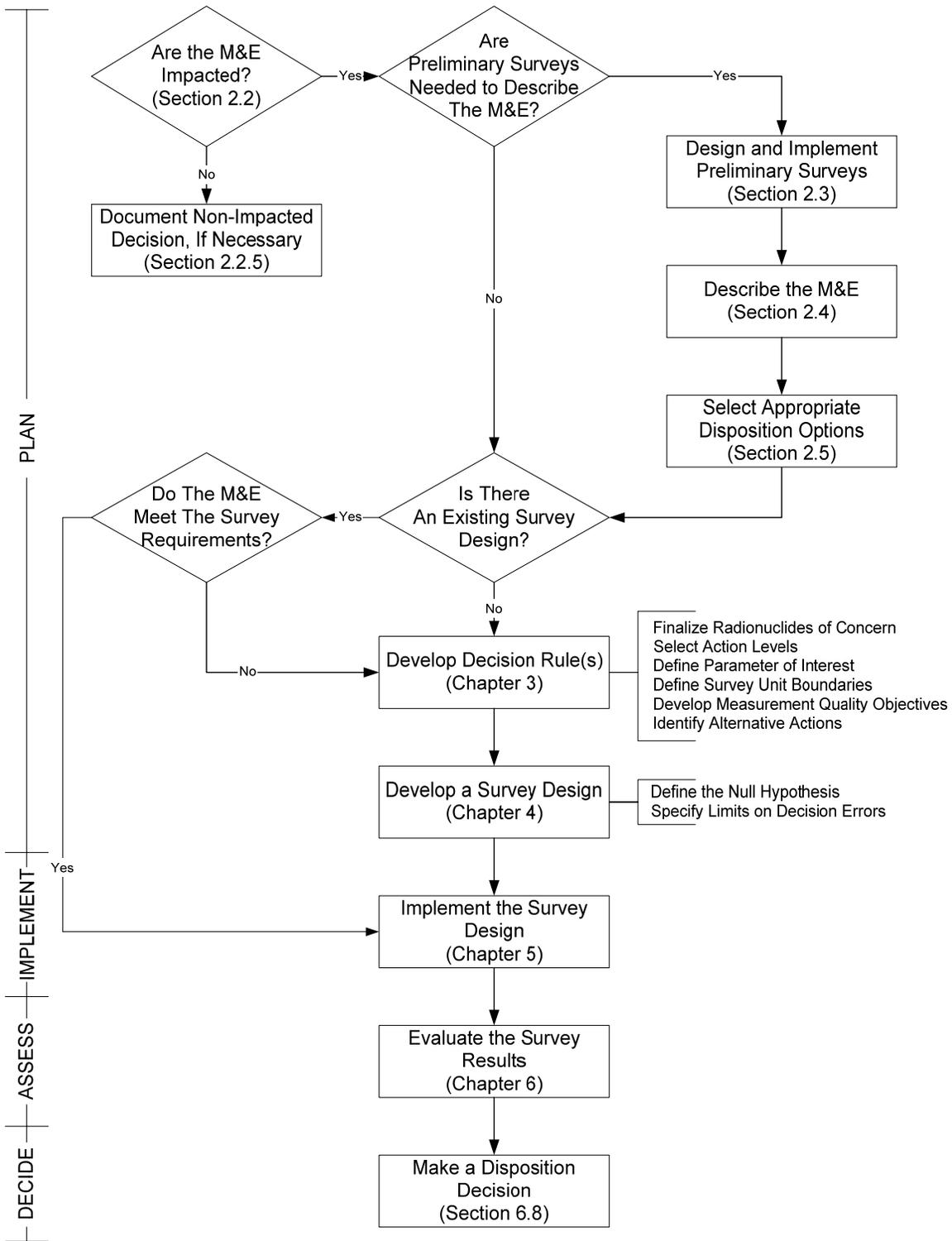
3 The Multi-Agency Radiation Survey and Assessment of Materials and Equipment
4 (MARSAME) is a supplement to the Multi-Agency Radiation Survey and Site
5 Investigation Manual (MARSSIM 2002). MARSAME provides technical information on
6 approaches for planning, implementing, assessing, and documenting surveys to determine
7 proper disposition of materials and equipment (M&E).

8 The technical information in MARSAME is based on the Data Life Cycle, similar to
9 MARSSIM. Survey planning is based on the Data Quality Objectives (DQO) Process
10 and is discussed in MARSAME Chapters 2, 3, and 4. Implementation of the survey
11 design is described in MARSAME Chapter 5, with discussions on selection of
12 instruments and measurement techniques as well as handling and segregating the M&E.
13 MARSAME also includes the concept of measurement quality objectives (MQOs) for
14 selecting and evaluating instruments and measurement techniques from the Multi-Agency
15 Radiological Laboratory Analytical Protocols Manual (MARLAP 2004). Assessment of
16 the survey results uses Data Quality Assessment (DQA) and the application of statistical
17 tests as described in MARSAME Chapter 6.

18 The scope of MARSSIM was limited to surfaces soils and building surfaces. The scope
19 of MARSAME is M&E potentially affected by radioactivity, including metals, concrete,
20 tools, equipment, piping, conduit, furniture and dispersible bulk materials such as trash,
21 rubble, roofing materials, and sludge. The wide variety of M&E requires additional
22 flexibility in the survey process, and this flexibility is incorporated into MARSAME.

23 **The Goal of the Roadmap**

24 The increased flexibility of MARSAME comes with increased complexity. The goal of
25 the roadmap is to assist the MARSAME user in negotiating the information in
26 MARSAME and determining where important decisions need to be made on a project-
27 specific basis, as summarized in Roadmap Figure 1.



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29

Roadmap Figure 1. The Data Life Cycle Applied to Disposition Surveys

30 The roadmap is not designed to be a stand-alone document, but to be used as a quick
31 reference to MARSAME for users already familiar with the process of planning,
32 implementing, and assessing surveys. Roadmap users will find flowcharts summarizing
33 major decision points in the survey process combined with references to sections in
34 MARSAME with more detailed information. The roadmap assumes a familiarity with
35 MARSAME terminology. Section 1.2 of MARSAME discusses key terminology, and a
36 complete set of definitions is provided in the glossary.

37 **Initial Assessment**

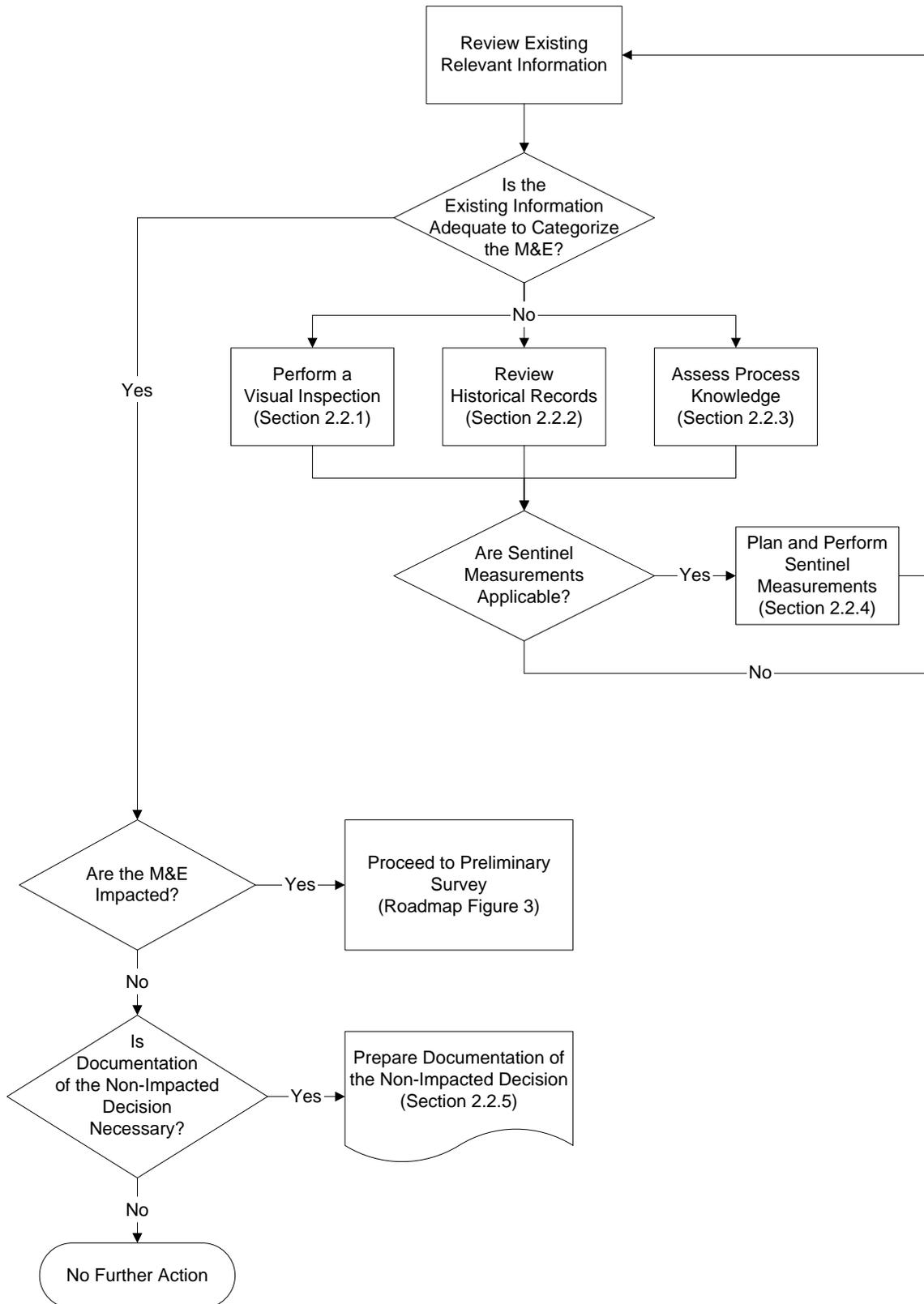
38 The Initial Assessment (IA) is the first step in the investigation of M&E, similar to the
39 Historical Site Assessment (HSA) in MARSSIM. The purpose of the IA is to collect and
40 evaluate information about the M&E to support a categorization decision and support
41 potential disposition of the M&E (e.g., release or interdiction). Project Managers are
42 encouraged to use the IA to evaluate M&E for other hazards (e.g., lead, PCBs, asbestos)
43 that could increase the complexity of the disposition survey design or pose potential risks
44 to workers during subsequent survey activities (see Section 5.2), or to human health and
45 the environment following subsequent disposition of the M&E.

46 **Categorization**

47 MARSAME uses the term categorization to describe the decision of whether M&E are
48 impacted or non-impacted. M&E with no reasonable possibility for containing
49 radioactivity in excess of natural background, fallout levels, or inherent levels of
50 radioactivity are non-impacted. Impacted M&E have a reasonable possibility for
51 containing radioactivity in excess of these levels. Roadmap Figure 2 shows the
52 categorization process as part of initial assessment (IA).

53 **Standardized Survey Designs**

54 Most operating radiological facilities maintain standard operating procedures (SOPs) as
55 part of a quality system. In many cases these SOPs include instructions for conducting
56 disposition surveys. The first step in evaluating an existing SOP is to determine whether
57 there is adequate information available to design a disposition survey. If the existing
58 information isn't adequate to design a disposition survey, it isn't adequate for



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Roadmap Figure 2. The Categorization Process as Part of Initial Assessment

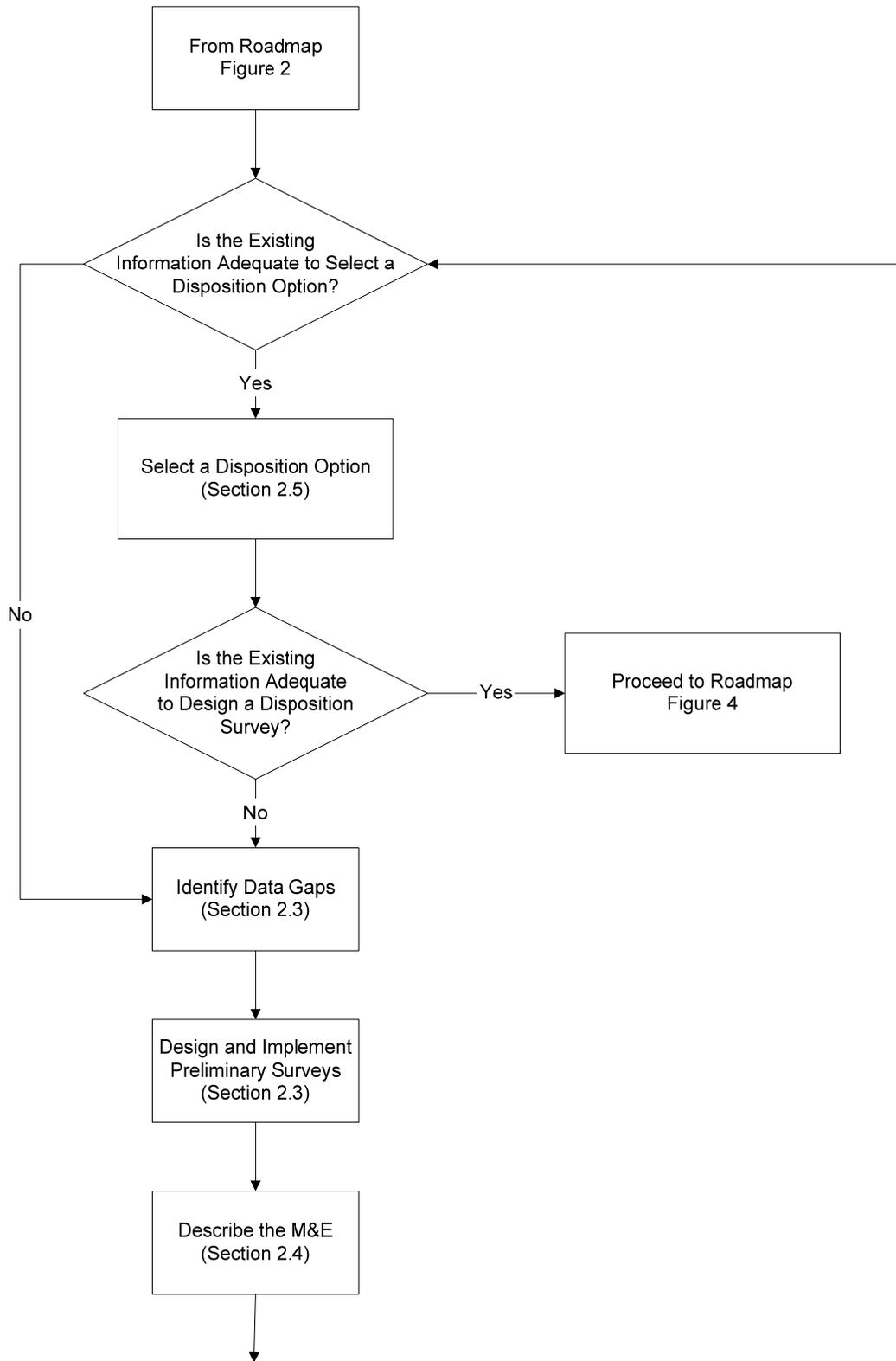
61 determining if an existing survey design is adequate either. Roadmap Figure 3 addresses
62 assessing the adequacy of existing information for designing disposition surveys.
63 Roadmap Figure 4 shows how implementing an existing SOP that is applicable to the
64 M&E being investigated takes the user from MARSAME Chapter 2 to MARSAME
65 Chapter 6. If a project-specific survey design needs to be developed, Roadmap Figure 4
66 directs the user to the information in MARSAME Chapter 3.

67 In some cases it may be possible to modify the M&E to match the assumptions used to
68 develop the existing SOP, or modify the existing SOP to address the M&E being
69 investigated. M&E may be modified by changing the physical attributes described in
70 Table 2.1 or the radiological attributes described in Table 2.2. Modifications to the SOP
71 are most often associated with MQOs such as the measurement detectability (see Section
72 5.7) or measurement quantifiability (see Section 5.8). Modifying the MQOs may result
73 in small changes such as an increased count time (e.g., to account for an increase in
74 measurement uncertainty or a decrease in counting efficiency) or larger changes such as
75 selecting a different instrument (e.g., a gas-proportional detector instead of a Geiger-
76 Mueller detector) or a different measurement technique (e.g., in situ measurements
77 instead of scan measurements). Information on evaluating an existing survey design to
78 determine if it will meet the DQOs for the M&E being investigated is provided in
79 Section 3.10.

80 **Develop a Decision Rule**

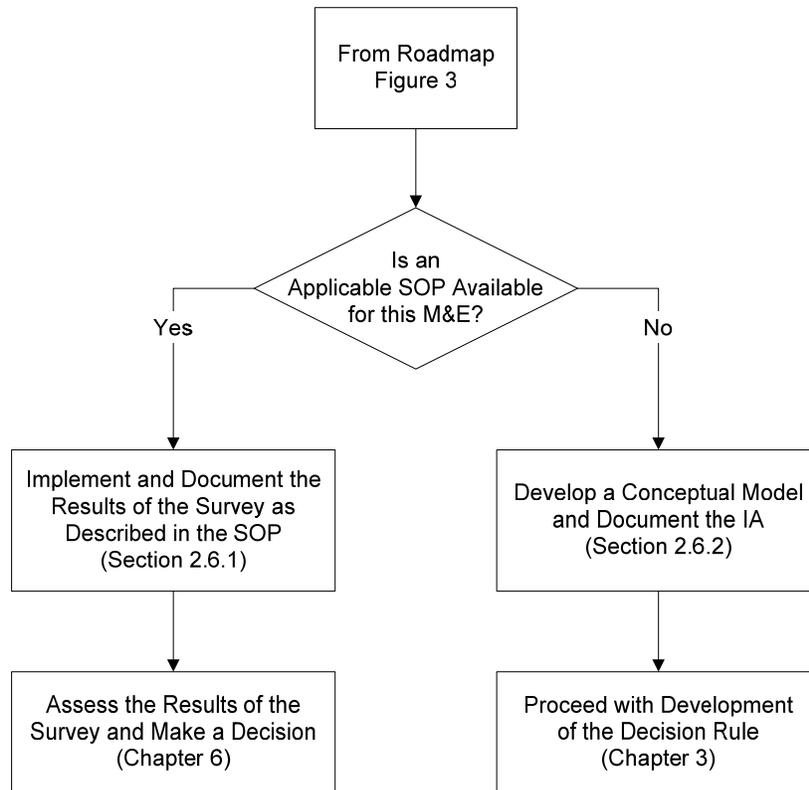
81 MARSAME Chapter 3 focuses on developing a decision rule by identifying inputs to the
82 decision. A decision rule is a theoretical “if...then...” statement that defines how the
83 decision maker would choose among alternative actions. There are three parts to a
84 decision rule:

- 85 • An action level that causes a decision maker to choose between the alternative
86 actions (see Roadmap Figure 5 and Section 3.3),
- 87 • A parameter of interest that is important for making decisions about the target
88 population (see Section 3.4), and
- 89 • Alternative actions that could result from the decision (see Section 3.5).



90

91 **Roadmap Figure 3. Assessing Adequacy of Information for Designing**
 92 **Disposition Surveys**



93

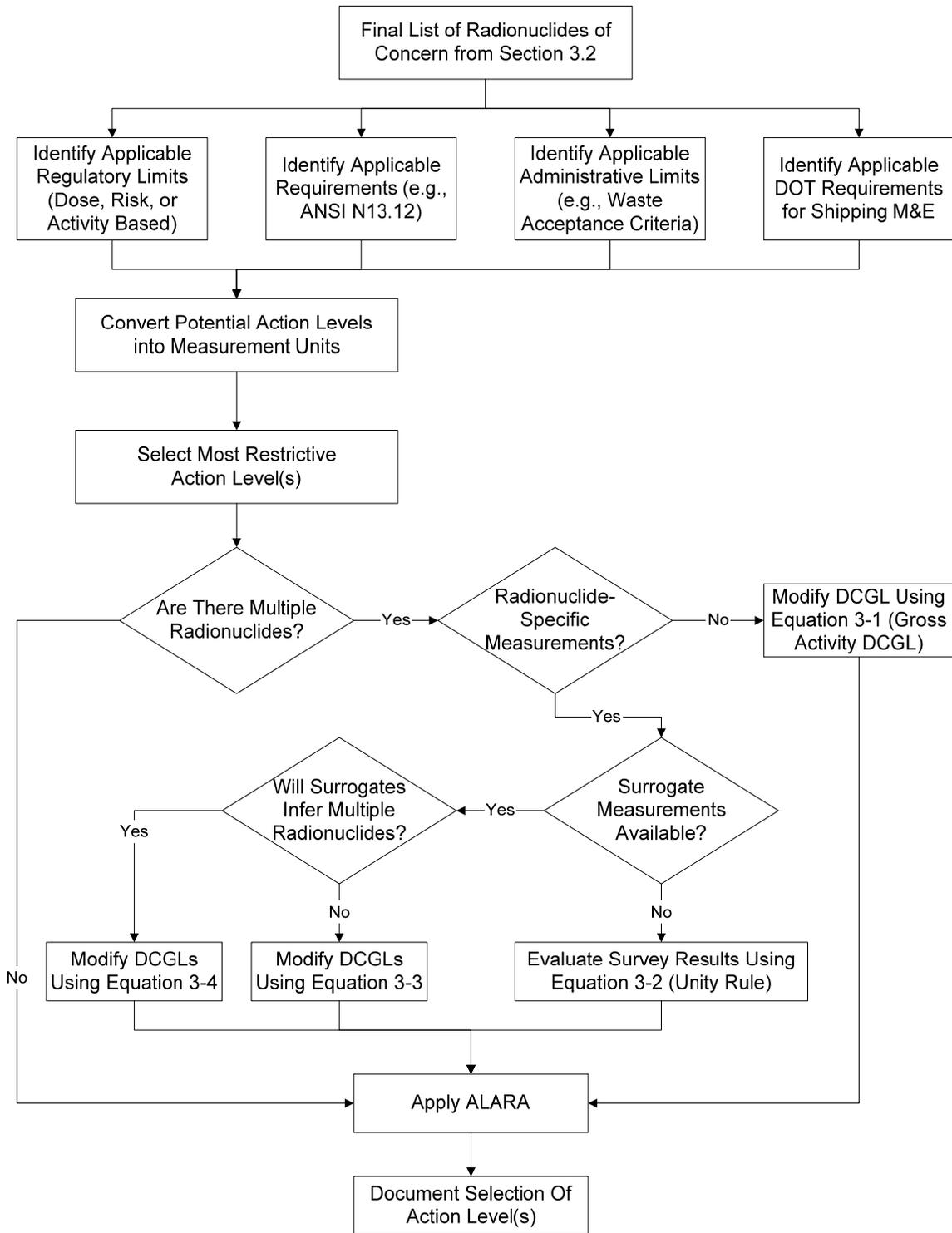
94

Roadmap Figure 4. Assessing the Applicability of Existing SOPs

95 Other inputs to the decision that are discussed in MARSAME Chapter 3 include selecting
 96 radionuclides or radiations of concern (see Section 3.2), developing survey unit
 97 boundaries (see Section 3.6), inputs for selecting provisional measurement methods (see
 98 Section 3.8), and identifying reference materials if necessary (see Section 3.9).

99 Survey Design

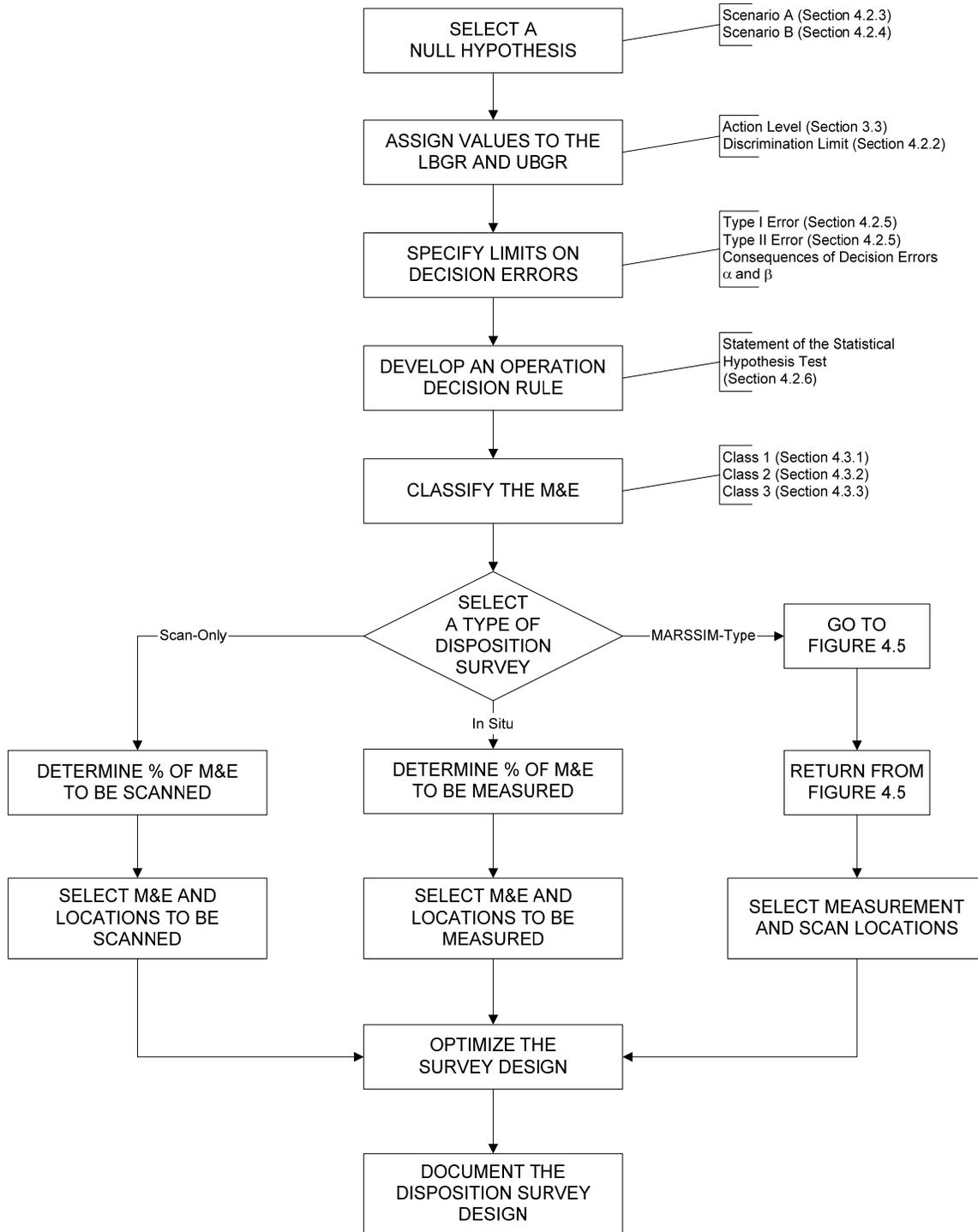
100 Once a decision rule has been developed, a disposition survey can be designed for the
 101 impacted M&E being investigated. The disposition survey incorporates all of the
 102 available information to determine the quality and quantity of data required to support a
 103 disposition decision. Roadmap Figure 6 shows a flow diagram describing disposition
 104 survey design.



105

106

Roadmap Figure 5. Identifying Action Levels



107

108 **Roadmap Figure 6. Flow Diagram for Developing a Disposition Survey Design**

109 MARSAME, like MARSSIM, provides information on using a null hypothesis that
110 radionuclide concentrations or activity levels associated with the M&E exceed the action
111 level (i.e., Scenario A). MARSAME also incorporates additional technical information
112 from NUREG-1505 (NRC 1998a) and MARLAP for designing surveys using Scenario B
113 where the null hypothesis is that the radionuclide concentrations or activity levels are less
114 than the action level. The assignment of values to the lower bound of the gray region
115 (LBGR) and upper bound of the gray region (UBGR), specification of decision error
116 rates, and classification are all similar to information provided in MARSSIM.

117 MARSAME provides information on three different types of survey designs (see
118 Roadmap Figure 6):

- 119 • Scan-only survey designs (Section 4.4.1),
- 120 • In situ survey designs (Section 4.4.2), and
- 121 • MARSSIM-type survey designs (Section 4.4.3 and MARSSIM Section 5.5).

122 Scan-only survey designs use scanning techniques to measure the M&E. In general,
123 scan-only survey designs may be applied to all types of M&E, from small individual
124 items to large quantities of materials to large, complex machines. Scan-only surveys
125 range from hand-held instruments moving over the M&E to conveyORIZED systems that
126 move the M&E past the detectors. Scan-only survey designs often require the least
127 amount of resources to design and implement, and are easy to incorporate into SOPs or
128 project-specific survey designs. In many cases it is not necessary to document the results
129 of individual scanning measurements since it is easy to identify results that exceed some
130 threshold corresponding to the action level. With the real-time feedback available during
131 Class 1 scan-only surveys, the user can implement a “clean as you go” practice by
132 segregating M&E that exceed the threshold for additional investigation. Drawbacks to
133 scan-only surveys include increased measurement uncertainty because of variations in
134 scan speed and source to detector distance making it difficult to detect or quantify
135 radionuclides with action levels close to zero or background.

136 In situ survey designs use static measurements to measure the M&E. In situ surveys are
137 generally applicable to situations where scan-only surveys are determined to be
138 unacceptable. There are a wide variety of in situ measurement techniques available
139 including box counters, portal monitors, in situ gamma spectroscopy systems, and direct
140 measurements with hand-held instruments. In situ surveys are characterized by limited
141 numbers of measurements with long count times relative to scan-only surveys, and often
142 require more resources for planning and implementation relative to scan-only surveys.

143 MARSSIM-type survey designs combine a statistically-based number of static
144 measurements or samples to determine average radionuclide concentrations with
145 scanning to identify localized areas of elevated activity. MARSSIM-type surveys are
146 designed using the information in MARSSIM. The process of identifying survey unit
147 sizes, laying out systematic or random measurement grids, and calculating project- and
148 item-specific area factors requires significantly greater effort during planning and
149 implementation than either scan-only or in situ survey designs. In general, MARSSIM-
150 type surveys of M&E are only performed on large, complicated M&E with a high
151 inherent value after scan-only and in situ survey designs have been considered and
152 rejected as inappropriate or unacceptable.

153 **Measurement Quality Objectives**

154 Measurement Quality Objectives (MQOs) are characteristics of a measurement method
155 required to meet the objectives of the survey. Additional information on MQOs can be
156 found in MARSAME Section 3.8 and Section 5.5, as well as MARLAP Chapter 3.

157 MQOs are an important concept that was not presented in MARSSIM, and should be an
158 important factor when evaluating existing survey designs and SOPs for applicability to
159 surveying M&E.

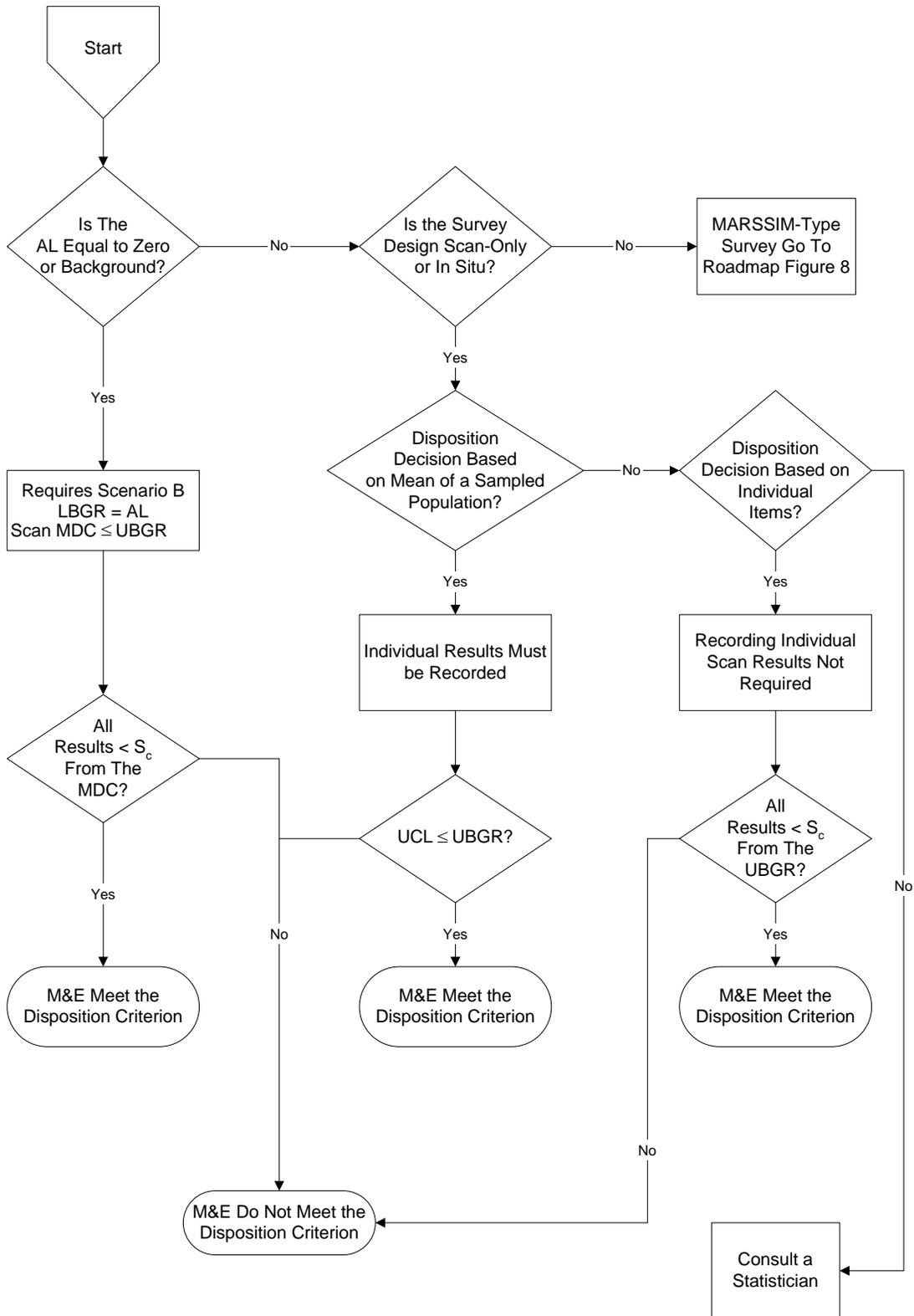
160 MQOs for a project include, but are not limited to:

- 161 • The measurement method uncertainty at a specified concentration expressed
162 as a standard deviation (see Section 3.8.1 and Section 5.5),

- 163 • The measurement method's detection capability expressed as the minimum
164 detectable concentration (MDC, see Section 3.8.2 and Section 5.7),
- 165 • The measurement method's quantification capability expressed as the
166 minimum quantifiable concentration (MQC, see Section 3.8.3 and
167 Section 5.8),
- 168 • The measurement method's range, which defines the measurement method's
169 ability to measure the radionuclide or radiation of concern over some
170 specified range of concentration or activity (see Section 3.8.4 and
171 Appendix D),
- 172 • The measurement method's specificity, which refers to the ability of the
173 measurement method to measure the radionuclide or radiation of concern in
174 the presence of interferences (see Section 3.8.5), and
- 175 • The measurement method's ruggedness, which refers to the relative stability
176 of measurement method performance for small variations in measurement
177 method parameter values (see Section 3.8.6 and Appendix D).

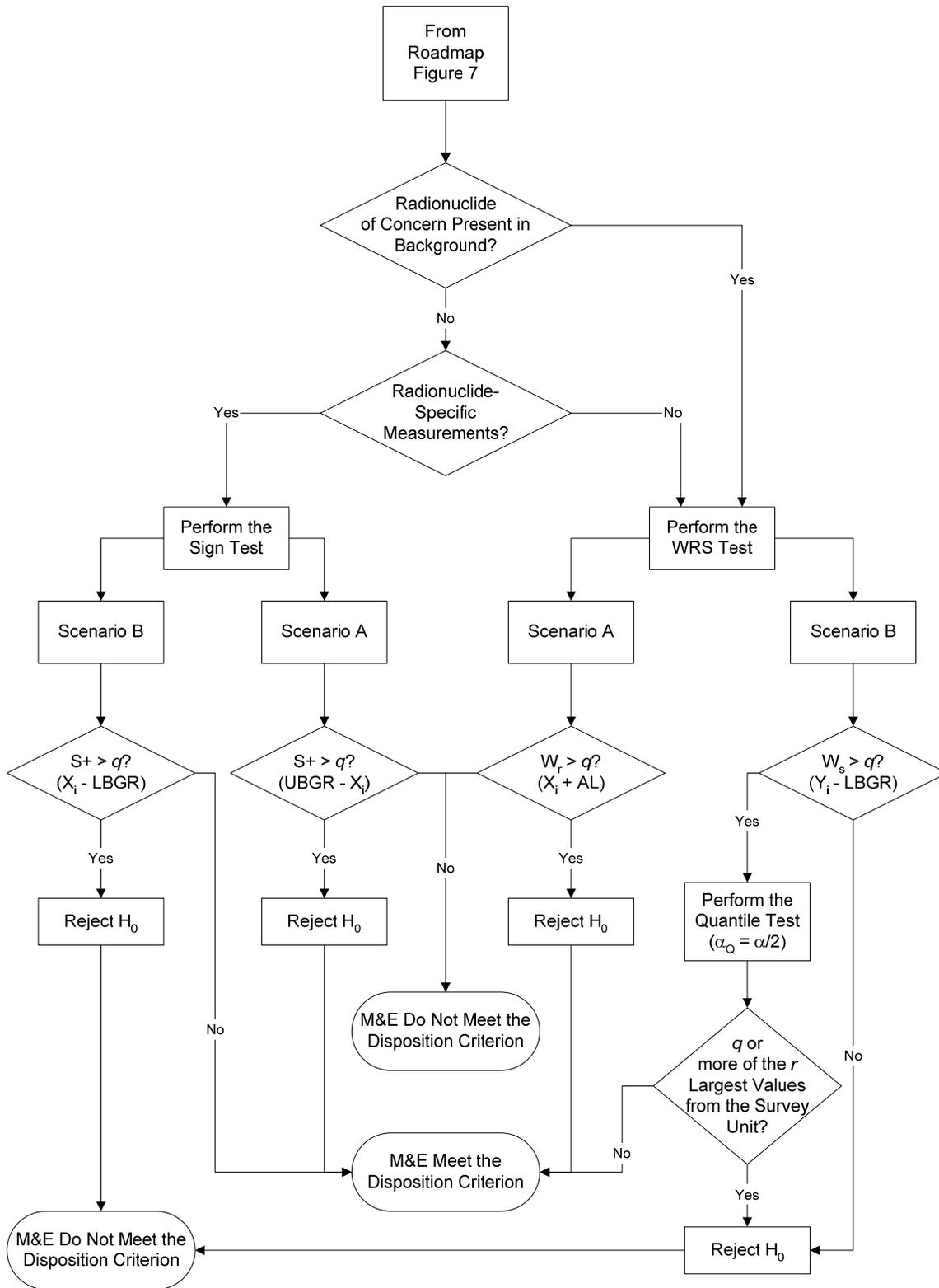
178 **Evaluate the Results**

179 The assessment phase of the Data Life Cycle involves evaluating the results of the
180 survey. DQA is used to evaluate the survey results. DQA is a scientific and statistical
181 evaluation that determines whether data are the type, quality, and quantity to support their
182 intended use. When individual measurement results are not recorded, as allowed in some
183 scan-only survey designs, the preliminary data review will be brief and based primarily
184 on the results of quality control (QC) measurements. To increase the flexibility and
185 general applicability of MARSAME, several evaluation methods have been incorporated
186 in addition to the Sign test and Wilcoxon Rank Sum (WRS) test used in MARSSIM.
187 Roadmap Figure 7 presents information on interpreting survey results for scan-only and
188 in situ surveys. Roadmap Figure 8 presents information on interpreting survey results for
189 MARSSIM-type surveys.



190

191 **Roadmap Figure 7. Interpretation of Survey Results for Scan-Only and**
 192 **In Situ Surveys**



193

194

Roadmap Figure 8. Interpretation of Survey results for MARSSIM-Type Surveys

195 **Summary**

196 The roadmap presents a summary of the Data Life Cycle as it applies to disposition
197 surveys in MARSAME and identifies where information on important topics are located
198 in MARSAME. Flow charts are provided to summarize major steps in the survey design
199 process, again citing appropriate references in MARSAME.

1 INTRODUCTION AND OVERVIEW

2 1.1 Purpose and Scope of MARSAME

3 Large quantities of materials and equipment (M&E) potentially affected by radioactivity are
4 present throughout the United States. The potential for residual radioactivity can come from use
5 of source, byproduct, and special nuclear materials as well as naturally occurring radioactive
6 material (NORM), naturally occurring and accelerator-produced radioactive materials (NARM)
7 and technologically enhanced naturally occurring radioactive material (TENORM). This M&E
8 may be commercial, research, education, or defense related. The M&E might be:

- 9 • used or stored at sites and facilities licensed to handle radioactivity,
- 10 • commercial products purposely containing radionuclides (e.g., smoke detectors),
- 11 • commercial products incidentally containing radionuclides (e.g., phosphate
12 fertilizers), or
- 13 • associated with NARM and TENORM.

14 The owners of M&E potentially affected by radioactivity need to determine acceptable
15 disposition options for M&E currently under their control. Industries or facilities sensitive to the
16 presence of radioactivity need to evaluate the acceptability of M&E coming under their control.
17 Regulatory agencies need to distinguish items in general commerce that are inherently
18 radioactive from illicit trafficking of radioactive M&E.

19 The Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME)
20 is a supplement to the Multi-Agency Radiation Survey and Site Investigation Manual
21 (MARSSIM). Like MARSSIM, MARSAME is a joint effort by the Department of Defense
22 (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear
23 Regulatory Commission (NRC). Information on MARSSIM can be found on the World Wide
24 Web (MARSSIM 2002). MARSAME also incorporates information for measuring radioactivity
25 from the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP).
26 Information on MARLAP can be found on the World Wide Web (MARLAP 2004). This
27 supplement provides information on surveys where radiological control of M&E could be

28 initiated, maintained, removed, or transferred (i.e., an M&E disposition) to another responsible
29 party. In addition, MARSAME discusses the need for a graded approach to surveying M&E.

30 MARSAME provides technical information on approaches for planning, implementing,
31 assessing, and documenting surveys to determine proper disposition of M&E. Release
32 (including clearance) and interdiction are types of disposition options in MARSAME. Detailed
33 descriptions of these disposition options are provided in Chapter 2.

34 Examples of M&E include metals, concrete, tools, equipment, piping, conduit, furniture, and
35 dispersible bulk materials such as trash, rubble, roofing materials, and sludge. Liquids, gases,
36 and solids stored in containers (e.g., drums of liquid, pressurized gas cylinders, containerized
37 soil) are also included in the scope of this document.

38 Radionuclides or radioactivity on workers or members of the public are outside the scope of the
39 document. Liquid and gaseous effluent releases, and real property (e.g., fixed buildings and
40 structures, surface and subsurface in situ soil) are also outside the scope of this document.

41 The purpose of this supplement is to provide information for the design and implementation of
42 technically defensible surveys for disposition of M&E. MARSAME provides information on
43 selecting and properly applying disposition survey strategies and selecting measurement
44 methods. The data quality objectives (DQO) process is used for selecting the best disposition
45 survey design based on the selected disposition option, action level, description of the M&E
46 (e.g., size, accessibility, component materials), and description of the radioactivity (e.g.,
47 radionuclides, types of radiation, surficial versus volumetric activity). Detailed information on
48 the DQO Process can be found in EPA QA/G-4 (EPA 2006a), MARSSIM Appendix D, and
49 MARLAP Appendix B. This supplement describes a number of different approaches for
50 performing technically defensible disposition surveys and provides information for optimizing
51 survey designs. However, MARSAME does not represent the only acceptable approach to
52 radiologically evaluate M&E. MARSAME describes a graded approach that the signatory
53 agencies find acceptable and useful for most situations. The signatory agencies recognize that
54 alternative approaches or modification of the MARSAME procedures may be appropriate or
55 necessary for some situations. Nothing in MARSAME should be construed to prohibit the use of
56 other appropriate procedures.

57 Disposition surveys may be performed as a single event or as part of a routine process. Single
58 event disposition surveys are usually performed once in association with a specific project.
59 Surveying a backhoe at the completion of a decommissioning project is one example of a single
60 event disposition survey. Routine process disposition surveys are usually associated with
61 ongoing tasks where similar surveys are performed repeatedly. One example of a routine
62 process disposition survey would be a radiological survey of tools prior to removal from a
63 controlled area at a nuclear facility. Both single event and routine process types of surveys are
64 included in the scope of MARSAME.

65 MARSAME assumes the user has some historical knowledge of the M&E being investigated.
66 The historical information is gathered during the Initial Assessment (IA) to determine acceptable
67 disposition options (see Chapter 2). The characteristics, history of prior use, and inherent
68 radioactivity of the M&E are important when determining the appropriate disposition options.
69 The historical information is termed “process knowledge.” The role of process knowledge
70 (discussed in Chapter 2) is important in providing information on the nature and amount of
71 radioactivity that might be expected on, or incorporated in, the M&E being investigated. If no
72 historical information is available, information on the current status of the M&E can be
73 determined using preliminary surveys (i.e., scoping, characterization, remedial action support)
74 prior to designing a disposition survey.

75 The recommendations in this supplement may be applied to a broad range of regulations,
76 including dose-, risk-, or radionuclide concentration-based regulations. The translation of a
77 regulatory dose or risk limit to a corresponding concentration level is not addressed in
78 MARSAME. The terms dose, risk, and dose- or risk-based regulation are used throughout the
79 supplement, but these terms are not intended to limit the applicability of this supplement.
80 MARSAME can be applied to activity concentrations (e.g., Bq/m²) without associated dose or
81 risk values. MARSAME does not address the regulatory status of the M&E (e.g., NRC
82 exempted or excluded materials).

83 MARSAME uses the word “should” as a recommendation. This is not to be interpreted as a
84 requirement. The user need not assume that every recommendation in this supplement will be
85 taken literally and applied to every project. Rather, it is expected the survey documentation will
86 address how the recommendations will be applied on a project-specific basis.

87 **1.2 Understanding Key MARSAME Terminology**

88 In order to understand the information in MARSAME, the user should first become familiar with
89 the scope of this supplement, the terminology, and the concepts in this document. As a
90 supplement to MARSSIM, MARSAME uses terms generally consistent with MARSSIM. Some
91 additional terms were developed for MARSAME, while other commonly used terms were
92 adopted from other sources. This section explains some of the terms used in this supplement.

93 The terms *impacted*, *non-impacted*, and *graded approach* are defined in MARSSIM. These
94 terms are used consistently in MARSSIM and MARSAME. Unlike MARSSIM which applies to
95 land, structures, or buildings, MARSAME applies to M&E. The action taken may initiate,
96 maintain, remove, or transfer radiological controls associated with the M&E. The decision to
97 take action may be largely based on the results of a radiological survey designed to evaluate the
98 disposition of the M&E, either through release or interdiction. Therefore, the terms *release*
99 *criterion*, *derived concentration guideline level (DCGL)*, and *final status survey* used in
100 MARSSIM are replaced by the more generic terms *disposition criterion*, *action level*, and
101 *disposition survey*, respectively, in MARSAME.

102 *Disposition* is the future use, fate, or final location for something (e.g., recycle, reuse, disposal).
103 Disposition options range from release to interdiction:

- 104 • *Release* - A reduction in the level of radiological control, or a transfer of control to
105 another party. Examples of release include clearance (i.e., unrestricted release of
106 materials and equipment to the public sector), recycle, reuse, disposal as waste, or
107 transfer of control of radioactive M&E from one authorized user to another.
- 108 • *Interdiction* - The authoritative refusal to approve or assent to an action. Examples of
109 interdiction include identification of uncontrolled radioactive material that results in the
110 initiation of radiological controls, or decision not to accept control of M&E. The goal of
111 an interdiction survey is often to detect radioactivity that should be controlled.

112 *Categorization* is the act of determining whether M&E are impacted or non-impacted. This is a
113 departure from MARSSIM where this decision was referred to as classification. This change
114 was made to emphasize the difference between the decision of whether a survey is needed (i.e.,
115 impacted or non-impacted) and the determination of the appropriate level of survey effort (i.e.,
116 classification).

117 *Classification* is the act or result of separating impacted M&E or survey units into one of three
118 designated classes: Class 1, Class 2, or Class 3. Classification is the process of determining the
119 appropriate level of survey effort based on estimates of activity levels and comparison to action
120 levels, where the activity estimates are provided by historical information, process knowledge,
121 and preliminary surveys.

122 *Measurable radioactivity* is radioactivity that can be quantified using known or predicted
123 relationships developed from historical information, process knowledge or preliminary
124 measurements as long as the relationships are developed, verified, and validated as specified in
125 the DQOs and measurement quality objectives (MQOs). Measurability is of primary importance
126 in MARSAME.

127 *Surficial radioactive material* is radioactive material distributed on any of the surfaces of a solid
128 object. Surficial radioactive material may be *removable* (by non-destructive means such as
129 casual contact, wiping, brushing, or washing) or *fixed*. Surfaces may either be accessible or
130 difficult-to-measure. Changes to the surface (e.g., paint, dirt, oxidation) may affect the
131 measurability and the physical condition of surficial radioactive material.

132 *Survey unit* for M&E is the specific lot, amount, or piece of equipment on which measurements
133 are made to support a disposition decision concerning the same specific lot, amount, or piece of
134 equipment. The survey unit defines the spatial boundaries for the disposition decision and a
135 separate decision is made for each survey unit, similar to MARSSIM. The survey unit
136 boundaries also define the population for the parameter of interest.

137 *Volumetric radioactive material* is radioactive material that is distributed throughout or within
138 the material or equipment being measured, as opposed to a surficial distribution. Volumetric
139 radioactive material may be homogeneously (e.g., uniformly activated metal) or heterogeneously
140 (e.g., activated reinforced concrete) distributed throughout the M&E. Volumetric radioactive
141 material may be distributed throughout the M&E being measured or distributed in layers. Layers
142 of volumetric radioactive material may start at the surface (e.g., porous surfaces penetrated by
143 radioactive material) or under a layer of other material (e.g., activated rebar inside a concrete
144 wall). By definition all radioactive liquids and gases in containers and all bulk quantities of
145 radioactive material when measured as a whole are volumetric radioactive material.

146 The concept of whether radioactivity is measurable is the major factor in demonstrating
147 compliance with an action level. MARSAME does not provide an exact definition for the
148 transition between surficial and volumetric radioactive material. Rather, the assumptions used to
149 quantify the radioactivity need to be clearly defined and identified so they can be compared to
150 the DQOs and MQOs. Individual action levels may specify applicability to surficial or
151 volumetric radioactivity. In these cases, the definition of surficial and volumetric radioactivity
152 should be specified as part of the definition of the action level.¹

153 *Accessible area* is an area that can be reached or where measurements can be readily performed.
154 In many cases M&E must be physically accessible to perform a measurement. However,
155 radioactivity may be measurable even if M&E are not physically accessible (e.g., energetic
156 gamma rays may be quantified even after passing through a layer of shielding).

157 *Difficult-to-measure radioactivity* is radioactivity that is not measurable until the M&E to be
158 surveyed is prepared. Preparation of M&E may be relatively simple (e.g., cleaning) or more
159 complicated (e.g., disassembly or complete destruction). Given sufficient resources, all
160 radioactivity can be made measurable; however, it is recognized that increased survey costs can
161 outweigh the benefit of some dispositions.

162 *Initial Assessment (IA)* is an investigation to collect existing information describing M&E and is
163 similar to the Historical Site Assessment (HSA) described in MARSSIM. The IA provides
164 initial categorization of M&E as impacted or non-impacted. In addition to the HSA activities
165 described in MARSSIM, the IA may lead to grouping or segregating M&E with similar
166 characteristics as well as designing and implementing preliminary surveys. The IA also
167 identifies the expected disposition of the M&E (e.g., clearance, radiological control, recycle,
168 reuse, disposal). The results of the IA provide most, if not all, information needed to design a
169 disposition survey for impacted M&E. A graded approach is used to determine the level of
170 effort applied during the IA.

¹ This idea is consistent with the definition of a surface soil sample provided in the MARSSIM Glossary. A surface soil sample is a sample that reflects the modeling assumptions used to develop the DCGL for surface soil activity. The example in MARSSIM references 40 CFR 192, which defines surface soil as the first 15 centimeters of soil.

171 *Sentinel measurement* is a biased measurement performed at a key location to provide
172 information specific to the objectives of the IA (see Section 2.2.4). Sentinel measurements
173 cannot be used as the only source of information to support a decision that M&E are non-
174 impacted. The objective of performing sentinel measurements as part of the IA is to gather
175 additional information to support a decision regarding further action, verify assumptions based
176 on process knowledge, provide additional support to a finding of impacted or non-impacted for
177 M&E, and to distinguish illicit or inadvertent transport of radioactive materials from items in
178 general commerce that are inherently radioactive (e.g., fertilizers, phosphates, sand-blasting grit).

179 **1.3 Use of MARSAME**

180 MARSAME provides technical information describing a framework for planning, implementing,
181 and assessing radiological surveys of M&E. MARSAME does not establish or supersede any
182 regulatory or license requirements. Federal and State regulatory agencies may have
183 requirements or guidance that differs from what is presented in MARSAME and may be
184 implemented as appropriate. Consequently, persons planning, implementing, and assessing
185 disposition surveys should also obtain appropriate regulatory approval for the procedures that are
186 in use to maintain regulatory compliance.

187 Potential users of this supplement are Federal, State, and local government officials having
188 authority for control of radioactive M&E, their contractors, and other parties such as
189 organizations with licensed authority to possess and use radioactive materials. This supplement
190 to MARSSIM is intended for a technical audience having knowledge of radiation health physics
191 and an understanding of statistics as well as experience with the practical applications of
192 radiation protection. Understanding and applying the recommendations in this supplement
193 requires knowledge of instrumentation and measurement methodologies as well as expertise in
194 planning, approving, and implementing radiological surveys. Certain situations and projects may
195 require consultation with more experienced or specialized personnel (e.g., a statistician).

196 MARSAME recommends that a graded approach be applied to the disposition of M&E. Non-
197 impacted M&E are removed from further consideration early in the process through
198 categorization. Impacted M&E are classified based on the level of residual radioactivity so that a
199 higher level of scrutiny can be applied to M&E with the highest potential for residual

200 radioactivity. Finally, MARSAME includes practical considerations such as inherent value of
201 the M&E and handling the M&E when evaluating options for disposition. The combination of
202 these considerations results in a graded approach where an appropriate level of survey effort is
203 applied to M&E to minimize the impacts of any decision errors.

204 **1.4 Overview of MARSAME**

205 The Data Life Cycle is the foundation for the design, implementation, and assessment of surveys
206 for disposition of M&E in this supplement. However, before commencing survey planning the
207 user must select an appropriate disposition option. Multiple disposition options may exist.
208 Consider all of the various disposition options and develop the most appropriate option for a
209 given situation. Survey designs may then be planned using the DQO Process, which is often
210 iterative. The DQO Process iterations may take place at different times during the disposition
211 process, for example during the IA as well as during the disposition survey. The different survey
212 designs are compared and the most resource-effective design that meets the survey objectives is
213 selected for implementation. Following implementation of the selected survey design, the results
214 are evaluated using Data Quality Assessment (DQA). A technically defensible decision
215 regarding disposition of the M&E can then be made.

216 Whenever practical, MARSAME recommends designing disposition surveys where one hundred
217 percent of the M&E are measurable. This means that all radioactivity associated with the M&E
218 has been measured and quantified (e.g., 100% scan with conventional instruments, measurement
219 with a box counter, or measurement using in situ gamma spectroscopy), a known or accepted
220 relationship was used to estimate concentrations for difficult to measure radionuclides using
221 surrogate measurements,² or that a known or accepted relationship allows quantification of
222 radioactivity in areas that were not measured. MARSAME employs the use of a graded
223 approach to determine if a 100% measurable survey is practical and to ensure that a sensible,
224 commensurate balance is achieved between resource expenditures and risk reduction.

² The MARSSIM term “surrogate measurement” as used here is consistent with the MARLAP term “alternate radionuclide.”

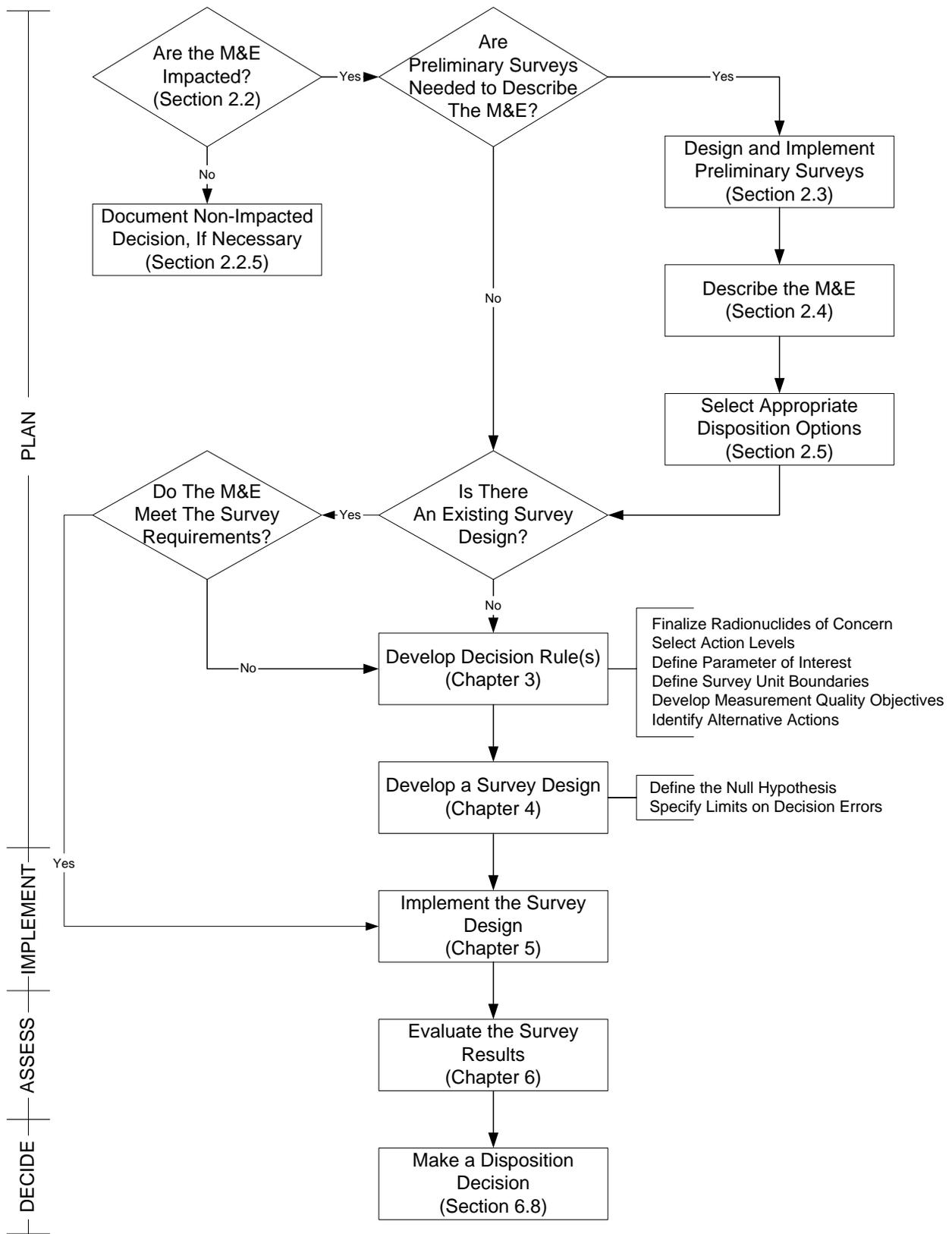
225 MARSAME uses the Data Life Cycle to design disposition surveys. The Data Life Cycle is
 226 described in MARSSIM Section 2.3, and consists of four phases:

- 227 • Planning phase (MARSAME Chapters 2, 3, and 4; MARSSIM Chapters 3, 4, and 5),
- 228 • Implementation phase (MARSAME Chapter 5; MARSSIM Chapters 6 and 7),
- 229 • Assessment phase (MARSAME Chapter 6; MARSSIM Chapter 8), and
- 230 • Decision-making phase (MARSAME Chapter 6; MARSSIM Chapter 8).

231 A brief description of each of the phases and how they apply to the disposition survey design
 232 process is provided in the following sections. Table 1.1 provides a simplified overview of the
 233 principal steps in designing a disposition survey and illustrates how the Data Life Cycle can be
 234 used in an iterative fashion within the survey process. Figure 1.1 illustrates how the Data Life
 235 Cycle is applied to disposition surveys.

236 **Table 1.1 The Data Life Cycle Used to Support Disposition Survey Design**

Disposition Survey Design Process	Data Life Cycle		MARSAME Processes
Categorization	Categorization Data Life Cycle	Plan Implement Assess Decide	Provides information on collecting and assessing existing data (Section 2.2)
Preliminary Surveys	Preliminary Survey Data Life Cycle	Plan Implement Assess Decide	Discusses the purpose (i.e., filling data gaps) and general approach to performing preliminary surveys (Section 2.3)
Disposition Survey	Disposition Survey Data Life Cycle	Plan Implement Assess Decide	Provides detailed information for planning (Chapters 3 and 4), implementing (Chapter 5), and assessing (Chapter 6) disposition surveys



237

238

Figure 1.1 The Data Life Cycle Applied to Disposition Surveys

239 1.4.1 Planning Phase

240 The planning phase is where the survey design is developed and documented using the DQO
241 Process. The survey design documents the decision rule as well as the number, type, and
242 location of measurements required to support the disposition decision. Soliciting input from
243 regulatory agencies early in the planning phase helps ensure the disposition survey results will
244 meet regulatory needs.

245 MARSAME processes begin with the historical evaluation of the M&E being investigated. This
246 IA usually combines a review of process knowledge and historical records with a visual
247 inspection of the M&E. The results of the IA are used to develop a conceptual model describing
248 the physical characteristics of the M&E and providing information on the radioactivity
249 potentially associated with the M&E. The physical description of the M&E should include
250 information on the size, shape, complexity (e.g., can it be broken down or combined with other
251 M&E), accessibility (e.g., can the surveyor physically access areas of concern to perform
252 measurements), and inherent value (i.e., resources associated with reuse, recycle, repair,
253 remediation, replacement, and disposal). Information on radioactivity should include the
254 radionuclides of potential concern, the expected levels of radioactivity, the distribution of
255 radioactivity (e.g., uniform or not), and the location of the radioactivity (i.e., surface or volume).

256 The IA may also include limited data collection in the form of sentinel measurements. The
257 results of sentinel measurements can be used as the basis to reject assumptions based on process
258 knowledge. However, sentinel measurements alone cannot be used to justify the categorization
259 of M&E as non-impacted (see Section 2.2.4 for information on sentinel measurements).

260 There are two decisions associated with the IA. The first decision, called categorization, is
261 whether or not the M&E are impacted. Non-impacted M&E do not require additional
262 investigation, but may require documentation of the non-impacted decision. The second decision
263 is to select an appropriate disposition option for impacted M&E at the end of the IA to provide
264 direction for designing a disposition survey. Additional information may be required before a
265 disposition survey can be designed. Preliminary surveys (e.g., scoping, characterization, and
266 remedial action support surveys) may be performed as part of the IA to collect this additional
267 information.

268 For single event surveys, the IA should focus on collecting the information necessary to develop
269 a technically defensible disposition survey design. Information necessary to design a disposition
270 survey includes a description of the M&E and the radioactivity potentially associated with the
271 M&E. The results of the IA are carried forward and used to develop the survey design, which is
272 usually documented in a project-specific work plan.

273 For routine process surveys, the IA should lead to an existing survey design from a standard
274 operating procedure (SOP), if applicable, or develop a new survey design for documentation in
275 an SOP. The SOP should clearly state the assumptions used to develop the survey design, along
276 with a description of the M&E and radioactivity that are covered by the SOP. The selection
277 process is based on evaluating the M&E to determine if the survey design in a specific SOP is
278 applicable. Documentation of individual survey results may not be required as long as there are
279 records showing that the SOP was approved, the instruments were working properly, and the
280 personnel performing the survey were properly trained. Development of SOPs is usually
281 accomplished using the same processes as those used to develop single event surveys. There
282 may be regulatory or site-specific guidance that specifies documentation requirements for SOPs.
283 Information on developing SOPs can be found in EPA QA/G-6 (EPA 2001).

284 Following the IA, it is necessary to develop a decision rule for the disposition of M&E being
285 investigated. The decision rule is an “if...then...” statement consisting of three parts:

- 286 • Action level(s),
- 287 • Parameter of interest, and
- 288 • Alternative actions.

289 An example of a decision rule might be “If the average surficial activity concentration is less
290 than a level specified by the regulator, then the M&E can be cleared, otherwise the M&E are not
291 cleared.” The parameter of interest is closely related to the description of the M&E, the
292 description of the radioactivity, and the survey unit boundaries. The action level reflects the
293 selection of a disposition option. The selected disposition option defines two alternative actions.
294 A decision rule should be developed for each decision to be made concerning the M&E. For
295 example, if the action level is stated in terms of total activity, generally only one decision rule is
296 required. If, on the other hand, the action level provides limits for fixed, removable, and
297 maximum levels of radioactivity, e.g., DOE Order 5400.5, Figure IV-1 (DOE 1993), then a

298 decision rule is required to evaluate each action level. The measurement performance
299 requirements, or MQOs, are also evaluated when developing a decision rule to ensure that an
300 acceptable measurement technique is available to support the proposed survey design.

301 Once the decision rule(s) have been established, a survey design is developed. The survey
302 design specifies the number and quality of measurements required to support a disposition
303 decision recorded in the decision rule. MARSAME recommends applying a graded approach to
304 designing disposition surveys (see Section 4.4). The survey design, definitions of decision
305 errors, and burden of proof are determined by the selection of a null hypothesis (see Section 4.2).

306 The survey design should be documented in a quality document (e.g., QA Survey Plan, SOP)
307 that has been reviewed and accepted by the appropriate authority (e.g., technical expert,
308 management, or regulator). Survey designs that are often repeated may be documented in SOPs
309 along with supporting records on instrument performance and personnel training. Other types of
310 disposition surveys are usually documented in a project-specific work plan and survey results are
311 presented in a disposition survey report (see Section 2.5 and Section 4.5). If the selected survey
312 design is not technically or economically practical, the planning team can investigate additional
313 disposition options if necessary (see Section 2.4 and Section 4.4).

314 **1.4.2 Implementation Phase**

315 To ensure flexibility and encourage the use of optimal measurement techniques for a specific
316 project, MARSAME does not provide detailed information on specific implementation
317 techniques. However, detailed descriptions of several measurement techniques are provided (see
318 Chapter 5 and Appendix D). These descriptions serve as a template for information required to
319 evaluate different measurement techniques. It is important to remember that the survey design is
320 usually linked to a specific option for disposition of the M&E (see Chapter 3 and Chapter 4).

321 During implementation, the descriptions of measurement techniques are compared to the MQOs
322 defined during survey planning. A measurement method (i.e., combination of a measurement
323 technique with an instrument, see Section 5.9) is selected based on its ability to meet the MQOs.
324 The number and type of measurements specified in the documented survey design are performed
325 at the locations specified in the survey design. If a measurement method is specified in the
326 survey design, that method should generally be used during implementation. If the specified

327 measurement method cannot be performed (e.g., the instrument is unavailable or the
328 measurement method does not meet the MQOs), another measurement method should be
329 selected based on the MQOs. The selection of the replacement measurement method should be
330 documented in the survey design and survey report.

331 Quality control (QC) data are collected and analyzed during implementation to provide an
332 estimate of the uncertainty associated with the survey results. QC measurements are technical
333 activities performed to measure the attributes and performance of a survey. A well-designed QC
334 program increases efficiency and provides for early detection of problems. This can save time
335 and money by averting rework and enables the user to make decisions more expeditiously
336 (EPA 2002c).

337 **1.4.3 Assessment Phase**

338 The assessment phase begins with verification and validation of the survey results. Data
339 verification is used to ensure the requirements documented in the survey design were
340 implemented as prescribed. Data validation ensures the results of the data collection activities
341 support the objectives of the survey (i.e., DQOs), or permit a determination that these objectives
342 should be modified (MARSSIM Section 9.3 and MARSSIM Appendix N).

343 DQA determines if the collected data are of the right type, quality, and quantity to support their
344 intended use. DQA helps complete the Data Life Cycle by providing the assessment needed to
345 determine that the planning objectives are achieved. DQA is described in detail in EPA QA/
346 G-9R (EPA 2006b), MARSSIM Section 8.2, and MARSSIM Appendix E.

347 The preliminary data review is performed to learn about the structure of the data (e.g.,
348 identifying patterns, relationships, or potential anomalies). Graphical techniques are used to help
349 visualize the data. Calculation of basic statistical quantities is used to help describe the
350 distribution of data.

351 The survey data are evaluated using a statistical test. A test statistic is calculated and compared
352 to a critical value. The critical value divides the potential values of the test statistic into two
353 regions. The critical region includes values for the test statistic where the null hypothesis is
354 rejected. The null hypothesis is not rejected for values of the test statistic outside the critical
355 region.

356 **1.4.4 Decision-Making Phase**

357 Following the assessment phase, a decision is made regarding the disposition of the M&E. The
358 decision rule defines the final decision. The statistical test or data comparison determines
359 whether the parameter of interest exceeds the action level. Based on the outcome, a decision can
360 be made regarding the alternative actions. If multiple decision rules are defined for a single
361 disposition survey (e.g., a MARSSIM-type survey where the average activity is evaluated using a
362 statistical test and small areas of elevated activity are evaluated using the elevated measurement
363 comparison) any one decision that the action level has been exceeded should result in additional
364 investigation.

365 **1.5 Organization of MARSAME**

366 The planning, implementation, and assessment of disposition surveys in MARSAME are based
367 on the Data Life Cycle. Each chapter in MARSAME provides information for specific steps in
368 the process. The planning phase is discussed in Chapters 2, 3, and 4. The implementation phase
369 is discussed in Chapter 5, and Chapter 6 discusses the assessment phase and decision-making
370 phase.

371 Chapter 2 focuses on the IA. Information is provided on categorizing whether the M&E are
372 impacted or non-impacted in Section 2.2. Discussions of historical data that will be required to
373 design a disposition survey are provided in Section 2.3. The selection of a disposition option and
374 development of a conceptual model are discussed in Section 2.5. Information pertaining to
375 documenting the results of the IA is provided in Section 2.6.

376 Chapter 3 provides information on developing a decision rule and discusses other inputs needed
377 to design a disposition survey. Section 3.2 addresses selecting the radionuclides or radiations of
378 concern which must be established before forming a decision rule. There are three parts to a
379 decision rule:

- 380 • Action level(s), discussed in Section 3.3,
- 381 • Parameter of interest, discussed in Section 3.4, and
- 382 • Alternative actions, discussed in Section 3.5.

383 Section 3.7 brings these three components together to develop decision rule(s) that are used to
384 design the disposition survey in Chapter 4. Survey units are discussed in Section 3.6, and inputs
385 for selecting measurement methods are presented in Section 3.8. Section 3.9 identifies reference
386 materials that can be used to estimate background radionuclide concentrations or radiation levels.
387 The process for evaluating an existing survey design is described in Section 3.10.

388 Chapter 4 completes the planning phase with the development of a survey design. This chapter
389 discusses the selection of a null hypothesis and setting tolerable limits on decision errors (Section
390 4.2), determines the level of survey effort for the disposition survey (Section 4.3), and
391 determines the type, number, and location of measurements to support a disposition decision
392 (Section 4.4). Information pertaining to disposition survey design documentation is provided in
393 Section 4.5. The processes in Chapter 4 result in a documented survey design.

394 The implementation processes in Chapter 5 focus on selection of an appropriate measurement
395 technique. Recommendations are provided on issues related to health and safety that may impact
396 the implementation of disposition surveys (Section 5.2). Chapter 5 also provides information on
397 process control and handling of potentially radioactive M&E (Section 5.3). The use of
398 segregation to help improve the efficiency of measurements and detectability of radioactivity,
399 and as a tool to limit the uncertainty is described in Section 5.4. Sections 5.5 through 5.8 discuss
400 the establishment of measurement uncertainty, measurement detectability, and measurement
401 quantifiability as MQOs to validate the measurement method's ability to meet the established
402 performance objectives. Information is provided on several measurement techniques (Section
403 5.9) that can be used for comparison to the MQOs developed in Chapter 3. These descriptions
404 can also be used during the planning phase to specify a measurement technique in the survey
405 design. Recommendations related to QC are also provided to ensure that survey instruments are
406 functioning properly, and the data meet defined performance limits specified during planning
407 (Section 5.10). Information related to collecting and documenting survey data is discussed in
408 Section 5.11.

409 Chapter 6 provides methods for the assessment and decision-making phases. Recommendations
410 are provided for performing the preliminary data review, calculating statistical quantities, and
411 preparing graphic representations that will assist the user in exploring the data (Section 6.2).
412 Disposition decisions about individual items may be based on individual measurement results by

413 comparing data to the upper bound of the gray region (UBGR, Section 6.3). Information is also
414 provided for calculating the upper confidence limit (Section 6.4). Details on performing
415 recommended statistical tests are also included (Sections 6.5 through 6.7). This chapter also
416 describes how to make a disposition decision based on the survey results (Section 6.8) and the
417 documentation to support the decision (Section 6.9).

418 Chapter 7 provides detailed case studies implementing specific concepts found throughout
419 MARSAME. The case studies cover a range of material, equipment, radionuclides, and
420 disposition options. Examples from these case studies are used to illustrate specific concepts
421 throughout the supplement.

422 MARSAME contains several appendices to provide additional information on specific topics.
423 Appendix A provides copies of statistical tables needed to implement the information in
424 MARSAME. Appendix B lists sources of environmental radiation such as natural background
425 and fallout. A list of potential radionuclides grouped by industry or type of facility is provided in
426 Appendix C. Appendix D provides detailed information on specific measurement systems
427 unique to disposition surveys. Appendix E lists and describes some of the potential sources of
428 action levels applicable to decisions regarding disposition of M&E.

429 **1.6 Similarities and Differences Between MARSSIM and MARSAME**

430 During the 1990's, there was a concerted effort to improve the planning, implementation,
431 evaluation, and documentation of building surface and surface soil final radiological surveys for
432 demonstrating compliance with standards. This effort included the preparation of NUREG-1505
433 (NRC 1998a) and NUREG-1507 (NRC 1998b) by the NRC and culminated in 1997 with the
434 issuance of MARSSIM (MARSSIM 2002). MARSSIM was a joint effort by DOD, DOE, EPA,
435 and NRC to develop a multi-agency approach for planning, performing, and assessing the ability
436 of surveys to meet dose- or risk-based standards while at the same time encouraging effective
437 use of resources. MARSSIM provided recommendations for developing appropriate final status
438 survey designs using the DQO Process to ensure survey results were of sufficient quality and
439 quantity to support a final decision. MARSSIM (MARSSIM 2002), NUREG-1505 (NRC
440 1998a), and NUREG-1507 (NRC 1998b) replaced the previous approach for such surveys
441 contained in NUREG/CR-5849 (NRC 1992).

442 This MARSAME supplement expands the scope of MARSSIM methods and processes to
443 provide technical information supporting the disposition decision for M&E, specifically the
444 design and implementation of disposition surveys, to ensure the disposition decision is
445 technically defensible and optimized for efficiency. MARSSIM addressed the disposition of real
446 property (e.g., buildings and land) where the only disposition options were unrestricted release,
447 restricted release, or maintaining radiological controls. MARSAME addresses the disposition of
448 non-real property (e.g., M&E) and includes additional options for future use including recycle or
449 disposal as radioactive waste (see Section 2.5). Increasing radiological controls and interdiction
450 are also included as potential disposition options. While several, or all, disposition alternatives
451 may be acceptable for a specific project, optimizing the disposition survey design based on the
452 selected disposition alternative is described in MARSAME.

453 MARSAME as a supplement to MARSSIM expands the scope of technically sound
454 measurement processes and methods to include M&E. Table 1.2 summarizes the major
455 similarities between MARSSIM and MARSAME, which result from application of a graded
456 approach to support a technically defensible decision regarding disposition. Table 1.3
457 summarizes the major differences between MARSSIM and MARSAME, which result from the
458 change from real to non-real property.

Table 1.2 Similarities Between MARSSIM and MARSAME

Parameter	MARSSIM	MARSAME
Graded Approach	Used to place greater survey effort on areas that have, or had, the highest potential for residual radioactivity.	Used to place greater survey effort on M&E that have, or had, the highest potential for residual radioactivity.
Data Quality Objectives (DQO) Process	Used to design technically defensible surveys to support decisions on disposition of real property.	Used to design technically defensible surveys to support decisions on disposition of non-real property (e.g., M&E).
Data Quality Assessment (DQA)	Used to evaluate survey results and support a decision of whether to release real property.	Used to evaluate survey results and support a disposition decision for non-real property.
Process Knowledge	Used during the Historical Site Assessment to support the determination of whether an area is impacted and provide information for designing subsequent surveys.	Used during the Initial Assessment to support the determination of whether M&E are impacted and provide information for designing subsequent surveys.
Classification	Determines the level of survey effort based on the potential amount of residual radioactivity present.	Determines the level of survey effort based on the potential amount of residual radioactivity present.
Flexibility	MARSSIM allows and encourages flexibility in the design and implementation of final status surveys for application to diverse site conditions.	MARSAME allows and encourages flexibility in the design and implementation of disposition surveys for application to diverse M&E.
Statistics	Used to develop a technically defensible survey design.	Used to develop a technically defensible survey design.
Scale of Decision Making	A separate release decision is made for every survey unit.	A separate release decision is made for every survey unit.
Inherent Radioactivity	Inherent radioactivity is site-specific and generally cannot be separated from ambient radiation.	Inherent radioactivity is specific to the M&E being investigated. Segregation of M&E based on inherent radioactivity can be used to reduce measurement variability.

Table 1.3 Differences Between MARSSIM and MARSAME

Parameter	MARSSIM	MARSAME
Scope	Surface soil and building surface surveys (i.e., real property).	Materials and equipment (i.e., non-real property).
Disposition Options	Restricted or unrestricted release, or fail to release.	Release survey (maintain, remove, or transfer of radiological controls; clearance for reuse, recycling, or disposal), or Interdiction survey (initiation of radiological controls or decision not to accept control of M&E).
Categorization	Included as part of classification in MARSSIM.	Separates the decision to survey from determining level of survey effort.
Application of the Graded Approach	Classification and survey unit size result in varying levels of survey effort.	Multiple disposition options result in varying levels of survey effort.
Sentinel Measurements	Not described in MARSSIM.	Allows use of sentinel measurements during IA to check validity of certain process knowledge assumptions.
Documentation of Survey Designs	Assumes project-specific survey designs will be developed for individual sites.	In addition to project-specific survey design, allows SOPs for categories of M&E to provide standard approach to disposition surveys.
Preliminary Surveys	Scoping and characterization surveys regularly used to obtain information needed to design a final status survey.	Scoping and characterization surveys rarely used to obtain information needed to design a disposition survey. Historical information obtained during the IA is generally sufficient to design a disposition survey. If not, preliminary surveys may be used to provide the necessary information.

461

Table 1.3 Differences Between MARSSIM and MARSAME (continued)

Parameter	MARSSIM	MARSAME
Ambient Radiation	Ambient radiation is site-specific and generally cannot be separated from inherent radioactivity.	Ambient radiation is selected based on location where disposition surveys are performed, and can be separated from inherent radioactivity.
Interdiction	Not addressed in MARSSIM.	Surveys may be performed to identify uncontrolled radioactive material resulting in the initiation of radiological controls, or deciding not to accept control of M&E .
Null Hypothesis	MARSSIM recommends using the null hypothesis: 'The activity in the survey unit exceeds the action level (Scenario A).' MARSSIM allows using the null hypothesis: 'The activity in the survey unit is indistinguishable from background (Scenario B) with information from NUREG-1505 (NRC 1998a).'	User selects the appropriate null hypothesis: 'The activity in the survey unit exceeds the action level (Scenario A).'
Scan Survey to Release	Not addressed in MARSSIM	M&E may be released based on the results of scan-only surveys provided the scan measurements meet the MQOs for the survey.

462

2 INITIAL ASSESSMENT OF MATERIALS AND EQUIPMENT

2.1 Introduction

The Initial Assessment (IA) is the first step in the investigation of materials and equipment (M&E), similar to the Historical Site Assessment (HSA) described in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM 2002). The purpose of the IA is to collect and evaluate information about the M&E in order to determine if it is impacted or non-impacted (i.e., categorization). During the IA process, additional information is collected to identify and support potential disposition of impacted M&E (e.g., clearance, increased radiological controls, remediation, or disposal). Project Managers are encouraged to use the IA to evaluate M&E for other hazards (e.g., lead, PCBs, asbestos) that could increase the complexity of the disposition survey design or pose potential risks to workers during subsequent survey activities (see Section 5.2), or to human health or the environment following subsequent disposition of the M&E.

There are five major activities associated with the performance of the IA:

- Categorize the M&E as impacted or non-impacted based on visual inspection, historical records, process knowledge, and results of sentinel measurements (Section 2.2).
- Design and implement preliminary surveys to adequately describe the M&E and address data gaps based on a preliminary description of the M&E (Section 2.3).
- Describe the physical and radiological attributes of the M&E (Section 2.4).
- Select appropriate disposition option(s) and define alternative actions applicable to impacted M&E (Section 2.5).
- Document the results of the IA through the use of a standard operating procedure (SOP) or development of a conceptual model (Section 2.6).

For M&E that have been categorized as impacted, an existing survey design in the form of an SOP may be available for investigating the radiological status of the M&E. If an applicable SOP is available, the instructions in the SOP should be followed for implementing and assessing the results of the survey. The information on performing preliminary surveys (Section 2.3) can be

29 used to determine whether an SOP is applicable to the M&E being investigated. The information
30 on describing the M&E (Section 2.4) can be used to determine if preliminary surveys are
31 necessary. The information on selecting a disposition option (Section 2.5) and documenting the
32 results of the IA (Section 2.6) can be used for project-specific applications, or for developing a
33 new SOP.

34 **2.2 Categorize the M&E as Impacted or Non-Impacted**

35 The first decision made when investigating M&E is whether they are impacted or non-impacted.
36 M&E with no reasonable potential for containing radioactivity in excess of natural background,
37 fallout levels, or inherent levels of radioactivity are non-impacted. Impacted M&E have a
38 reasonable potential to contain radionuclide concentration(s) or radioactivity above background.

39 The decision of whether M&E are impacted or non-impacted is primarily based on existing
40 information. Figure 2.1 describes the categorization process. If adequate information is readily
41 available to support a categorization decision, the decision maker should decide if the M&E are
42 impacted or non-impacted. A complex piece or group of M&E may be divided into portions that
43 are impacted and portions that are non-impacted. This is illustrated in the front loader example
44 described in Section 7.4, where the bucket and tires may be impacted while the engine and cab
45 interior are non-impacted. If additional information is required to support the categorization
46 decision, visual inspection (Section 2.2.1), collection and review of historical records (Section
47 2.2.2), and assessment of process knowledge (Section 2.2.3) are the most common sources of
48 additional existing information. Assumptions may be made regarding the use and interpretation
49 of existing information. Data collection activities may be performed during the IA to
50 specifically address questions about these assumptions. These data collection activities are
51 called sentinel measurements and are discussed in Section 2.2.4.

52 Additional investigation is required to make technically defensible disposition decisions
53 regarding impacted M&E. All impacted M&E must receive some level of additional
54 investigation, even if the expected disposition is disposal as radioactive waste. For example,
55 M&E shipped for disposal as radioactive waste must meet waste acceptance criteria at the
56 disposal facility as well as Department of Transportation (DOT) requirements for transporting

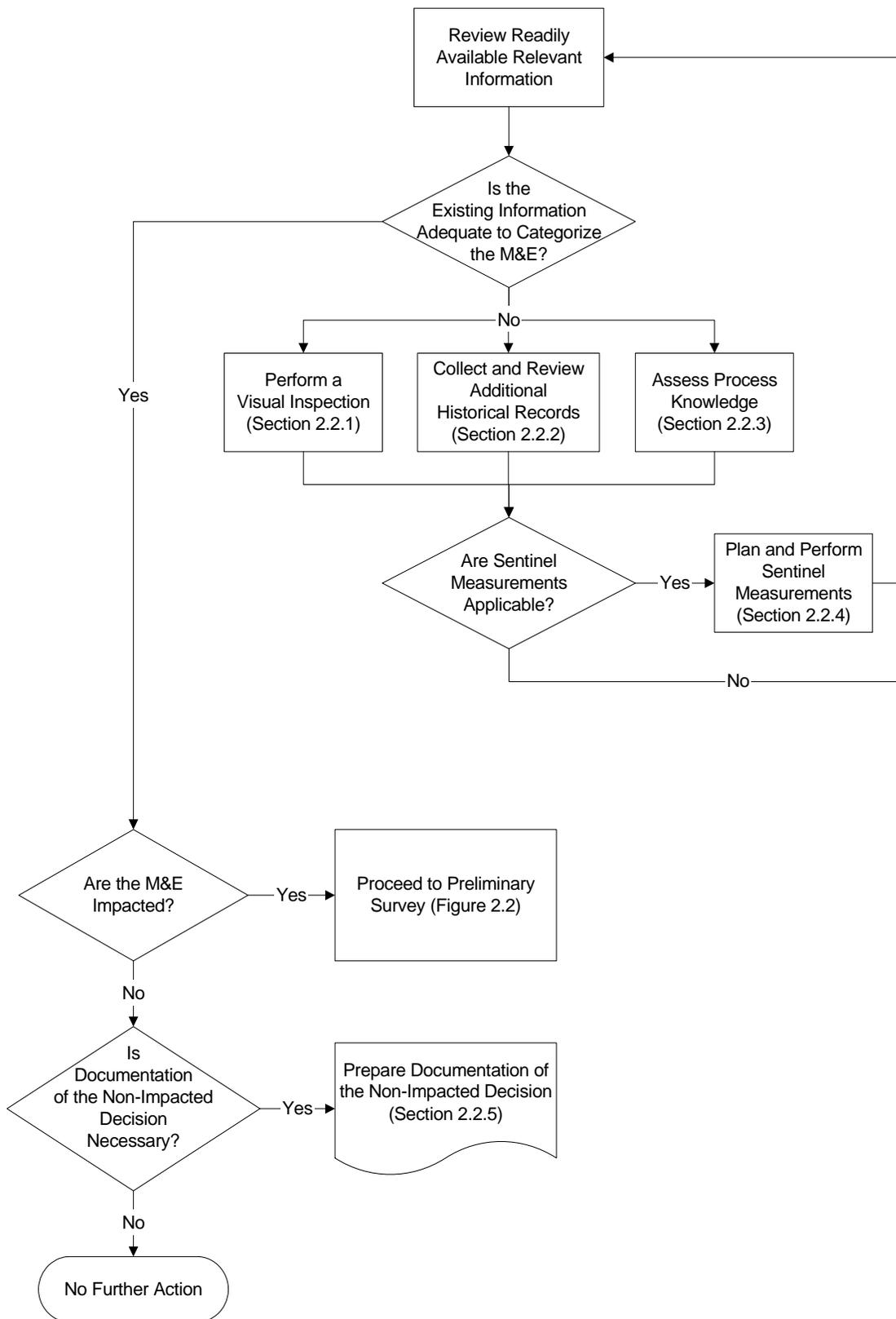


Figure 2.1 The Categorization Process as Part of Initial Assessment

58 radioactive material. The results of any additional investigation must clearly demonstrate
59 compliance with any applicable requirements, and be appropriately documented. Non-impacted
60 M&E do not receive any additional radiological investigation.

61 **2.2.1 Perform a Visual Inspection**

62 The purpose of the visual inspection is to identify and document the physical characteristics of
63 the M&E (e.g., size, kind of material, shape, and condition) when this description is not readily
64 available to support a categorization decision. The visual inspection may be performed during a
65 site visit, or by reviewing photographs or videos of the M&E. Photographs and video also
66 provide a means for documenting the results of the visual inspection. The visual inspection
67 corresponds to the Site Reconnaissance presented in Section 3.5 of MARSSIM. Information will
68 be used to support the following activities:

- 69 • Developing survey unit boundaries (Section 3.6).
- 70 • Defining the parameter of interest during the development of a decision rule for
71 impacted M&E (Section 3.4).
- 72 • Verifying the requirements of an SOP are met before performing a routine survey
73 (Section 4.5.1).
- 74 • Evaluating any health and safety concerns (Section 5.2).
- 75 • Developing handling protocols for implementation of the disposition survey (Section
76 5.3 and 5.4).

77 Prior to performing a visual inspection, the surveyor should review what is known about the
78 M&E. If little or no information is available describing potential hazards associated with the
79 M&E, care should be exercised in performing a visual inspection. Screening measurements for
80 radiation, chemical, and other hazards, along with the use of personal protective equipment (e.g.,
81 gloves, coveralls, respirators), may be necessary depending on available information. Situations
82 with known or expected risks (i.e., M&E that are radiologically or chemically impacted) may
83 require preparation of a study plan or SOP anticipating activities to be performed and identifying
84 specific information to be collected. Casual visual inspections of M&E with an unknown history
85 are not recommended. Detailed visual inspections (e.g., disassembly of potentially impacted

86 equipment to examine interior surfaces) should not be performed without proper precautions and
87 are more appropriately handled by performing preliminary surveys (Section 2.3).

88 While the primary objective for performing a visual inspection is to collect information used to
89 design a disposition survey, the information can be used for other purposes. Development of
90 handling protocols for implementation of the disposition survey (see Section 5.3) and evaluation
91 of health and safety concerns (see Section 5.2) are two examples where visual inspection
92 information would be used.

93 **2.2.2 Collect and Review Additional Historical Records**

94 Historical records may provide specific information on the identity, concentration, and
95 distribution of radioactivity when these types of records are not readily available to support a
96 categorization decision. Information on the physical characteristics of the M&E (e.g., size,
97 shape, condition) and the characteristics of the radioactivity (e.g., radionuclides of concern,
98 expected concentrations) will be used to select a disposition option in Section 2.5 and describe
99 initial survey unit boundaries in Section 3.6.1. The historical information is then used to define
100 the action level, parameter of interest, and alternative actions during the development of a
101 decision rule for impacted M&E (Section 3.7, EPA 2006a).

102 Types of historical records that provide useful information are described in MARSSIM Section
103 3.4.1, and may include:

- 104 • A facility or site radioactive materials license;
- 105 • Permits or other documents that authorize use of radioactive materials;
- 106 • Other permits and environmental program files;
- 107 • Operating records (e.g., previous surveys, waste disposal records, effluent releases);
- 108 • Corporate contract files (e.g., purchasing records, shipping records);
- 109 • A site or facility description (e.g., locations of M&E, site photographs).

110 Another source of historical information is interviews with current or previous employees.
111 Interviews may be conducted early in the data collecting process or close to the end of the IA.
112 Interviews conducted early in the IA cover general topics, and information gathered is used to
113 guide subsequent data collection activities. Interviews conducted late in the IA allow the

114 investigator to direct the investigation to specific areas that require additional information or
115 clarification.

116 Once the historical records have been collected, they should be reviewed to identify information
117 that supports the categorization decision. Historical information used to support the
118 categorization decision should be evaluated using the Data Quality Assessment (DQA) process
119 (EPA 2006b). In particular, historical information should be examined carefully because:

- 120 • Previous data collection efforts may not be compatible with IA objectives;
- 121 • Previous data collection efforts may not be extensive enough to fully describe the
122 M&E being investigated;
- 123 • Measurement techniques or protocols may not be known or compatible with IA
124 objectives;
- 125 • Conditions may have changed since the data were collected.

126 Additional information on evaluating data can be found in the following documents:

- 127 • The Environmental Survey Manual Appendix A - Criteria for Data Evaluation (DOE
128 1987);
- 129 • Upgrading Environmental Radiation Data, Health Physics Committee Report HPSR-1
130 (EPA 1980);
- 131 • Guidance for Data Usability in Risk Assessment, Part A (EPA 1992a);
- 132 • Guidance for Data Usability in Risk Assessment, Part B (EPA 1992b).

133 Historical records describing impacted M&E may include additional information that can be
134 used to support additional activities during the disposition process. For example, historical
135 records may provide descriptions of the M&E that are sufficient to design a disposition survey
136 (Chapter 4). On the other hand, the historical records can be used to identify data gaps that are
137 addressed by performing preliminary surveys (Section 2.3).

138 **2.2.3 Assess Process Knowledge**

139 The characteristics, history of prior use, and inherent radioactivity are critical for evaluating the
140 impacted status of M&E. This information is termed process knowledge. Process knowledge is
141 obtained through a review of the operations conducted in facilities or areas where M&E may

142 have been located and the processes where M&E were involved when this information is not
143 readily available to support a categorization decision. This information is used to evaluate
144 whether M&E—such as structural steel, ventilation ductwork, or process piping—had been in
145 direct contact with radioactive materials or had been activated, which would lead to a decision
146 the M&E are impacted. Descriptions of the physical attributes of the M&E (see Section 2.4.1)
147 and radiological attributes of the M&E (see Section 2.4.2) can be obtained from process
148 knowledge. In addition, process knowledge supports the selection of a disposition option (see
149 Section 2.5). The disposition option is then used to identify sources of action levels, a parameter
150 of interest, and alternative actions during the development of a decision rule for impacted M&E
151 (Section 3.7, EPA 2006a).

152 Process knowledge is obtained by researching the M&E and understanding the origin, use, and
153 potential disposition. The level of detail required from process knowledge is project specific.
154 The description of M&E could be simple, such as a set of hand tools being removed from a
155 controlled area where the radiological conditions are well known. At the other extreme is a
156 complex situation that requires knowledge of the manufacturing process, investigations of
157 multiple processes that could impact the radiological conditions associated with the M&E, and
158 understanding of recycle and reuse options that include movement of radionuclides through the
159 environment. Sections 2.4.1 and 2.4.2 describe types of information that may be obtained from
160 process knowledge and are necessary to support the development of a disposition survey.

161 In some cases, process knowledge of the equipment being investigated can be used to support
162 categorization decisions. Consider a pump used to circulate demineralized make-up water.
163 Maintenance records do not show the presence of radioactivity and operating records indicate no
164 events where the pump could have been used with radioactivity. Radiological samples of the
165 demineralized make-up water do not show the presence of radioactivity. Based on this process
166 knowledge, the interior of the pump is categorized as non-impacted.

167 Historical records (see Section 2.2.2) are one source of process knowledge. Historical records,
168 including interviews, provide site- and project-specific information on historical use and
169 radiological processes that may affect the M&E. Engineering and chemistry books and journals
170 provide information on the origins (e.g., manufacturing) and potential disposition of the M&E.
171 Industry documents and company records are also potential sources of process knowledge.

172 Other sources of information on M&E should be considered during the IA, indicating how,
173 where, and when the M&E were used in areas where they potentially could have been affected
174 by radionuclides or activation. These sources of information include:

- 175 • purchasing records showing when M&E were obtained
- 176 • maintenance records showing where and how they were used
- 177 • operating logs for systems which utilized or could have affected the M&E,
- 178 • disposal records showing survey results for similar types of M&E indicating types
179 and locations of radionuclides or radioactivity

180 In some instances, process knowledge may not be available for the M&E being considered for
181 release. For example, consider an outdoor material staging area for a nuclear facility where
182 various pieces of surplus equipment and metal have accumulated over the years. The origin of
183 these M&E is unknown. In this case, it is particularly important that preliminary surveys be
184 performed on the M&E to determine if excess radioactivity is present and to finalize the list of
185 radionuclides of concern.

186 Techniques used to protect equipment or prevent radioactivity from entering difficult-to-measure
187 areas or penetrating porous surfaces can be used to support categorization decisions. Consider
188 the following examples of protection and prevention techniques:

- 189 • Plan and coordinate all work to minimize exposure of equipment, tools, and vehicles
190 to radioactivity.
- 191 • Evaluate materials, tools, and equipment for ease of decontamination and disassembly
192 (that may be required for decontamination or release) prior to use.
- 193 • Use prefilters or have a separate source of outside air on the intake for internal
194 combustion equipment subject to airborne radionuclides or radioactivity.
- 195 • Use a filtered inlet for high volume air handling equipment such as blowers,
196 compressors, etc., to minimize the potential for internal contamination due to build up
197 of low-level radioactivity.
- 198 • Do not bring electrically driven mobile equipment into controlled areas.
- 199 • Use protective sheathing/covers, strippable coatings, or protective caps to minimize
200 the potential for surficial radionuclides or radioactivity.

- 201 • Cover and protect all openings on equipment, tools, or vehicles that may permit
202 radioactivity to enter difficult-to-access or difficult-to-clean areas.
- 203 • Select technologies that minimize radiological airborne emissions, secondary wastes,
204 and tool or equipment damage.

205 **2.2.4 Perform Sentinel Measurements**

206 Sentinel measurements are biased measurements performed at key locations to provide
207 information specific to the objectives of the IA. The objective of performing sentinel
208 measurements as part of the IA is to gather sufficient information to support a decision regarding
209 further action (e.g., categorization). Sentinel measurements may also be used to verify
210 assumptions based on existing information or obtain information on the current status of the
211 M&E. Sentinel measurements are not a risk assessment, scoping survey, or study of the full
212 extent of radionuclides or radioactivity associated with the M&E.

213 Sentinel measurements alone cannot be used to show that M&E are non-impacted. Positive
214 results are definitive for determining that M&E are impacted. However, negative results provide
215 only part of the evidence required for determining that the M&E are non-impacted. Since
216 radioactivity in difficult-to-measure areas cannot be measured directly without accessing the area
217 (e.g., disassembling equipment), sentinel measurements performed at access points to difficult-
218 to-measure areas could be used to indicate that it is unlikely that radioactivity entered that area.
219 Because sentinel measurements are usually associated with difficult-to-measure areas, they are
220 not generally applicable to dispersible bulk materials.

221 If protection and prevention techniques (described in Section 2.2.3) were applied to equipment
222 used around radioactive material, sentinel measurements can be used in connection with process
223 knowledge to support a decision of whether difficult-to-measure areas were impacted. For
224 example, if prefilters are used to capture particulate airborne radioactivity of a specific size
225 before the particulates enter difficult-to-measure areas, sentinel measurements can be made on
226 the prefilters.

227 It should be noted that access points are often modified to limit personnel radiation exposure to
228 difficult-to-measure areas after use (e.g., capped, sealed, cleaned). Care should be taken to avoid
229 performing sentinel measurements at modified access points to reduce the probability of making

230 an incorrect decision about the status of the M&E. QA and QC should be considered during
231 planning for collection of sentinel measurements. The measurement and subsequent evaluation
232 of the results should be consistent with the assumptions used to define sentinel measurements.

233 **2.2.5 Decide Whether M&E are Impacted**

234 Once there is adequate information to support a categorization decision, the decision maker
235 needs to decide whether the M&E are impacted or non-impacted. The categorization decision is
236 built on four sources of information: visual inspection, historical records review, process
237 knowledge, and the results of sentinel measurements.¹ If the results for any part of the
238 categorization process indicate a reasonable potential for radionuclide concentrations or
239 radioactivity above background, the decision is the M&E are impacted. For example, if the
240 visual inspection, historical records, and process knowledge all indicate the M&E are non-
241 impacted but the sentinel measurements indicate impacted, the M&E are impacted. Similarly, if
242 the visual inspection and sentinel measurements indicate the M&E are non-impacted but the
243 historical records and process knowledge indicate the M&E are impacted, the M&E are
244 impacted. An important point is that sentinel measurements alone cannot be used to support a
245 decision in declaring M&E as non-impacted.

246 In most cases, the categorization decision is obvious based on the available information. In cases
247 where the decision is not obvious, the consequences of making a decision error usually result in a
248 determination that the M&E are impacted. For example, the consequence of incorrectly
249 categorizing M&E as impacted when they are not impacted includes performing a radiological
250 survey. However, the consequence of incorrectly categorizing M&E as non-impacted when they
251 are impacted could result in inadvertent exposure for members of the public and lack of
252 confidence in other radiological decisions.²

¹ Sentinel measurements are not required to support a categorization decision. If sentinel measurements are performed they should be evaluated to determine the categorization of the M&E.

² The consequences of incorrectly categorizing M&E are also discussed in Section 4.3.4.

253 Collectively, this information should be used to develop survey strategies targeting different
254 types of materials in recognition that a single survey method or procedure may not necessarily fit
255 the technical requirements of all materials, given their diverse properties. For example, one
256 procedure may be used to address only the routine releases of tools and equipment. On the other
257 hand, a separate procedure may be developed to address infrequent releases of large amounts of
258 bulk materials, such as concrete rubble. The approach suggested here is one of
259 compartmentalizing the release activities into manageable and common functional elements with
260 each one being optimized in the context of facility operations as to its effectiveness, while
261 demonstrating compliance with applicable regulations. The development of standardized survey
262 procedures for infrequent releases necessitates that the MARSAME user utilize processes in the
263 remainder of this chapter and then move to Section 3.10 for evaluating and implementing
264 standard operating procedures (SOPs).

265 If there is insufficient information available to design a disposition survey following
266 categorization, preliminary surveys may be performed to obtain additional information
267 describing the physical and radiological characteristics of the M&E (this is described in Section
268 2.4). These preliminary surveys facilitate the development of an effective and efficient
269 disposition survey design.

270 The decision maker should consider whether documentation of the M&E categorization decision
271 is necessary or not for M&E that are categorized as non-impacted, since no additional
272 investigation is required. In most cases it is not necessary to document decisions that M&E are
273 impacted since this decision will be documented later in the disposition process (e.g.,
274 documentation of the IA results in Section 2.6, documentation of the survey design in Section
275 4.5, and documentation of the disposition survey results in Section 6.6).

276 **2.3 Design and Implement Preliminary Surveys**

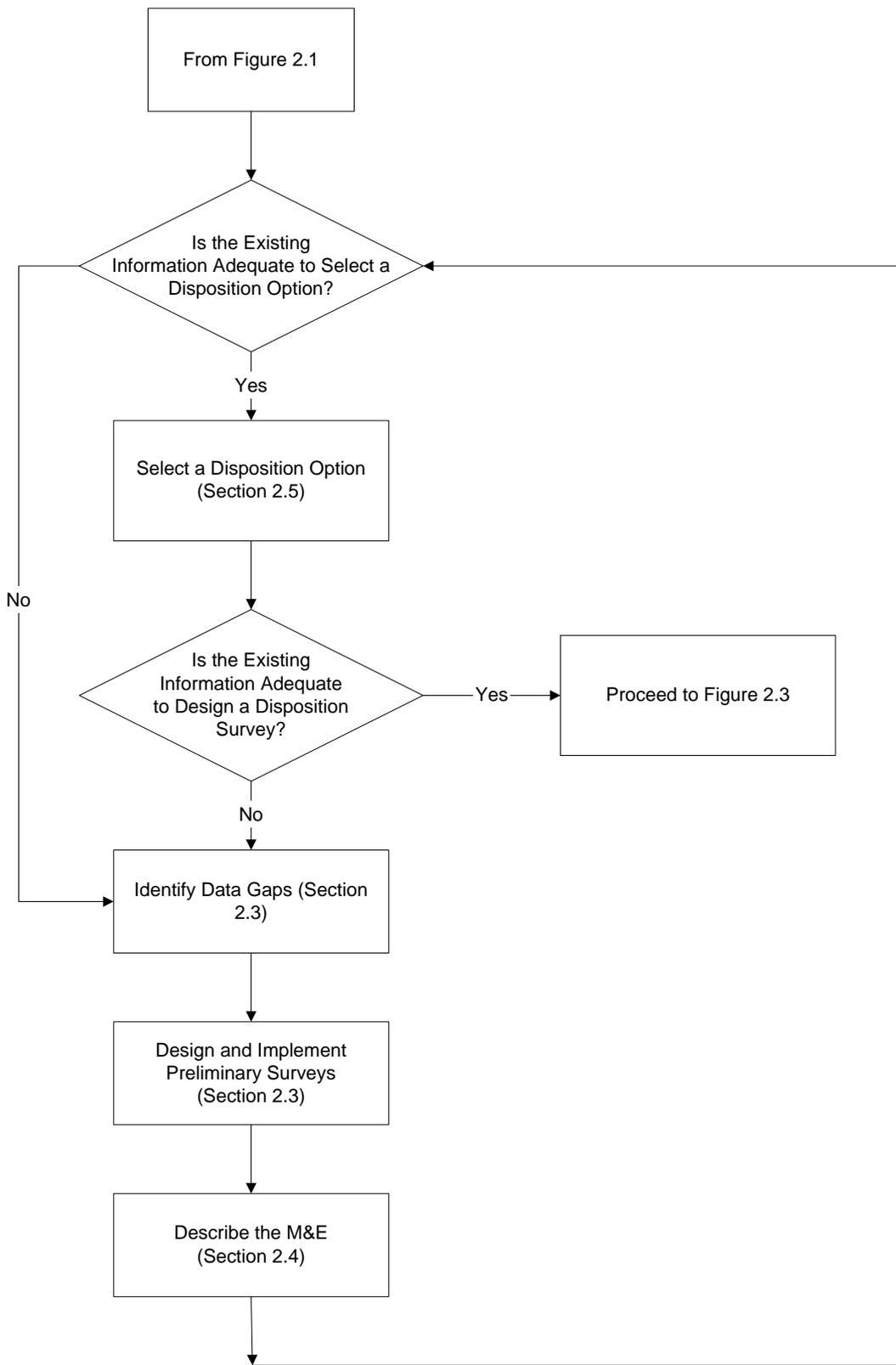
277 If there is insufficient information available to design a disposition survey following
278 categorization, it may be necessary to perform preliminary surveys to obtain the required
279 information. Preliminary surveys of M&E correspond to scoping and characterization surveys
280 described in MARSSIM Sections 5.2 and 5.3.

281 Following a decision that the M&E being investigated are impacted, the decision maker should
282 determine if an applicable standardized survey design is available, usually in the form of an SOP.
283 If an SOP is available and applicable to the M&E being investigated, the instructions in the SOP
284 should be implemented and the results of the survey evaluated as specified in the SOP (see
285 Figure 2.2 and Section 2.6.1).

286 It may be necessary to evaluate the quantity and quality of data describing the M&E to determine
287 if the existing data are adequate for implementing an existing SOP or developing a disposition
288 survey design. If the data are adequate, no additional data collection is required. On the other
289 hand, if there are data gaps that need to be addressed prior to completing a disposition survey
290 design, preliminary surveys can be used to obtain the necessary data.

291 The purpose of performing preliminary surveys is to obtain information describing the physical
292 and radiological characteristics of the M&E. The ultimate goal is to minimize heterogeneity in
293 the subset of M&E being surveyed. Minimizing heterogeneity helps to control the measurement
294 uncertainties (see Section 5.6), and may be helpful in selecting a disposition option (see Section
295 2.5). For example, if a subset of the M&E is identified as difficult-to-measure while the majority
296 of the M&E is relatively easy to measure and is considered for release, minimizing heterogeneity
297 of all the M&E by segregating the difficult-to-measure subset for potential disposal may simplify
298 measurements and be cost-effective. See Section 5.4 for information on segregation of M&E to
299 minimize heterogeneity during implementation of the disposition survey design.

300 In general, preliminary surveys are designed using professional judgment to address specific
301 questions concerning the existing data. Once a data gap has been identified, a survey is designed
302 and implemented to obtain the information required to fill that data gap. The results of the
303 survey are evaluated to ensure the data gap has been adequately addressed and the results are
304 documented. In some cases these surveys will be large and complicated, with written survey
305 designs reviewed by stakeholders prior to implementation. In other cases, these will be small ad
306 hoc surveys that quickly provide some small piece of information required to proceed with the
307 disposition survey design. By necessity, there is no single approach that will address all types of
308 preliminary surveys. However, the DQO Process can be applied to successfully design a
309 preliminary survey (EPA 2006a).



310

311 **Figure 2.2 Assessing Adequacy of Information for Designing Disposition Surveys**

312 The first step in designing a preliminary survey is to identify the data gaps to be addressed.
313 Section 2.4.1 and Section 2.4.2 discuss the minimum information required to describe the M&E
314 and design a disposition survey. Any of the required information that is not available or is not of
315 sufficient quality represents a data gap. In addition, there may be project-specific information
316 needed to complete the disposition survey design that could also represent potential data gaps. In
317 order to complete the list of potential data gaps, it is recommended that the planning team work
318 through the entire disposition survey planning process (see Chapters 3 and 4). Whenever a data
319 gap is identified, the planning team should make reasonably conservative assumptions or
320 proceed with multiple survey designs based on a reasonable range of values to fill the data gap.
321 Identifying a complete list of data gaps will help ensure the necessary additional information can
322 be collected effectively and efficiently, with minimal waste of limited resources. If a separate
323 preliminary survey is designed and implemented for every data gap as it is identified, there is an
324 increased possibility of duplication of effort and increased demands on limited resources. As
325 with all environmental data collection activities, QA and QC should be considered during
326 planning and evaluated during assessment of the results.

327 **2.4 Describe the M&E**

328 The M&E being investigated must be described with regards to its physical and radiological
329 attributes in order to establish the information necessary to design a survey approach that can
330 adequately survey the M&E. This description is intended to ensure that residual radioactivity
331 associated with the M&E will not be missed by the disposition survey, the M&E is left in a
332 usable condition, and that any data collected meet the objectives of the disposition survey.

333 **2.4.1 Describe the Physical Attributes of the M&E**

334 A description of the physical characteristics defining the investigated M&E is required to help
335 the user develop a disposition survey design. The preliminary physical description is usually
336 developed using some combination of the techniques presented in Section 2.2 (i.e., visual
337 inspection, historical records, and process knowledge). The physical description of the M&E is
338 used to help define survey unit boundaries (see Section 3.6.1) and develop a decision rule (see
339 Section 3.7), which has a direct impact on the disposition survey design.

340 Table 2.1 lists the four attributes that should be addressed when describing the physical
341 characteristics of the M&E being investigated (dimensions, complexity, accessibility, and
342 inherent value). Questions related to the evaluation of the attributes are provided, along with a
343 list of minimum information expected to be provided by the IA. The planning team should
344 consider designing and implementing preliminary surveys (see Section 2.3) to verify existing
345 information and investigate data gaps identified during the initial steps of the IA.

346 2.4.1.1 Describe the Physical Dimensions of the M&E

347 It is important to understand the dimensions of the M&E being investigated in order to define the
348 scale of decision making (see Section 3.6 on identifying survey unit boundaries), support
349 evaluation of measurement techniques (see Section 3.8 and Section 5.9), and identify any
350 handling issues that may need to be addressed (see Section 5.3). The dimensions are generally
351 defined as the size and shape of the M&E being investigated. The size is primarily related to the
352 scale of decision-making, and may be defined as the length, width, and depth of an item, or as
353 the quantity of M&E. Quantity may be expressed in terms of a number (e.g., 25 pumps) or a
354 volume (e.g., 200 cubic yards of concrete rubble), and may be related to the mass of the M&E.
355 An estimate of the total mass of the M&E should be provided. The shape of the M&E is
356 primarily related to the evaluation of measurement techniques. The description of shape should
357 consider surface conditions (e.g., clean or dirty, rough or smooth, curved or flat) that affect the
358 surface efficiency for radiation instruments. An estimate of the total surface area of the M&E
359 should be provided when the radionuclides of concern are, or could be, surficial.

360 2.4.1.2 Describe the Complexity of the M&E

361 The complexity of the M&E also affects the disposition survey design. Complexity refers to the
362 number and types of components that make up the M&E, as well as the ability to segregate or
363 combine the M&E into similar groups. M&E consisting of a single component is a simple case.
364 Consider the situation where several hundred feet of pipe are being investigated and the entire
365 pipe is made from steel.

Table 2.1 Physical Attributes Used to Describe M&E

Attribute	Minimum Information	Questions for Consideration
Dimensions	Size (Total Mass) Shape (Total Surface Area)	Are there issues with size and shape that affect how the M&E should be handled?
Complexity	M&E may require segregation to design a technically defensible disposition survey. M&E may be combined into similar groups and still allow a technically defensible disposition survey.	Are there situations where segregation (e.g., disassembly) could affect the usefulness of the M&E? Are there situations where segregation (e.g., disassembly) could result in the release of radioactivity or hazardous chemicals to non-impacted areas? Are there situations where engineering controls are required to prevent the release of radioactivity or hazardous chemicals to non-impacted areas? Are there component materials that are inherently radioactive or hazardous? Are there multiple component materials in the M&E?
Accessibility	Identification of impacted, difficult-to-measure areas for performing conventional handheld measurements. Known or potential relationships between radionuclide concentrations or radioactivity in accessible and difficult-to-measure areas.	Are there issues with size or shape that limit accessibility (e.g., bottom of a large, bulky object)? Are there porous surfaces that could allow permeation of radioactivity? Are there seams, ruptures, or corroded areas where radioactivity could penetrate to difficult-to-measure areas?
Inherent Value	The inherent value of the M&E being investigated.	Can the M&E be reused or recycled? Can the M&E be repaired or remediated? What are the replacement and disposal costs?

367 A complex situation occurs when the M&E consist of a variety of component materials.
368 Consider the same amount of pipe, but some pipe is steel, some is copper, and some is lined with
369 rubber, lead, or PVC. Some types of process equipment (e.g., pipe originating from mineral
370 processing industries) are internally lined with rubber, lead, or PVC. The presence of such liners
371 can complicate the initial categorization, as well as subsequent characterization and survey of
372 such equipment. The presence of lead can complicate the final disposition of process equipment
373 (e.g., recycling as ferrous steel or disposal in landfills).

374 Equipment once used in process plants or systems should be checked for the presence of
375 internally deposited sediment, sludge, oil, grease, water, and presence of process chemicals and
376 reagents. The presence of such residues may require the implementation of special worker
377 health and safety measures, procedures to collect and properly dispose of such hazardous
378 material, and may restrict possible disposition options.

379 Complexity also comes from the ability to break down or combine the M&E into similar groups.
380 A steel I-beam represents a simple case, where there is one material that can be cut into the
381 desired lengths. Dispersible bulk materials represent a situation that is slightly more complex,
382 especially when different types of materials have been combined. One example is a pile of scrap
383 metal, where the metal can be segregated by material (e.g., aluminum versus steel) or type (e.g.,
384 sheet metal versus pipe versus I-beams).

385 Equipment tends to be more complex, because it often contains a variety of components that can
386 generally be broken down by disassembling the equipment. Consider the case of a power tool
387 consisting of a casing, an electric motor, and controls. There are different types of metal, plastic,
388 and possibly glass or ceramics that make up the item, but disassembly into the individual
389 components may render the tool unusable and may expose component materials that are
390 inherently radioactive or hazardous. Disassembly of certain items could also result in the release
391 of radioactivity or hazardous chemicals to non-impacted areas, and may require engineering
392 controls to prevent such releases. The disposition survey design often increases in complexity as
393 the equipment increases in size and complexity. However, complex M&E may also allow the
394 user to segregate impacted from non-impacted items or components. This segregation may
395 reduce the amount of M&E requiring additional investigation. One example is a front loader
396 used to move piles of potentially radioactive material at a decommissioning or cleanup site. The

397 bucket and tires of the front loader may be identified as impacted while the engine and cab are
398 identified as non-impacted, depending on the controls in place while the equipment was being
399 used. However, there may be cases where an adequate survey design cannot be developed based
400 on decisions made earlier in the planning process. In these cases, it may be necessary to revisit
401 some of the decisions made earlier, for example, re-evaluating the cost to benefit analysis.

402 2.4.1.3 Describe the Accessibility of the M&E

403 Accessibility is the next attribute to consider when describing the M&E being investigated.
404 Accessibility has a direct impact on measurability, so it is a critical issue for making technically
405 defensible disposition decisions. Areas (including surfaces and individual items) are accessible
406 or difficult-to-measure. Accessible areas are areas where radioactivity can be measured, and the
407 results of the measurement meet the DQOs and measurement quality objectives (MQOs) defined
408 for the survey. During the IA it is necessary to distinguish areas that are accessible from areas
409 that may be difficult to measure.

410 The determination of whether an area is accessible, for purposes of the IA, should be based on
411 whether a measurement could be performed using a conventional hand-held radiation instrument
412 such as a sodium iodide (NaI(Tl)) detector, or Geiger-Mueller (GM) Pancake probe. If difficult-
413 to-measure areas are identified and these areas are categorized as impacted, the IA should
414 attempt to identify if there are any known or potential relationships between radionuclide
415 concentrations or radioactivity in accessible areas and radionuclide concentrations or
416 radioactivity in difficult-to-measure areas. This information will be evaluated in Section 3.3.3
417 for the potential to use surrogate measurements as a method of estimating radionuclide
418 concentrations or radioactivity in difficult-to-measure areas.

419 The potential for permeation and penetration of radioactivity should also be discussed as part of
420 accessibility. Permeation describes the spread of radioactivity throughout a material and is
421 usually associated with porous materials or surfaces (e.g., wood, concrete, unglazed ceramic).
422 Certain chemical and physical forms can increase the permeation rate (e.g., liquids permeate
423 faster than solids; small particles permeate faster than large particles). Penetration describes
424 infiltrating or forcing a way into difficult-to-measure areas, and is generally associated with

425 radioactivity entering through access points, seams, or ruptures. Corrosion of surfaces may also
426 result in penetration of radioactivity into difficult-to-measure areas.

427 2.4.1.4 Describe the Inherent Value of the M&E

428 A part of describing M&E that is often overlooked during the IA is determining the inherent
429 value of the materials or equipment being considered for release. Estimates of the value of
430 materials and equipment should include the replacement cost, condition (i.e., can the materials or
431 equipment be reused or recycled), and disposal cost. Replacement costs may consider increased
432 productivity due to upgrades to existing facilities and equipment, decontamination costs for
433 existing and new items, and the ultimate disposal of the replacements. Condition of the materials
434 and equipment may include maintenance and repair costs to start or keep the items operational,
435 as well as costs to decontaminate and release the items from radiological controls. Disposal
436 costs may include shipping and handling of potentially hazardous material. The limited capacity
437 of existing radiological waste disposal facilities may need to be considered along with the
438 monetary cost of disposal.

439 **2.4.2 Describe the Radiological Attributes of the M&E**

440 A description of the radioactivity potentially associated with M&E being investigated is required
441 to design a disposition survey. The review of historical documents (see Section 2.2.2) and
442 process knowledge (see Section 2.2.3) are the primary sources of information on radioactivity
443 associated with M&E. Sentinel measurements (see Section 2.2.4) may also provide information,
444 such as types of radiations and identity of radionuclides. The information describing the
445 radioactivity is used to support a decision of whether the M&E are impacted and supports the
446 development of a disposition survey for impacted M&E. The description of the radioactivity is
447 divided into four attributes: radionuclides, activity, distribution, and location.

448 Table 2.2 lists the four attributes to be addressed when describing radioactivity potentially
449 associated with the M&E being investigated. Questions related to the evaluation of the attributes
450 are provided, along with a list of minimum information expected to be provided by the IA. The
451 planning team should consider designing and implementing preliminary surveys (see Section
452 2.3) to obtain information that is not provided by the IA.

453

Table 2.2 Radiological Attributes Used to Describe M&E

Attribute	Minimum Information	Questions for Consideration
Radionuclides	List of radionuclides of potential concern, including major radiations and energies.	What were the potential sources and mechanisms for the radioactivity to come into contact with the M&E?
Activity	List of expected radionuclide concentrations or radioactivity (e.g., average, range, variance) associated with the M&E List of known and potential relationships between radionuclide activities (e.g., activation and corrosion products, fission products, natural decay series).	What is the basis for the expected radionuclide concentrations or radioactivity? What is the basis for the known and potential relationships (e.g., process knowledge of similar sources, measurements of equilibrium conditions)?
Distribution	List of areas where the radioactivity is uniformly distributed. List of areas where the distribution of radioactivity is spotty. List of areas where the distribution is unknown.	Can the M&E be divided into sections where the distribution of radioactivity is uniform? Are there areas where small areas of elevated activity are a concern?
Location	State whether the radioactivity is surficial, volumetric, or a combination of both. State whether surficial radioactivity is fixed or removable.	Is the volumetric activity uniformly distributed, is there a gradient, or is the activity random or spotty?

454 2.4.2.1 Identify the Radionuclides of Potential Concern

455 Identification of the radionuclides of potential concern is a critical step in making disposition
456 decisions. At a minimum, the planning team should review the information available from
457 Section 2.2 to identify the radionuclides of potential concern. The quality and completeness of
458 the existing information should be evaluated. Information on known or expected relationships
459 between radionuclides of potential concern should be identified and evaluated for applicability to
460 current conditions. If necessary, a study to identify a complete list of radionuclides of potential
461 concern and determine relationships between radionuclides may be initiated before designing the
462 disposition survey.

463 A list of radionuclides of potential concern should be developed based on existing data. The list
464 should consider all potential sources of radioactivity, but only include radionuclides that are
465 actually of concern for the M&E being investigated.

466 The list is designed to help focus the disposition decision. The list of radionuclides of potential
467 concern should include the major types of radiation (e.g., alpha, beta, photon) and their
468 corresponding energies. A discussion of the sources of radionuclides of potential concern, and
469 their chemical and physical form should also be included, if possible.

470 Include a description of how the M&E became impacted if it is known. For example, it is
471 important to document whether the potential radioactivity resulted from deposition of airborne
472 particulate material, or from placing the M&E in an area of neutron flux that resulted in
473 activation. All potential mechanisms for radioactivity to become associated with the M&E
474 should be described.

475 A list of radionuclides of potential concern should be developed based on existing data. The list
476 should consider all potential sources of radioactivity, but only include radionuclides that are
477 actually of concern (e.g., potential to exceed an action level) for the M&E being investigated.
478 The list is designed to help focus the disposition decision. The list of radionuclides of potential
479 concern should include the major types of radiation (e.g., alpha, beta, photon) and their
480 corresponding energies. A discussion of the sources of radionuclides of potential concern, and
481 their chemical and physical form should also be included, if possible.

482 Include a description of how the M&E became impacted if it is known. For example, it is
483 important to document whether the potential radioactivity resulted from deposition of airborne
484 particulate material, or from placing the M&E in an area of neutron flux that resulted in
485 activation. All potential pathways for radioactivity to become associated with the M&E should
486 be described.

487 The description of potential radioactivity from the IA may also identify known or suspected
488 relationships between radionuclides (e.g., equilibrium conditions for natural decay series, relative
489 activities of fission products or activation products based on process knowledge). Additional
490 investigations (e.g., preliminary surveys) may be performed to verify the presence of
491 radionuclides of potential concern and provide estimates of the activity relationships between

492 radionuclides. These investigations may include field measurements and sample collection with
493 laboratory analysis.

494 The identification of radionuclides of potential concern may impact other decisions made during
495 development of a disposition survey design. Since the sources of action levels are radionuclide
496 or radiation-specific, the identification of radionuclides of potential concern directly affects the
497 selection of an appropriate action level. The planning team should consider the impact of the list
498 of radionuclides of potential concern on other decisions (e.g., selection of measurement
499 techniques or instruments) as well as the impact of other decisions on the action levels when
500 considering potential sources of action levels. For example, the identification of available
501 measurement techniques (see Section 3.8) is also directly related to the radionuclides of potential
502 concern. The determination of surficial or volumetric radioactivity (see Section 2.4.2.4) may be
503 based on the energy and penetrating power of the radiation emissions, which would be indirectly
504 related to the radionuclides of potential concern. Caution must be used in evaluating
505 radionuclide concentrations or radioactivity for M&E with high levels of inherent background
506 radioactivity.

507 2.4.2.2 Describe the Radionuclide Concentrations or Radioactivity Associated with the M&E

508 A description of expected radionuclide concentrations or radioactivity is also important for
509 supporting disposition decisions for M&E. Radionuclide concentrations or radioactivity in
510 excess of background (see Section 3.9 and Appendix B) support a finding that the M&E are
511 impacted. Historical records (see Section 2.2.2) and process knowledge (see Section 2.2.3) are
512 sources of information on radionuclide activities associated with M&E. In addition, sentinel
513 measurements (see Section 2.2.4) can provide information on radionuclide concentrations or
514 radioactivity. A description of the expected radionuclide concentrations or radioactivity should
515 be developed for each of the radionuclides of potential concern. At a minimum, the average
516 expected activity should be provided. Some assumption regarding the expected activity will be
517 required in order to design a disposition survey using the guidance in Chapter 4. If no
518 assumption can be made, a preliminary survey should be performed. If possible, information on
519 the expected range and uncertainty (σ , as described in Sections 3.8.1 and 5.6) of the activity
520 should be provided. The description of the expected activity should include the units, an
521 estimate of uncertainty in the values, and a summary of how the data were obtained (e.g.,

522 purpose of data collection efforts, actual measurements, instrument used, count time, or process
523 knowledge). Any known or suspected relationships between concentrations for individual
524 radionuclides should be included in the description. For example, there is an expected
525 relationship between fission products from a nuclear reactor because of the common source of
526 the radionuclides (i.e., nuclear fission). Similarly, there is an expected relationship for activation
527 and corrosion products. Members of the natural decay series (i.e., thorium series, uranium series,
528 actinium series, see Appendix B) are also expected to have a relationship for activities based on
529 equilibrium conditions.

530 2.4.2.3 Describe the Distribution of Radioactivity

531 The distribution of radioactivity is primarily concerned with whether the activity is spotty or
532 more uniformly distributed throughout the item. A uniform distribution of activity has little
533 spatial variability, so the radionuclide concentrations or levels of radioactivity are fairly constant.
534 A spotty distribution of activity has high spatial variability, and small areas of elevated activity
535 are present as well as areas with little or no activity above background. The expected
536 distribution of radioactivity could include areas with uniform radionuclide concentrations or
537 levels of radioactivity and areas where the radionuclide concentrations or radioactivity is non-
538 uniform. For example, airborne deposition could have produced a uniform distribution of
539 radioactivity on horizontal exterior surfaces, while penetration through seams and access points
540 could result in spotty radioactivity on interior surfaces. In addition, the interior surfaces could
541 have a uniform distribution of radioactivity over localized areas (e.g., areas around a vent or
542 cooling fan). Concentrations of radionuclides on M&E can change over time due to in-growth,
543 decay, or diffusion.

544 2.4.2.4 Describe the Location of Radioactivity

545 The location of radioactivity is primarily concerned with whether the activity is located on the
546 surface or distributed throughout the volume of the M&E. Surficial radioactivity is restricted to
547 the surface of the M&E and is further described as removable, fixed, or some combination of
548 these two. Removable (or non-fixed) radioactive material is radioactive material that can be
549 readily removed from a surface by wiping with an absorbent material. Fixed radioactive material
550 is not readily removed from a surface by wiping. Surficial radioactivity is generally associated

551 with non-permeable solid M&E. Volumetric radioactivity is not restricted to the surface of the
552 M&E and is usually associated with permeable materials, surfaces, or activation by neutrons or
553 other particles.

554 The question of surficial vs. volumetric radioactivity is a complicated issue that may or may not
555 have a significant impact on the disposition survey design. The description of the location of
556 radioactivity used to design the survey may be independent of where the radioactivity is
557 physically located. For example, consider two different methods for surveying ⁶⁰Co activity
558 concentrations distributed on the surface of several thousand small bolts. First, the bolts may be
559 surveyed in a container using in situ gamma spectrometry assuming the radioactivity is
560 volumetrically distributed.³ If the same bolts are surveyed individually using a conveyORIZED
561 survey monitor the conceptual model may describe the ⁶⁰Co as surficial radioactivity.

562 In some cases, the location of the residual radioactivity may be well known. For example,
563 surface deposition of radioactivity on a non-porous material (e.g., smooth stainless steel) will not
564 penetrate into the material to a significant extent under most conditions, so the residual
565 radioactivity could be identified as surficial. Activated materials and bulk quantities of materials
566 usually have volumetric residual radioactivity, although surficial radioactivity may also be
567 present. On the other hand, the actual location of the residual radioactivity may be less well
568 known or unknown.

569 Process knowledge is the primary source of information on the location of residual radioactivity.
570 The planning team should review the information from Section 2.2.3 to determine the expected
571 location of residual radioactivity and the level of knowledge (i.e., well known, less well known,
572 unknown) associated with the information.

573 When the location of the residual radioactivity is well known, the planning team should proceed
574 with a survey design based on the appropriate assumption, surficial or volumetric. When the

³ This example does not imply that any measurement technique should be applied to every situation. The information in Section 3.8 should be used to develop the measurement quality objectives (MQOs) for a project. The MQOs can be used to evaluate measurement techniques against the action levels and select the techniques best suited for a specific application.

575 location is less well known or unknown, the planning team may choose to proceed with multiple
576 survey designs to determine the possible effect the location of the residual radioactivity may
577 have on the design of the disposition survey.

578 **2.4.3 Finalize the Description of the M&E**

579 A final description of the M&E should be prepared following implementation of any preliminary
580 surveys. The description of the M&E should consider the information in Table 2.1 and Table 2.2
581 and provide sufficient information to design the disposition survey.

582 **2.5 Select a Disposition Option**

583 The disposition of the materials and equipment will be a key factor in designing the disposition
584 survey. MARSAME broadly considers two types of disposition decisions: release and
585 interdiction. Release surveys are used to determine whether radiological controls can be
586 reduced, removed, maintained at the current level, or transferred to another qualified user.
587 Interdiction surveys are used to initiate radiological control, or to decide current radiological
588 controls are adequate.

589 Examples of potential disposition options for release of impacted M&E include:

- 590 1. Reuse in a controlled environment.
- 591 2. Reuse without radiological controls (i.e., clearance).
- 592 3. Recycle for use in a controlled environment (i.e., authorized disposition).
- 593 4. Recycle without radiological controls.
- 594 5. Disposal as industrial or municipal waste.
- 595 6. Disposal as low-level radioactive waste.
- 596 7. Disposal as high-level radioactive waste.
- 597 8. Disposal as transuranic (TRU) waste.
- 598 9. Maintain current radiological controls.

599 Examples of potential disposition options for interdiction of impacted M&E include:

- 600 1. Initiation of radiological controls for M&E identified by an interdiction survey.
- 601 2. Decision not to accept M&E following an interdiction survey.
- 602 3. Approval for continued radiologically unrestricted use of the M&E.

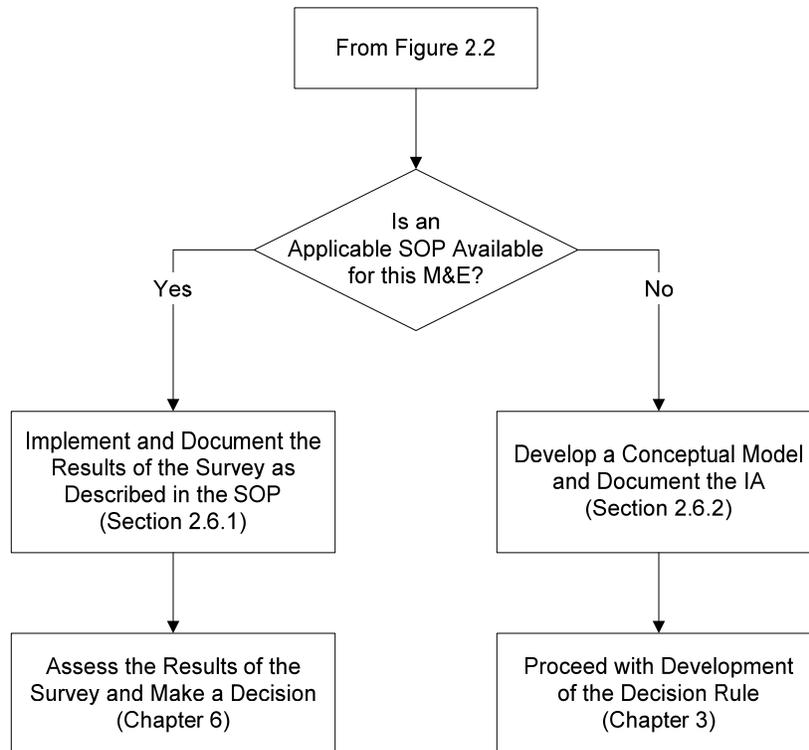
603 The selection of a disposition option should be based on the information available at the end of
604 the IA. The disposition option (e.g., reuse, recycle, disposal, initiation of control, or refusal)
605 defines the action level (see Section 3.3). The expected radionuclide concentrations or levels of
606 radioactivity associated with the M&E (see Section 2.4.2) are compared to the action level to
607 determine whether the M&E will be controlled or uncontrolled following the disposition survey.
608 The disposition option also defines the alternative actions for the decision rule to be developed in
609 Section 3.6. Different disposition options may be applied to separate parts of equipment. If so,
610 implementation of the different dispositions implies the necessity for total or partial disassembly.
611 For example, it may be possible to remove a bucket from a backhoe for disposal and allow reuse
612 of the rest of the equipment.

613 **2.6 Document the Results of the IA**

614 The results of the IA should be documented to the extent necessary to support the decisions
615 made. The level of documentation required will depend on the amount of information collected,
616 the quantity of M&E covered by the IA, the type of assessment (e.g., standardized or project-
617 specific), and, as applicable, administrative and regulatory requirements. Two options for
618 documenting the assessment results are the Standardized IA and the Conceptual Model as
619 described in the following sections. Figure 2.3 illustrates documentation of the IA.

620 **2.6.1 Standardized IA**

621 A standardized IA is a set of instructions or questions that are used to perform the IA. These
622 instructions are usually documented in an SOP. The SOP should be developed, reviewed, and
623 documented in accordance with an approved Quality System. Information on developing and
624 documenting a functional quality system can be found in EPA QA/G-1 (EPA 2002c). Guidance
625 on developing SOPs as part of a quality system can be found in EPA QA/G-6 (EPA 2001).



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Figure 2.3 Documentation of the Initial Assessment

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A standardized IA is generally associated with facilities or processes that regularly evaluate similar types of M&E. The release of small tools and personal items from an operating nuclear plant is one example of such a process. Another example, this time describing an interdiction process, would be evaluating truckloads of scrap metal entering a recycle facility. SOPs may be developed to describe repeated routine surveys of similar M&E for both situations.

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The documentation of the IA results is described in the SOP. The documentation should be sufficient to demonstrate that trained personnel using an approved SOP evaluated all potentially impacted M&E. For a standardized IA, all these records are maintained but may not be directly associated with the IA. Individual records for each item evaluated by an IA are not required.

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The SOP should clearly describe its scope and the applicable types of M&E. This information may be useful for determining whether the M&E are impacted as well as whether the SOP can be used to evaluate the M&E. For example, if the SOP is applicable to all M&E used for a certain process or within a certain part of a facility, this defines what M&E can be considered impacted by that process.

642 The SOP should also describe the M&E that were used to develop the instructions. The
643 description of the M&E being investigated (see Sections 2.2 and 2.3) should be compared to the
644 assumptions used to develop the instructions to determine if the SOP is appropriate. For
645 example, it may be appropriate to apply an SOP developed for scrap metal to evaluate hand
646 tools, since both are made from metal and may have similar surface radioactivity. Alternatively,
647 it may not be appropriate to use an SOP developed for scrap metal to evaluate dry active waste or
648 concrete rubble, since they may have volumetric activity and different surface efficiencies. At a
649 minimum, the rationale for applying the SOP to M&E other than specified in the SOP should be
650 documented.

651 The SOP should include the training requirements for personnel implementing the SOP.
652 Personnel performing the IA should be familiar with the SOP being implemented, as well as the
653 potential disposition options implied or explicitly stated in the SOP.

654 Additional documentation may be needed when the SOP is applied to situations other than those
655 considered during development of the SOP. The purpose of the additional documentation is to
656 determine whether the SOP may be applicable to a wider range of M&E. This documentation
657 will help provide technical support for modifying the SOP. If incorrect decisions are made
658 concerning the determination of whether M&E are impacted, or inappropriate recommendations
659 are made for disposition options, it may be necessary to modify the SOP to reduce the number of
660 decision errors. The additional documentation will help identify the source of the decision errors
661 and help provide technical support for modifying or revising the SOP.

662 **2.6.2 Conceptual Model**

663 If a standardized IA approach is not available for the M&E being investigated, the results of the
664 IA should be documented in a conceptual model. If the information in MARSAME is being
665 used to develop a standardized survey design (e.g., a new SOP), the information on developing a
666 conceptual model applies.

667 The conceptual model is applied in case-by-case situations and decisions. The conceptual model
668 describes the M&E and radioactivity expected to be present for the project. The definition of
669 impacted and non-impacted as it applies specifically to the project should be included in the

670 conceptual model. The conceptual model describes the processes involving radioactive
671 materials, as well as how the radioactivity could become associated with the M&E.

672 The description of the M&E documents the results of the IA investigation. At a minimum the
673 conceptual model should include a description of the physical attributes of the M&E (see Section
674 2.4.1 and Table 2.1), the radiological attributes of the M&E (see Section 2.4.2 and Table 2.2),
675 and a list of the applicable disposition options (see Section 2.5). In addition, the conceptual
676 model helps identify data gaps and develop potential collection strategies for filling data gaps.

677 The conceptual model will serve as the basis for the information and assumptions used to
678 develop the disposition survey design in Chapter 4. In many cases the information in the
679 conceptual model will be included in either the survey design documentation or in the
680 documentation of the results of the disposition survey. The structure and content of the
681 conceptual model should be based primarily on the future uses of the data.

682 The planning team should review the information on radionuclides of potential concern provided
683 by the IA for consistency with the conceptual model. If the data appear incomplete or the quality
684 of the data is not adequate for the disposition survey being designed, the planning team may
685 decide that additional information needs to be collected using preliminary surveys before
686 proceeding with the survey design.

1 **3 IDENTIFY INPUTS TO THE DECISION**

2 **3.1 Introduction**

3 The guidance in this chapter identifies sources of information needed to evaluate the disposition
4 option, or options, selected during the IA. During implementation of an existing SOP, this
5 information would have been considered during development of the SOP. This chapter discusses
6 factors affecting the selection of survey units, provides guidance on defining spatial and temporal
7 boundaries, and examines practical constraints on collecting data. The expected output from this
8 chapter is a decision rule, or multiple decision rules. A decision rule is a theoretical “if...then...”
9 statement that defines how the decision maker would choose among alternative actions if the true
10 state of nature could be known with certainty (EPA 2006a).

11 There are three parts to a decision rule (Section 3.7):

- 12 • An action level that causes a decision maker to choose between the alternative actions
13 (Section 3.3),
- 14 • A parameter of interest that is important for making decisions about the target
15 population (Section 3.4), and
- 16 • Alternative actions that could result from the decision (Section 3.5).

17 Other inputs to the decision discussed in this chapter include selecting radionuclides or radiations
18 of concern (Section 3.2), developing survey unit boundaries (Section 3.6), inputs for selecting
19 provisional measurement methods (Section 3.8), and identifying reference material (Section 3.9).
20 Also discussed in this chapter is the evaluation of an existing survey design to determine if it will
21 meet the DQOs (Section 3.10).

22 This chapter provides guidance on performing Step 3, Step 4, and Step 5 of the DQO Process
23 (EPA 2006a) for designing a disposition survey. These steps build on the IA where members of
24 the planning team were identified and M&E under investigation were identified as impacted
25 (non-impacted M&E do not require additional investigation). A conceptual model of the
26 disposition problem was developed (or SOP selected or developed, see Section 2.6) and a
27 disposition option selected (Section 2.5).

28 It is important to remember the DQO Process is an iterative process. This means new
29 information can be incorporated into the planning process and outputs from previous steps can be
30 modified to incorporate the new information. For example, if no measurement methods are
31 identified in Section 3.8 that meet the data requirements for a specific disposition option, the
32 planning team may return to Section 2.5 to select a different disposition option. Alternatively,
33 the selection of an action level or survey unit boundary may be affected by the available
34 measurement techniques. The issues associated with surficial vs. volumetric radioactivity (see
35 Section 2.4.2) affect the kinds of information (i.e., action level, survey unit identification, and
36 measurement techniques) as well as the definition of study boundaries (i.e., target population,
37 spatial boundaries, practical constraints on collecting data, subpopulation for which separate
38 decisions will be made).

39 At the end of this chapter the planning team should have the information required to design the
40 disposition survey and know whether appropriate measurement techniques are available. Spatial
41 and temporal boundaries will be identified, along with any practical constraints on data
42 collection activities. Examples of practical constraints on data collection include time, budget,
43 personnel, or equipment. For example, a box counter is selected to perform measurements for
44 clearance of items from a radiologically controlled area. Assume a five-minute count time is
45 required to achieve the survey objectives, and another minute is required to swap items in the
46 detector. This means that ten measurements can be performed each hour. More than 240 items
47 requiring clearance each day would be a practical constraint on data collection, since a single box
48 counter cannot clear all of the M&E. The decision rule(s) developed at the end of this chapter
49 will be used to develop survey designs in Chapter 4.

50 **3.2 Select Radionuclides or Radiations of Concern**

51 A list of radionuclides of potential concern was developed in Section 2.4.2.1 as part of the
52 description of radiological attributes associated with the M&E. Before a decision rule can be
53 developed or a disposition survey designed, a final list of radionuclides or radiations to be
54 measured must be prepared.

55 The selection of radionuclides or radiations of concern is linked to several inputs to the decision.
56 For example, the identification of an action level (see Section 3.3) may determine if the survey

57 results need to be radionuclide-specific, forcing the planning team to identify individual
58 radionuclides of concern. On the other hand, the selection of a non-radionuclide specific
59 measurement method may allow the selection of a radiation of concern (i.e., alpha (α), beta (β),
60 gamma (γ), x-ray, or neutron radiation) without ever finalizing a list of radionuclides of concern.
61 Finalizing the list of radionuclides or radiations of concern is an example of the iterative nature
62 of the survey design process. The planning team is expected to evaluate different survey
63 techniques and measurement methods. Evaluating these different survey techniques and
64 measurement methods will require the planning team to return to the list of radionuclides of
65 potential concern and go through the selection of radionuclides or radiations of concern. The
66 final selection of radionuclides or radiations of concern may not occur until development of a
67 plan for obtaining data in Step 7 of the DQO Process (see Section 4.4.4).

68 **3.3 Identify Action Levels**

69 The action level is the numerical value or values that cause a decision maker to choose one of the
70 alternative actions. The radionuclides of concern and disposition options selected at the
71 completion of the IA define the alternative actions for the disposition survey.

72 Figure 3.1 shows the process for selecting action levels. As shown in this figure, the iterative
73 nature of the DQO Process may result in changes to the action levels or disposition options based
74 on other factors (e.g., availability of appropriate measurement techniques, measurability,
75 surficial vs. volumetric activity). The planning team should consider the effect of action levels
76 on other steps in the survey design process, as well as any effects these other steps might have on
77 the action levels.

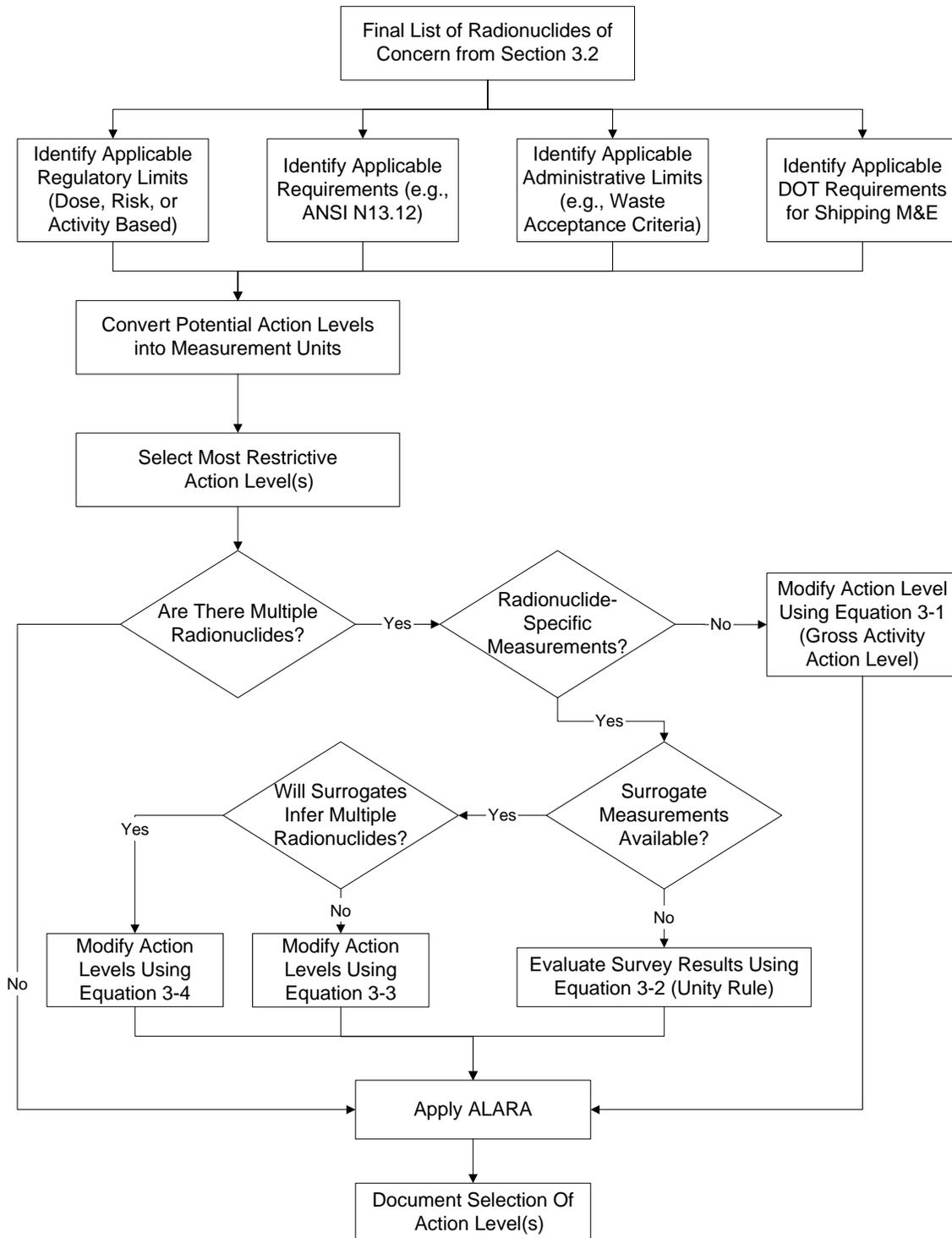
78 Action levels are radionuclide- or radiation-specific and in units of concentration or activity (e.g.,
79 Bq/kg of ^{137}Cs , Bq/m² of alpha radiation, Bq of ^{60}Co). Action levels may be provided, derived
80 from dose- or risk-based standards, or converted into more convenient units for a specific

81 measurement technique.¹ More than one action level may be required to demonstrate
82 compliance with a specific standard. For example, DOE Order 5400.5 Figure IV-1 (DOE 1993)
83 provides limits for average total surface activity, maximum total surface activity, and average
84 removable surface activity (see Appendix E). All three limits must be achieved to demonstrate
85 compliance for disposition of the M&E. Sometimes multiple regulatory requirements may
86 apply, for example transportation regulations combined with waste acceptance criteria and health
87 protection standards.

88 Action levels may be established based on total activity or incremental activity levels relative to
89 background. Examples of incremental action levels include activity levels based on dose or risk
90 above background, or interdiction at some multiple above background. For these types of action
91 levels it is important to establish a representative reference material (see Section 3.9) for
92 comparison.

93 At this point it is important to identify action levels appropriate for the disposition survey. If
94 multiple action levels are identified, the planning team may decide to continue with the
95 development of multiple survey designs that will be evaluated in Section 4.4.4. The decision
96 maker and the planning team will need to evaluate the action levels and select the action level
97 that best meets the DQOs developed for the survey. The selected action levels are used to
98 develop decision rules in Section 3.7. Alternatively, the planning team may decide to revisit the
99 selection of disposition options from the IA to further limit the scope of the disposition survey
100 and eliminate some of the action levels. In either case, the selection of action levels will be
101 finalized in Section 4.4 with the development of a disposition survey design. Information
102 supporting the selection of an action level(s) is discussed in Sections 3.3.1 through 3.3.4.

¹ Converting action levels to counts or counts per minute (cpm) may provide a useful comparison for real-time evaluation of field measurement results as long as field results (e.g., cpm) are converted to and recorded in the same radiological units as the action levels.



103

104 **Figure 3.1 Identifying Action Levels (Apply to each Disposition Option Selected in**
 105 **Section 2.5)**

106 3.3.1 Identify Sources of Action Levels

107 There are many potential sources of action levels available for use in developing disposition
108 surveys. An action level may be based on:

- 109 • Dose- or risk-based regulatory standard (i.e., disposition criterion),
- 110 • Waste acceptance criteria at a disposal site,
- 111 • Regulatory threshold standard (e.g., indistinguishable from background or no
112 detectable radioactivity),
- 113 • DOT regulations for shipping radioactive M&E,
- 114 • Activity-based standard,
- 115 • As low as reasonably achievable (ALARA) considerations,
- 116 • Administrative limits, or
- 117 • Limitations on technology (performance criteria for an analytical method).

118 Appendix E provides information on some of the sources of action levels that can be applied to
119 M&E. The list of sources for action levels is not exhaustive, but is intended to provide examples
120 of different types of action levels that are referred to throughout this supplement.

121 As previously stated, in many cases the action levels will be dictated by the disposition option
122 selected during the IA. For example, the action levels for M&E being considered for clearance
123 may be a regulatory standard, whereas the action levels for M&E being considered for disposal
124 as radioactive waste will often use the waste acceptance criteria for a disposal site.

125 Multiple sources of action levels may be identified for a single disposition option. Waste
126 acceptance criteria can be evaluated from several potential burial sites.

127 In addition, a single source of action levels could be acceptable for more than one disposition
128 option. Dose- and risk-based regulatory standards can be applied to both release and recycle
129 scenarios, as well as for surficial or volumetric radioactivity. On the other hand, activity-based
130 standards may have limited applicability, such as DOE Order 5400.5 (DOE 1993) that only
131 applies to release of M&E with surficial radioactivity.

132 The identification of sources for action levels may affect other decisions made during
133 development of a disposition survey design. Identification of survey units and spatial boundaries

134 for a survey are often directly linked to the action levels. In addition, the expected levels of
135 residual radioactivity identified during the IA (see Section 2.6) will often suggest which
136 disposition options are feasible.

137 At a minimum the planning team should identify at least one source of action levels applicable to
138 the disposition option(s) selected during the IA. Any information related to the action levels that
139 may affect other decisions should also be listed. A partial list of information that may be
140 available from sources of action levels includes:

- 141 • Radionuclides of concern or types of radiation
- 142 • Assumptions regarding surficial or volumetric residual radioactivity
- 143 • Area or volume over which the residual radioactivity can be averaged
- 144 • Assumptions about potential disposition of the M&E (e.g., exposure scenarios, reuse
145 vs. recycle)
- 146 • Conversions from dose or risk to activity or concentration (e.g., modeling and
147 modeling assumptions)

148 **3.3.2 Select the Most Restrictive Action Levels**

149 In cases where more than one source of action levels is identified, it is necessary to select an
150 action level to be the basis for the disposition survey design. Generally, the source that provides
151 the most restrictive action levels (i.e., the most protective of human health and the environment)
152 will be appropriate for designing the disposition survey. If the planning team cannot determine
153 which action levels are most restrictive, multiple survey design should be developed and the
154 selection of action levels will be determined by the selection of the most effective survey design
155 (Section 4.4).

156 The expected location of residual radioactivity is an important factor in the selection of
157 appropriate action levels. Some sources of action levels are only applicable for surficial
158 radioactivity (e.g., DOE 1993, DOT regulation 49 CFR 173.433). Other sources of action levels
159 (e.g., ANSI 1999) or dose assessments for deriving action levels (e.g., NRC 2003a) make
160 assumptions about whether the residual radioactivity is surficial or volumetric, or a combination
161 of both. Section 2.4.2.4 discusses the location of radioactivity associated with the M&E.

162 While the location of residual radioactivity is important in determining the most restrictive action
163 levels, other physical and radiological characteristics should also be considered. The final
164 selection of action levels should be supported by the description of the M&E provided by the IA
165 (Section 2.6).

166 **3.3.3 Modify Action Levels When Multiple Radionuclides are Present**

167 The implementation of action levels should be considered when evaluating whether they will be
168 applied to a specific survey unit or project. Section 3.3.1 discusses potential sources for action
169 levels, and Section 3.2 discusses the approach for selecting the radionuclides of concern.
170 Calculating the relative ratios among multiple radionuclides and determining the state of
171 equilibrium for decay series radionuclides is discussed in MARSSIM Section 4.3. This section
172 describes how individual action levels can be combined and applied when more than one
173 radionuclide is present.

174 Action levels are often provided for types of radioactivity or groups of radionuclides. For
175 example, DOE Order 5400.5 Figure IV-1 (DOE 1993) provides surface activity action levels for
176 four groups of radionuclides (see Appendix E). For the simple case in which the activity is
177 entirely attributable to one radionuclide, the action levels for that radionuclide are used for
178 comparison to survey data. In these examples, the disposition survey data may be obtained from
179 direct measurements of activity, scanning with data logging, conveyorized survey monitor
180 surveys, or other appropriate methods.

181 Dose or risk-based action levels may be radionuclide-specific. Each radionuclide-specific action
182 level corresponds to the chosen disposition criterion (e.g., regulatory limit in terms of dose or
183 risk). For example, ANSI 1999 provides surface and volumetric activity action levels for
184 individual radionuclides. When multiple radionuclides are present at concentrations equal to the
185 action levels, the total dose or risk for all radionuclides would exceed the disposition criterion.
186 In these cases it is possible to modify the action levels based on relationships between the
187 radionuclides of concern and still demonstrate compliance with the disposition criterion.

188 The method used to modify the action levels depends on the radionuclides of concern and the
189 selected measurement method. If the measurement method reports total activity for a type of
190 radiation (e.g., gross α , β , or γ assays) the method is non-radionuclide specific and the guidance

191 in Section 3.3.3.1 should be applied. If the measurement reports activity for individual
 192 radionuclides (e.g., gamma spectrometry, alpha spectrometry) the method is radionuclide
 193 specific and the guidance in Section 3.3.3.3 should be applied.

194 3.3.3.1 Modify Action Levels for Non-Radionuclide Specific Measurement Methods

195 For situations in which there are radionuclide-specific action levels and multiple radionuclides
 196 are present, a gross activity action level can be developed. Gross activity action levels are also
 197 discussed in Section 4.3.4 of MARSSIM. This approach enables field measurement of gross
 198 activity (using static direct measurements or scans), rather than determination of individual
 199 radionuclide activity, for comparison to the action levels. The gross activity action level for
 200 M&E with multiple radionuclides is calculated as follows:

- 201 1. Determine the relative fraction (f) of the total activity contributed by the
 202 radionuclide.²
- 203 2. Obtain the action level for each radionuclide present.
- 204 3. Substitute the values of f and action levels in the following equation.

$$205 \quad \text{Gross Activity AL} = \frac{1}{\left(\frac{f_1}{\text{AL}_1} + \frac{f_2}{\text{AL}_2} + \dots + \frac{f_n}{\text{AL}_n} \right)} \quad (3-1)$$

206 Where:

- 207 f_i = relative fraction of total activity contributed by radionuclide i ($i = 1, 2, \dots, n$)
 208 AL_i = action level for radionuclide i

209 For example, assume that 40 percent of the total radioactivity was contributed by a radionuclide
 210 with an action level of 1.4 Bq/cm² (8,400 dpm/100 cm²). An additional 40 percent of the total
 211 radioactivity was contributed by a radionuclide with an action level of 0.28 Bq/cm² (1,700

² The determination of relative fractions may be based on process knowledge, empirical data, or a combination of both. It may be difficult or impractical to determine the relative fractions contributed by all radionuclides of concern. The alternatives are to analyze each radionuclide independently, or use conservative assumptions to determine the relative fractions. Additional guidance is provided in MARSSIM Section 4.3.

212 dpm/100 cm²), and the final 20 percent of the radioactivity was contributed by a radionuclide
 213 with an action level of 0.14 Bq/cm² (840 dpm/100 cm²). Using Equation 3-1:

$$214 \quad \text{Gross Activity AL} = \frac{1}{\left(\frac{0.40}{1.4} + \frac{0.40}{0.28} + \frac{0.20}{0.14} \right)} = 0.32 \text{ Bq/cm}^2 \text{ (1,900 dpm/100 cm}^2\text{)}$$

215 Equation 3-1 may not be appropriate for survey units with radioactivity from multiple
 216 radionuclides having unknown or highly variable concentrations of radionuclides. In these
 217 situations, the best approach may be to select the most restrictive surface activity action level
 218 from the mixture of radionuclides present.³ If the mixture contains radionuclides that cannot be
 219 measured using field survey equipment, such as ³H or ⁵⁵Fe, laboratory analyses of M&E samples
 220 may be necessary.

221 3.3.3.2 Modify Action Levels for Non-Radionuclide Specific Measurements of Decay-Series 222 Radionuclides

223 Demonstrating compliance with surface activity action levels for radionuclides of a decay series
 224 (e.g., radium, thorium, and uranium) that emit both alpha and beta radiation may be
 225 demonstrated by assessing alpha, beta, or both radiations. However, relying on the use of alpha
 226 surface activity measurements often proves problematic because of the highly variable level of
 227 alpha attenuation by rough, porous, uneven, and dusty surfaces. Beta measurements typically
 228 provide a more accurate assessment of thorium and uranium (and their progeny) on most
 229 building surfaces because surface conditions cause significantly less attenuation of beta particles
 230 than alpha particles. Beta measurements, therefore, may provide a more accurate determination
 231 of surface activity than alpha measurements.

232 The relationship of beta and alpha emissions from decay chains or various enrichments of
 233 uranium should be considered when determining the surface activity for comparison with the
 234 action level values. When the initial member of a decay series has a long half-life, the
 235 radioactivity associated with the subsequent members of the series will increase at a rate

³ For the example provided, the most conservative action level is 0.14 Bq/cm².

236 determined by the individual half-lives until all members of the decay chain are present at
237 activity levels equal to the activity of the parent. This condition is known as secular equilibrium.
238 Pages 4-6 and 4-7 in MARSSIM also provide a discussion on secular equilibrium.

239 The difficulty with radionuclides that are part of a natural decay series is that time must pass for
240 a sufficient number of half-lives of the longest-lived progeny that intervenes between a
241 radionuclide and its parent in order to establish secular equilibrium. In the case of ^{232}Th , the
242 time to establish secular equilibrium is almost 40 years. This is because ^{232}Th decays into ^{228}Ra ,
243 which has a half-life of 5.75 years. In the case of ^{238}U , the time to establish secular equilibrium
244 is approximately 2 million years. This is because ^{238}U has a half-life of approximately 250,000
245 years. ^{226}Ra , another member of the ^{238}U decay series, presents special problems. ^{226}Ra decays
246 into ^{222}Rn , which is a noble gas that can escape the matrix and disrupt equilibrium. It is
247 important to remember the reason for determining relationships between radionuclides. If the
248 relationships are known or can be estimated,⁴ the costs and amount of time required for
249 performing measurements can be significantly reduced. The alternative to determining the
250 relationships between radionuclides is performing radionuclide-specific measurements for each
251 radionuclide of concern.

252 Consider an example in which the radionuclide of concern is ^{232}Th , and all of the progeny are in
253 secular equilibrium. Assume that a gas proportional detector will be used for surface activity
254 measurements. The detector's efficiency is dependent upon the radionuclide mixture measured
255 and the calibration source area. Guidance from the International Organization for
256 Standardization (ISO 1988) states:

257 "The dimensions of the calibration source should be sufficient to cover the window of the
258 instrument detector. Where, in extreme cases, sources of such dimensions are not
259 available, sequential measurements with smaller distributed sources of at least 100 cm²
260 active area shall be carried out. These measurements shall cover the whole window area
261 or at least representative fractions of it and shall result in an average value for the
262 instrument efficiency."

⁴ There are risks and tradeoffs associated with using estimated values. The planning team should compare the consequences of potential decision errors with the resources required to improve the quality of existing data to determine the appropriate approach for a specific project.

263 The concentration of ^{232}Th is inferred from a measurement that includes the parent and all of its
 264 progeny. The efficiency of such measurements, relative to each decay of ^{232}Th , can be greater
 265 than 100 percent. The efficiency, relative to each decay of ^{232}Th , is calculated by weighting the
 266 individual efficiencies from each of the radionuclides present (see Table 3.1).

267 **Table 3.1 Example Detector Efficiency Calculation (^{232}Th in complete equilibrium with its**
 268 **progeny) Using a Gas Proportional Detector**

Radionuclide	Energy* (keV)	Fraction	Instrument Efficiency	Surface Efficiency	Weighted Efficiency
^{232}Th	4.00 MeV alpha	1	0.40	0.25	0.1
^{228}Ra	7.2 keV beta	1	0	0	0
^{228}Ac	377 keV beta	1	0.54	0.50	0.27
^{228}Th	5.40 MeV alpha	1	0.40	0.25	0.1
^{224}Ra	5.67 MeV alpha	1	0.40	0.25	0.1
^{220}Rn	6.29 MeV alpha	1	0.40	0.25	0.1
^{216}Po	6.78 MeV alpha	1	0.40	0.25	0.1
^{212}Pb	102 keV beta	1	0.40	0.25	0.1
^{212}Bi	769 keV beta	0.64	0.66	0.50	0.211
^{212}Bi	6.05 MeV alpha	0.36	0.40	0.25	0.036
^{212}Po	8.78 MeV alpha	0.64	0.40	0.25	0.064
^{208}Tl	557 keV beta	0.36	0.58	0.50	0.104

Total efficiency = 1.29

269 * Alpha energies are weighted averages based on relative abundance of major particle emissions totaling at least
 270 90% of the total emissions. Beta energies are average energies. Source: Japanese Atomic Energy Research Institute
 271 data from NRC Radiological Toolbox Version 1.0.0 (NRC 2003b).

272 It is important to recognize that if the action level for ^{232}Th includes the entire ^{232}Th decay series,
 273 the total efficiency for ^{232}Th must account for all of the radiations in the decay series. The total
 274 weighted efficiency calculated in Table 3.1 may be used to modify action levels for non-
 275 radionuclide specific measurements using a gas proportional counter to measure thorium series
 276 radionuclides. The total weighted efficiency can be substituted into an equation (e.g.,
 277 MARSSIM equations 6-1, 6-2, 6-3, or 6-4) to convert the action level (e.g., activity units) into

278 measurement units (e.g., counts or cpm). The modified action level can then be compared
 279 directly to the measurement results for a real time assessment of the data.

280 3.3.3.3 Modify Action Levels for Radionuclide Specific Measurement Methods

281 In many cases action levels correspond to a disposition criterion (e.g., a regulatory limit) in terms
 282 of dose or risk. When multiple radionuclides are present at concentrations equal to the action
 283 levels, the total dose or risk for all radionuclides would exceed a risk or dose-based disposition
 284 criterion. In this case, the individual action levels would need to be adjusted to account for the
 285 presence of multiple radionuclides contributing to the total dose or risk. The surrogate
 286 measurements discussed in this section describe adjusting action levels to account for multiple
 287 radionuclides when radionuclide-specific analyses of media samples or radionuclide-specific in
 288 situ measurements (e.g., in toto measurements, in situ gamma spectroscopy) are performed. The
 289 use of surrogate measurements is also described in Section 4.3.2 of MARSSIM. Other methods
 290 used to account for the presence of multiple radionuclides include the use of the unity rule
 291 (MARSSIM Section 4.3.3) and development of a gross activity action level to adjust the
 292 individual radionuclide action levels (see Section 3.3.3.1 and MARSSIM Section 4.3.4).

293 The unity rule is satisfied when radionuclide mixtures yield a combined fractional concentration
 294 limit that is less than or equal to one. The unity rule can be described by Equation 3-2:

$$295 \quad \frac{C_1}{AL_1} + \frac{C_2}{AL_2} + \dots + \frac{C_n}{AL_n} \leq 1 \quad (3-2)$$

296 Where:

297 C_i = concentration or activity value for each individual radionuclide ($i = 1, 2, \dots, n$)⁵
 298 AL_i = action level value for each individual radionuclide ($i = 1, 2, \dots, n$)

299 For the disposition of M&E that contain multiple radionuclides, it may be possible to measure
 300 just one of the radionuclides and still demonstrate compliance for all of the radionuclides present
 301 in the M&E through the use of surrogate measurements. In the use of surrogates, it is often

⁵ C (radionuclide concentration) must be in the same units as the action level. If the action level is provided in activity units, C will also be in units of activity.

302 difficult to establish a “consistent” ratio between two or more radionuclides. Rather than follow
 303 prescriptive guidance on acceptable levels of variability for the surrogate ratio, the planning team
 304 should review the data collected to establish the ratio (e.g., from preliminary surveys or process
 305 knowledge) and account for the variability as a measurement quality objective (MQO) during
 306 selection of a measurement method (see Section 3.8 and Chapter 5). The action levels must then
 307 be modified to account for the fact that one radionuclide is being used to account for the
 308 presence of one or more other radionuclides.

309 Action levels for the measured radionuclide are modified ($AL_{\text{meas,mod}}$) to account for a single
 310 inferred radionuclide (e.g., inferring ^{55}Fe based on the presence of ^{60}Co) using Equation 3-3
 311 (modified from Equation 6.2 in Abelquist 2001):

$$312 \quad AL_{\text{meas,mod}} = (AL_{\text{meas}}) \left(\frac{AL_{\text{infer}}}{\left(\frac{C_{\text{infer}}}{C_{\text{meas}}} \right) AL_{\text{meas}} + AL_{\text{infer}}} \right) \quad (3-3)$$

313 Where:

314 $AL_{\text{meas,mod}}$ = modified action level for the radionuclide being measured
 315 AL_{meas} = action level for the radionuclide being measured
 316 AL_{infer} = action level for the inferred radionuclide (i.e., not measured)
 317 $C_{\text{infer}}/C_{\text{meas}}$ = surrogate ratio of the inferred to the measured radionuclide.

318 When the measured radionuclide will be used as a surrogate for more than one radionuclide,
 319 $AL_{\text{meas,mod}}$ can be calculated using Equation 3-4 (MARSSIM Equation I-14):

$$320 \quad AL_{\text{meas,mod}} = \frac{1}{\left(\frac{1}{AL_1} + \frac{R_2}{AL_2} + \frac{R_3}{AL_3} + \dots + \frac{R_n}{AL_n} \right)} \quad (3-4)$$

321 Where:

322 AL_1 = the action level for the measured radionuclide by itself
 323 AL_2 = the action level for the second radionuclide (or first radionuclide being
 324 inferred) that is being inferred by the measured radionuclide
 325 R_2 = the ratio of concentration of the second radionuclide to that of the measured
 326 radionuclide

327 AL_3 = the action level for the third radionuclide (or second radionuclide being
 328 inferred) that is being inferred by the measured radionuclide
 329 R_3 = the ratio of concentration of the third radionuclide to that of the measured
 330 radionuclide
 331 AL_n = the action level for subsequent radionuclides being inferred by the measured
 332 radionuclide
 333 R_n = the ratio of concentration of subsequent radionuclides to that of the measured
 334 radionuclide.

335 Recall that the benefit of using surrogates is the avoidance of costly laboratory-based analytical
 336 methods to provide estimates of activity for individual radionuclides of concern. Surrogates
 337 often emit γ -rays, which enable the use of noninvasive and nondestructive methods. However,
 338 α - and β -emitting radionuclides can also be used as surrogates, depending on the objectives of
 339 the survey and project-specific information. The surrogates come in two forms: (1) surrogates
 340 by virtue of a decay series, and (2) surrogates by virtue of association. Surrogates that are part of
 341 a decay series are discussed in Section 3.3.3.2. Radionuclides that are not part of a decay series
 342 have the potential to be surrogates when they are produced by the same nuclear process (usually
 343 fission or activation) and have similar chemical properties and release mechanisms. However,
 344 this type of surrogate needs special attention because there must be a consistent ratio between the
 345 measured radionuclide and surrogate, which is not always easy to demonstrate. For example, in
 346 the case of nuclear power reactors, ^{60}Co can be used as a surrogate of ^{55}Fe and ^{63}Ni because both
 347 are activation-corrosion products with similar chemical properties. Similarly, ^{137}Cs can be used
 348 as a surrogate for the β -emitting ^{90}Sr because both are fission products and are generally found in
 349 soluble cationic forms. While ^{137}Cs has been suggested as a possible surrogate for ^{99}Tc , it must
 350 be noted that ^{99}Tc has different chemical properties and, in nuclear power reactors, it has
 351 different release mechanisms. Additional information is available on surrogates and establishing
 352 ratios (MARSSIM 2002, NRC 2000, and EPRI 2003).

353 **3.3.4 Evaluate Interface With Exposure Pathway Models**

354 Disposition criteria may be provided in units that cannot be measured directly, for example total
 355 effective dose equivalent (TEDE) or lifetime risk of cancer incidence. These criteria are usually
 356 converted into action levels with concentration or activity units. This conversion is typically
 357 accomplished using exposure pathway models, such as RESRAD-Recycle for metals (DOE
 358 2005). While the selection and application of these models is outside the scope of MARSAME,

359 the assumptions used to develop action levels should be considered during development of a
360 disposition survey design.

361 Alternatively, disposition criteria may be provided in units more easily measured. In general,
362 there are assumptions used in the development of these types of action levels. It is the
363 responsibility of the authority issuing the action levels to ensure regulatory involvement in their
364 development and to document and make assumptions available to users.

365 The assumptions used to design the disposition survey (Section 4.4) need to match the
366 assumptions used to develop the action levels. Examples of parameters that could affect
367 disposition survey designs include:

- 368 • Volume, mass, or surface area of M&E
- 369 • Accessibility
- 370 • Physical and chemical characteristics of radionuclides or radiations of concern (types
371 of emissions, energies, half-lives, known or expected relationships)
- 372 • Distribution of radioactivity (uniform or variable)
- 373 • Location of radioactivity (surficial or volumetric)
- 374 • Fixed, removable, or some combination, radioactivity (resuspension)

375 **3.4 Describe the Parameter of Interest**

376 The parameter of interest is the population parameter (e.g., mean, median, percentile, or total
377 amount) that the planning team considers to be important for making decisions about the target
378 population (EPA 2006a). The target population is the collection of all possible measurement
379 results that could be used to support a disposition decision concerning the M&E being
380 investigated. The target population is defined by the selection of survey unit boundaries (see
381 Section 3.6), since a separate disposition decision will be made for each survey unit.

382 The parameter of interest may be specified as part of the action level. For example, DOE Order
383 5400.5 Figure IV-1 (DOE 1993) lists action levels (i.e., surface concentration limits in dpm per
384 100 cm²), parameters of interest (i.e., mean and maximum values), and target populations (i.e.,
385 1 m² for average concentration and 100 cm² for maximum and removable limits).

386 Alternatively, the planning team may need to select the parameter of interest based on project-
387 specific needs and considerations. The most common parameter used in decision-making is the
388 mean because the mean is frequently used to model random exposure to environmental
389 contamination (EPA 2006a). The more complex the parameter of interest, the more complex
390 will be the decision rule (see Section 3.7) and accompanying survey design. A statistician
391 should be consulted if the planning team is unsure of which parameter of interest to select.

392 **3.5 Identify Alternative Actions**

393 Before decision rules can be developed, the planning team needs to identify the alternative
394 actions based on the disposition options identified in Section 2.5. Alternative actions are the
395 possible actions that may be taken for disposition of M&E, including an alternative that requires
396 no action. Table 3.2 lists examples of alternative actions for disposition options listed in
397 Section 2.5.

398 **3.6 Identify Survey Units**

399 To make a decision concerning the disposition of M&E it is necessary to describe the total
400 collection of M&E being investigated and define what segment of the total will be considered for
401 individual decisions. In other words, the planning team must specify the amount of M&E for
402 which a separate disposition decision will be made. When the M&E consist of discrete items
403 surveyed individually (e.g., hand tools) this task is simple. However, disposition decisions are
404 often required for more complex situations (e.g., bulk dispersible materials, excavation
405 equipment). Survey unit boundaries should be clearly defined in order to know exactly what
406 amount of M&E is covered by a single decision. This clear and unambiguous definition will
407 make data interpretation more straightforward.

408 An M&E survey unit is the specific lot, amount, or piece of equipment on which measurements
409 are made to support a disposition decision concerning that specific lot, amount, or piece of
410 equipment. The purpose of this section is to identify the information that will be used to define
411 the survey unit boundaries. The expected output from this section is the identification of survey
412 unit boundaries that will be used to develop the decision rule in Section 3.7. Figure 3.2 shows
413 the process used to develop survey unit boundaries.

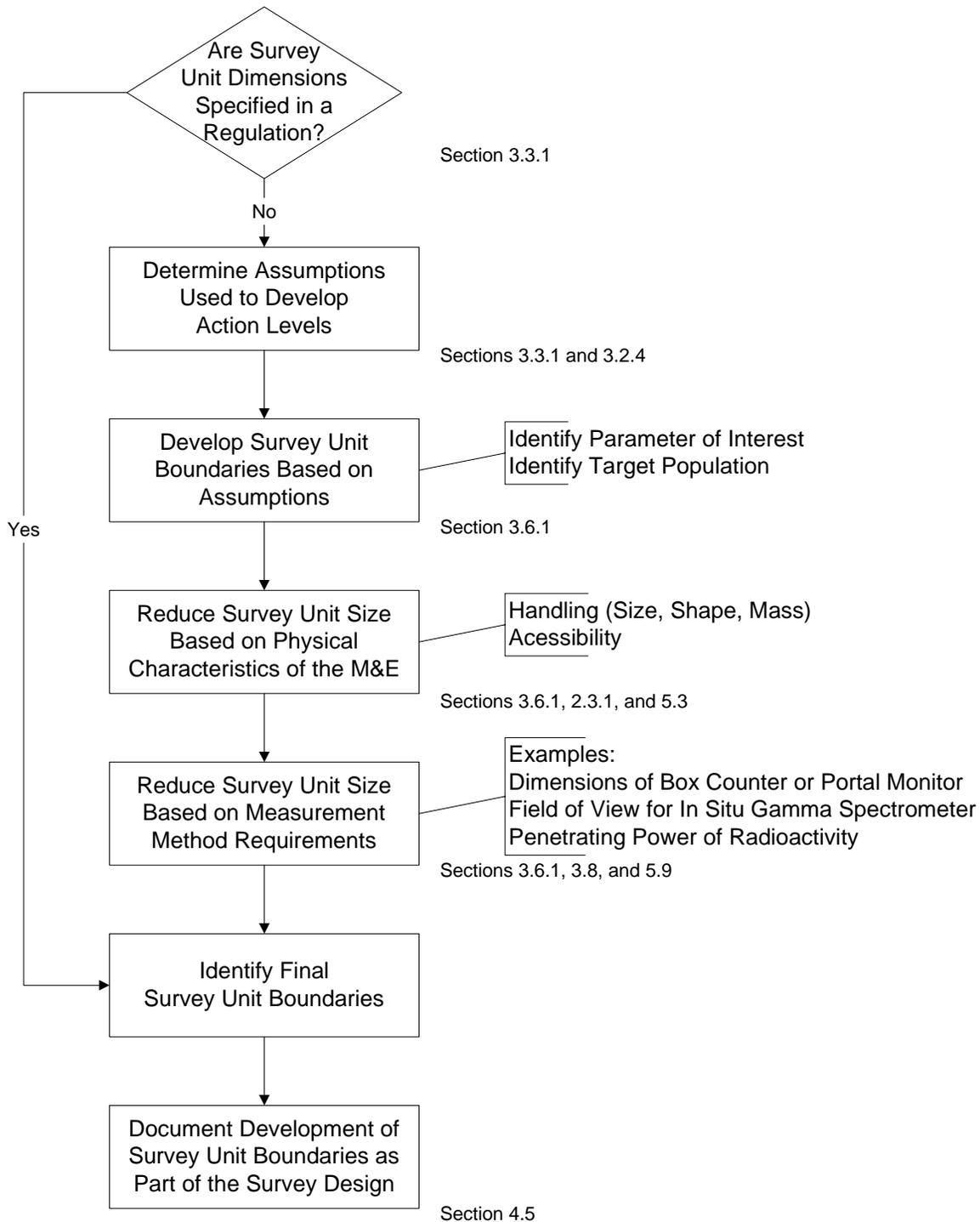
414

Table 3.2 Example Alternative Actions

Disposition Option	Alternative Actions
Release for reuse	Reuse without radiological controls
	Reuse with radiological controls
	Maintain current level of radiological control and do not reuse (no action)
Release for recycle	Recycle without radiological controls
	Recycle with radiological controls
	Maintain current level of radiological control and do not recycle (no action)
Release for disposal	Dispose of M&E as municipal or industrial waste
	Dispose of M&E as low-level radioactive waste
	Dispose of M&E as high-level radioactive waste
	Dispose of M&E as transuranic (TRU) waste
	Maintain current level of radiological control without disposal (no action)
Interdiction	Remove M&E from general commerce and initiate radiological controls
	Decision not to use or accept M&E for a specific application
	Continued unrestricted use of M&E (no action)

415 Survey unit boundaries are affected by many variables associated with the action level, physical
 416 properties of the M&E, characteristics of the radionuclides of concern, and available
 417 measurement techniques. Variables affecting the definition of survey units include:

- 418 • Action Level (Section 3.3)
 - 419 ○ Assumptions used to develop the action level (e.g., surficial or volumetric,
 420 Section 3.3.1)
 - 421 ○ Modeling assumptions used to convert from dose or risk to concentration or
 422 activity (Section 3.3.4)



423 **Figure 3.2 Developing Survey Unit Boundaries (Apply to all Impacted M&E for each set of**
 424 **Action Levels Identified in Section 3.3)**

- 425 • Physical Properties of the M&E (Section 2.4.1)
 - 426 ○ Dimensions (i.e., size, shape, surface area)
 - 427 ○ Complexity (i.e., number and type of components)
 - 428 ○ Accessibility (i.e., measurability)
 - 429 ○ Inherent value
- 430 • Radiological Attributes of the M&E (Section 2.4.2)
 - 431 ○ Radionuclides of concern (e.g., major radiations and energies, half-life)
 - 432 ○ Expected activity levels (e.g., average, range, variance, known or potential
 - 433 relationships)
 - 434 ○ Distribution (i.e., uniform or non-uniform)
 - 435 ○ Location (i.e., surficial or volumetric)
- 436 • Available Measurement Methods (Section 3.8, Section 5.9)
 - 437 ○ Measurement quality objectives (MQOs, Section 3.8)
 - 438 ○ Measurement performance characteristics (Section 5.5)

439 3.6.1 Define Initial Survey Unit Boundaries

440 Initial survey unit boundaries should be developed based on one primary factor and modified, as
 441 needed, using additional variables. MARSAME recommends using the assumptions used to
 442 develop the action levels as the primary factor used to develop survey unit boundaries. The
 443 modifying variables will usually be specific to a measurement technique, or determined by the
 444 M&E being investigated.⁶

445 In many cases the action levels will define the survey unit boundaries. For example, DOE Order
 446 5400.5 Figure IV-1 (DOE 1993) provides action levels for surface activity. The survey unit
 447 boundaries are restricted to the surface of the M&E being investigated. Alternatively, NUREG-

⁶ This approach differs from guidance found in MARSSIM Section 4.6. While MARSSIM also uses the assumptions used to develop the action levels (i.e., DCGLs) as the primary factor in developing survey unit boundaries, the modifications are different. MARSSIM guidance allows increasing and decreasing survey unit size based on classification. In MARSSIM, Class 1 survey units are generally smaller than the area assumed in the exposure pathway model, while MARSSIM allows Class 3 survey units to be larger in area. Additional modifications to survey unit boundaries in MARSSIM can be made based on site-specific variables (e.g., room size, topography).

448 1640 (NRC 2003a) provides modeling assumptions used to develop the action levels for different
449 materials. Radionuclide-specific action levels are provided for separate materials (e.g., ferrous
450 metals, concrete) for both surficial and volumetric radioactivity. In addition, each action level
451 lists the limiting exposure scenario. For example, exposure scenarios for concrete (NRC 2003a)
452 include:

- 453 • Worker processing concrete rubble at a satellite facility,
- 454 • Truck driver hauling concrete rubble,
- 455 • Worker building a road using recycled concrete,
- 456 • Driver on a road built using recycled concrete,
- 457 • Worker handling concrete rubble at an industrial landfill,
- 458 • Worker handling concrete rubble at a municipal landfill,
- 459 • Individual drinking groundwater contaminated with leachate from an industrial
460 landfill, and,
- 461 • Individual drinking groundwater contaminated with leachate from a municipal
462 landfill.

463 Each exposure scenario assumes different conditions that help define survey unit boundaries.
464 For example, a truck driver hauling concrete rubble would be exposed to one truckload of
465 concrete rubble, so the survey unit boundaries would be defined by a truckload of concrete
466 rubble (i.e., 2×10^4 kg [22 tons] or 8.3 cubic meters, NRC 2003a).

467 **3.6.2 Modify Initial Survey Unit Boundaries**

468 Modifications to survey unit boundaries are expected based on practical constraints for data
469 collection activities. In most cases smaller survey units will be acceptable, since a reduction in
470 size would not result in an increased dose or risk. Increasing the size of the survey unit may
471 result in increased dose or risk, and therefore requires approval of the planning team and
472 stakeholders.

473 Constraints on collecting data are often associated with specific measurement techniques, which
474 could affect the survey unit boundaries. For example, using in situ gamma spectrometry may
475 restrict survey unit sizes based on the field of view of the detector, the penetrating power of the

476 gamma energies being measured, or the assumptions used to develop the instrument efficiency.
477 Alternatively, using a box counter or portal monitor may restrict survey unit sizes based on what
478 will fit inside or through the detector. Information on measurement parameters affecting
479 disposition survey design is provided in Section 3.8. Chapter 5 and Appendix D provide detailed
480 information on specific measurement methods.

481 The M&E being investigated may also cause modifications to survey unit boundaries. These
482 modifications are often associated with physical characteristics (e.g., size, shape). Identification
483 of actual survey units as part of the final disposition survey design is discussed in Chapter 4.

484 **3.7 Develop a Decision Rule**

485 In order to design a disposition survey, the user should define a decision rule describing the
486 conditions for selecting between alternative actions. The planning team should assume that ideal
487 data are available and there is no uncertainty in the decision making process. The available data
488 are integrated into an “if...then...” statement, which is the theoretical decision rule.⁷

489 The decision rule is constructed by combining the action level (Section 3.3) and the parameter of
490 interest (Section 3.4) with the alternative actions (Section 3.5) in an “if...then...” statement.

491 For example:

492 Hypothetically, if the mean concentration of ²²⁶Ra in 20,000 kg (8.3 cubic meters,
493 one truckload) of concrete rubble is less than the clearance action level of 0.34
494 Bq/g for volumetric radioactivity, then the concrete rubble can be cleared,
495 otherwise radiological control of the concrete will continue.

496 It may be necessary to develop more than one decision rule. For example, if more than one
497 action level is selected in Section 3.3, a separate decision rule needs to be developed for each
498 action level. In addition, selection of multiple disposition options in Section 2.5 (e.g., release

⁷ This is called a theoretical decision rule because it is stated in terms of the true value for the parameter of interest, even though in reality this value cannot be known. An operational decision rule that is based on an estimate of the target population parameter of interest will be incorporated as part of the final disposition survey design selected and documented in Chapter 4.

499 and disposal as low-level radioactive waste) may result in multiple alternative actions requiring
500 multiple decisions and multiple decision rules. For example:

501 Hypothetically, if the mean concentration of ^{226}Ra in 20,000 kg (8.3 cubic meters,
502 one truckload) of concrete rubble is less than the clearance action level of 0.34
503 Bq/g for volumetric radioactivity, then the concrete rubble can be cleared,
504 otherwise the concrete will be considered for disposal as low-level radioactive
505 waste. If the concrete rubble meets the waste acceptance criteria for the low-level
506 radioactive waste disposal facility (e.g., mean and total activity levels, chemical
507 and physical form, toxicity) the concrete will be packaged and transported for
508 disposal, otherwise radiological control of the concrete will continue.

509 **3.8 Develop Inputs for Selection of Provisional Measurement Methods**

510 The identification and evaluation of provisional measurement methods is an important step in
511 developing a disposition survey design. A measurement method is the combination of
512 instrumentation (e.g., GM detector, NaI(Tl) scintillation detector, gamma spectrometer) with a
513 measurement technique (i.e., scan, in situ, sample collection). The selection of a measurement
514 method is discussed in more detail in Section 5.9. The availability of measurement methods and
515 the amount of resources required to implement specific measurement methods is an important
516 factor in selecting between different survey designs, or in reducing the number of options to be
517 considered when developing potential disposition survey designs.

518 There are two potential results of this evaluation of provisional measurement methods. First, the
519 evaluation may identify specific measurement methods that will be included in the final
520 documentation of the selected disposition survey design (see Section 4.5). For example,
521 scanning 100% of a piece of equipment using a 2-inch by 2-inch NaI(Tl) detector at a specified
522 height above the surface using a specified scan speed may be identified as the measurement
523 method. Second, the evaluation may identify characteristics of a measurement method required
524 to meet the objectives of a survey. These characteristics are called measurement quality
525 objectives (MQOs).

526 Examples of MQOs are described in the following sections. A list of minimum MQOs required
527 for a survey can be developed and documented in the final disposition survey design (see Section
528 4.5). The selection of a measurement technique that meets the MQOs is accomplished during
529 implementation of the survey design.

530 This section focuses on measurability. Most of the variables that need to be considered for the
531 identification of measurement techniques have been discussed earlier in this chapter. The
532 identification of measurement methods is directly or indirectly related to:

- 533 • Identification of radionuclides of concern,
- 534 • Location of residual radioactivity,
- 535 • Application of action levels,
- 536 • Physical properties of the M&E,
- 537 • Uniformity of residual radioactivity,
- 538 • Expected levels of residual radioactivity,
- 539 • Relationships between radionuclide activities,
- 540 • Equilibrium status of natural decay series, and
- 541 • Background radioactivity.

542 Measurable radioactivity is radioactivity that can be quantified and meets the DQOs and MQOs
543 established for the survey. Radioactivity that is quantified using known or predicted
544 relationships developed from process knowledge or preliminary measurements is considered
545 measurable as long as the relationships are developed and verified as specified in the DQOs and
546 MQOs. The Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP)⁸
547 lists method performance characteristics that should be considered when establishing MQOs for
548 a project. This list is not intended to be exhaustive.

- 549 • The method uncertainty at a specified concentration (expressed as a standard
550 deviation),
- 551 • The method's detection capability (expressed as the minimum detectable
552 concentration, or MDC),

⁸ MARLAP was developed for selecting laboratory protocols. Applying the framework and performance-based approach for planning and conducting radiological work from MARLAP to the selection of field measurement techniques is an expansion of the original scope and purpose of MARLAP.

- 553 • The method's quantification capability (expressed as the minimum quantifiable
554 concentration, or MQC),
- 555 • The method's range, which defines the method's ability to measure the radionuclide
556 of concern over some specified range of concentration,
- 557 • The method's specificity, which refers to the ability of the method to measure the
558 radionuclide of concern in the presence of interferences, and
- 559 • The method's ruggedness, which refers to the relative stability of method
560 performance for small variations in method parameter values.

561 Project-specific method performance characteristics should be developed as necessary and may
562 or may not include the characteristics listed here. Once lists of performance characteristics that
563 affect measurability have been identified, the planning team should develop MQOs describing
564 the project-specific objectives for potential measurement techniques. Potential measurement
565 techniques should be evaluated against the MQOs to determine if they are capable of meeting the
566 objectives for measurability.

567 **3.8.1 Measurement Method Uncertainty**

568 The required measurement method uncertainty is perhaps the most important MQO to be
569 established during the planning process. Chapter 4 discusses the rationale involved in setting the
570 required measurement method uncertainty. Chapter 5 discusses procedures for determining the
571 required method uncertainty and whether or not it has been achieved. MARLAP uses the term
572 method uncertainty to refer to the predicted uncertainty of a measured value that would likely
573 result from the performance of a measurement at a specified concentration, typically the action
574 level. Reasonable values for method uncertainty can be predicted for a particular measurement
575 technique based on typical values for specific parameters (e.g., count time, efficiency) and
576 process knowledge for the M&E being investigated (see Section 5.5). The MQO for
577 measurement method uncertainty is related to the width of the gray region (see Section 4.2.2).
578 The required measurement method uncertainty is directly related to the MDC and the minimum
579 quantifiable concentration (MQC) discussed below.

580 The distinction between imprecision and bias as a data quality indicator depends on context.
581 Additional information on data quality indicators can be found in MARSSIM Appendix N and

582 EPA QA/G-5 (EPA 2002a). A reliable estimate of bias requires a data set that includes many
583 measurements, so MARSAME and MARLAP focus on developing an MQO for measurement
584 method uncertainty. Measurement method uncertainty effectively combines imprecision and
585 bias into a single parameter whose interpretation does not depend on context. This approach
586 assumes that all potential sources of bias present in the measurement process have been
587 considered in the estimation of the measurement uncertainty and, if not, that any appreciable bias
588 would only be detected after a number of measurements of quality control (QC) and performance
589 evaluation samples have been performed (see QC discussion in Section 5.10). MARLAP
590 Appendix C provides examples on developing MQOs for measurement method uncertainty of
591 laboratory measurement techniques.

592 **3.8.2 Detection Capability**

593 The MDC (see Section 5.6) is recommended as the MQO for defining the detection capability,
594 and is an appropriate MQO when decisions are to be made based on a single measurement as to
595 whether excess radioactivity is present or not. The MDC must not exceed the action level if the
596 MDC is to be used as a decision parameter. Chapter 5 provides guidance on implementation of
597 the selected measurement technique, including calculation of the MDC. Additional information
598 on calculating the MDC can be found in MARSSIM (Section 6.7, examples in Appendix H) and
599 MARLAP (Chapter 19, Appendix C).

600 **3.8.3 Quantification Capability**

601 When the average of several measurements will be compared to a disposition criterion, an MQO
602 more stringent than the MDC is required. The MQC (see Section 5.7) is recommended as the
603 parameter for defining the measurement capability for making quantitative comparisons of
604 averages to a limit. An MQO for the required measurement method uncertainty (see Section 5.6)
605 is related to an MQO for the quantification capability since an MQC is defined as the
606 concentration at which a specified relative standard uncertainty is achieved. MARLAP presents
607 three reasons why it is important to consider this measurement method performance
608 characteristic:

- 609 1. To emphasize the importance of the quantification capability of a measurement technique
610 for instances when the issue is not whether a radionuclide is present or not (e.g.,
611 measuring ^{238}U in soil where the activity is inherent) but rather how precisely the
612 radionuclide can be measured,
- 613 2. To promote the MQC as an important measurement method performance characteristic
614 for comparison of measurement techniques, and
- 615 3. To provide an alternative to the overemphasis on establishing required MDCs in
616 instances where detection (i.e., reliably distinguishing a radionuclide concentration from
617 zero) is not the key analytical issue.

618 The MQC must not exceed the action level if the MQC is to be used as a decision parameter.
619 Chapter 5 provides guidance on implementation of the selected measurement technique,
620 including calculation of the MQC. Section 5.8 describes the theoretical basis of the MQC
621 calculation. Additional information on calculating the MQC can be found in MARLAP Chapter
622 19, with examples in MARLAP Appendix C.

623 **3.8.4 Range**

624 The expected concentration range for a radionuclide of concern (see Section 2.4.2) may be an
625 important measurement method performance characteristic. Most radiation measurement
626 techniques are capable of measuring over a wide range of radionuclide concentrations.
627 However, if the expected concentration range is large, the range should be identified as an
628 important measurement method performance characteristic and an MQO should be developed.
629 The MQO for the acceptable range should be a conservative estimate. This will help prevent the
630 selection of measurement techniques that cannot accommodate the actual concentration range.

631 **3.8.5 Specificity**

632 Specificity is the ability of the measurement method to measure the radionuclide concern in the
633 presence of interferences. To determine if specificity is an important measurement method
634 performance characteristic, the planning team will need information on expected concentration
635 ranges for the radionuclides of concern and other chemical and radionuclide constituents, along
636 with chemical and physical attributes of the M&E being investigated (see Section 2.4). The
637 importance of specificity depends on:

- 638 • The chemical and physical characteristics of the M&E being investigated,
639 • The chemical and physical characteristics of the residual radioactivity, and
640 • The expected concentration range for the radionuclides of concern.

641 If potential interferences are identified (e.g., inherent radioactivity, similar radiations), an MQO
642 should be established for specificity.

643 If inherent radioactivity is associated with the M&E being investigated, a method that measures
644 total activity may not be acceptable. Consider concrete, which contains measurable levels of
645 naturally occurring radioactivity and emits radiation in the form of alpha particles, beta particles,
646 and photons. If the action level for the radionuclide of concern is close to background (e.g.,
647 within a factor of 3) gross measurement methods may not meet the survey objectives.

648 Performing gross alpha measurements using a gas proportional detector may not provide an
649 acceptable MDC or MQC for plutonium isotopes, where a more specific measurement method
650 such as alpha spectrometry following radiochemical separation would be acceptable.

651 Radionuclides have similar radiations if they emit radiations of the same type (i.e., alpha, beta,
652 photon) with similar energies. For example, both ^{226}Ra and ^{235}U emit a gamma ray with energy
653 of approximately 186 keV. Gamma spectrometry may not be able to resolve mixtures of these
654 two radionuclides, which are both associated with naturally occurring radioactivity. More
655 specific methods involving ingrowth of ^{226}Ra daughters or chemical separation prior to
656 measurement can be used to accurately quantify the radionuclides.

657 Documented measurement methods should include information on specificity. MARSSIM Table
658 7.2 lists examples of references providing laboratory measurement methods. NUREG-1506
659 (NRC 1995) provides generic information on field measurement techniques, but most field
660 measurement methods are documented in proprietary SOPs. If specificity is identified as an
661 important issue for a project, consultation with an expert in radiometrics or radiochemistry is
662 recommended.

663 **3.8.6 Ruggedness**

664 For a project that involves field measurements that are performed in hostile, hazardous, or
665 variable environments, or laboratory measurements that are complex in terms of chemical and

666 physical characteristics, the measurement method's ruggedness may be an important method
 667 performance characteristic. Ruggedness refers to the relative stability of the measurement
 668 technique's performance when small variations in method parameter values are made. For field
 669 measurements the changes may include temperature, humidity, or atmospheric pressure. For
 670 laboratory measurements, a change in pH or the quantity of a reagent may be important. In order
 671 to determine if ruggedness is an important measurement method performance characteristic, the
 672 planning team needs detailed information on the chemical and physical characteristics of the
 673 M&E being investigated and operating parameters for the radiation instruments used by the
 674 measurement technique. Information on the chemical and physical characteristics of the M&E is
 675 available as outputs from the IA. Information on the operating parameters for specific
 676 instruments should be available from the instrument manufacturer. Generic information for
 677 radiation detector operating parameters may be found in consensus standards. A limited list of
 678 examples of consensus standards is provided in Table 3.3.

679 **Table 3.3 Examples of Consensus Standards for Evaluating Ruggedness**

Standard Number	Title
ANSI N42.12-1994	American National Standard Calibration and Usage of Thallium-Activated Sodium Iodide Detector Systems for Assay of Radionuclides
ANSI N42.17A-2003	American National Standard Performance Specifications for Health Physics Instrumentation – Portable Instrumentation for Use in Normal Environmental Conditions
ANSI N42.17C-1989	American National Standard Performance Specifications for Health Physics Instrumentation – Portable Instrumentation for Use in Extreme Environmental Conditions
ANSI N42.34-2003	American National Standard Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides.
IEEE 309-1999/ ANSI N42.3-1999	Institute of Electrical and Electronics Engineers, Inc. Standard Test Procedures and Bases for Geiger Mueller Counters
ASTM E1169-2002	Standard Guide for Conducting Ruggedness Tests

680 If it is determined that measurement method ruggedness is an important performance
681 characteristic, an MQO should be developed. The MQO may require performance data that
682 demonstrate the measurement technique's ruggedness for specified changes in select
683 measurement method parameters. Alternatively, the MQO could list the acceptable ranges for
684 select measurement method parameters and monitor the parameters as part of the QC program
685 for the project (see Section 5.10). For example, sodium iodide detectors are required to perform
686 within 15% of the calibrated response between zero and 40 degrees Celsius (32 and 104 degrees
687 Fahrenheit, respectively) (ANSI 1994). The disposition survey design may call for a work
688 stoppage at temperatures outside this range, or an increase in the frequency of QC measurements
689 at temperatures outside this range.

690 **3.9 Identify Reference Materials**

691 Action levels may be developed that are related to background radioactivity, either based on an
692 incremental dose or risk above background, as an administrative limit based on background, or
693 as a limit on technology (e.g., minimum detectable concentration). For situations where the
694 action levels are incremental above background, reference materials should be identified to
695 provide an estimate of background. MARSSIM Section 4.5 provides guidance on determining
696 when a reference material is required.

697 Reference materials are used to develop an estimate of the distribution of background
698 radioactivity that can be compared to the measurements performed in a comparable survey unit.
699 The reference material is selected to provide information on the level of radioactivity that would
700 be present if the M&E being investigated had not been radiologically impacted.

701 The ideal reference data is obtained by performing a survey of the M&E before it comes in
702 contact with radiological materials. The M&E can then be surveyed prior to leaving the area to
703 determine the level of residual radioactivity. This works especially well for decommissioning or
704 cleanup applications where M&E are brought into a radiologically controlled area for a limited
705 time and a specific application. Unfortunately, there are numerous situations where pre-contact
706 surveys are not possible.

707 If the M&E cannot be used as its own reference material, it is necessary to identify reference
708 material that is representative of the M&E being investigated. Non-impacted M&E that closely

709 resembles the impacted M&E being investigated (i.e., similar chemical, physical, and
710 radiological characteristics) will generally be acceptable as reference material. For example, if
711 the conceptual model shows that only surficial activity is expected, the impacted surface may be
712 removed and the non-impacted volume used as the reference material. When similar materials
713 are not available, the best match available should be used as reference material. It may be
714 necessary to evaluate more than one source of reference material before an acceptable match is
715 identified. It may be important to perform reference material surveys in areas of low ambient
716 background. Consider M&E consisting of individual objects that are small relative to the size of
717 the detector used to perform the measurements. When each object receives a separate
718 measurement, the ambient background may have a larger impact on the measurement than the
719 background contributed by the M&E itself.

720 As shown in Table B.1 in Appendix B, background radionuclide concentrations for materials can
721 vary significantly. For example, concentrations for thorium series radionuclides in concrete can
722 range from 15 to 120 Bq/kg (Eicholz 1980), so it is important to identify an appropriate reference
723 material.

724 The planning team should understand that background is variable. Ambient background can
725 change with location and over time. It may be possible to simply move the M&E being
726 investigated to an area with a lower ambient background to improve the detection capability of a
727 measurement method. Local conditions (e.g., temperature, barometric pressure, precipitation)
728 can cause variations in ambient background as discussed in NUREG-1501 (NRC 1994).
729 NUREG-1505 (NRC 1998a) Chapter 13 provides information on accounting for variability in
730 background.

731 The planning team should evaluate the process knowledge from the IA and use professional
732 judgment to identify M&E that require reference materials, and identify potential reference
733 materials to support the disposition survey.

734 **3.10 Evaluate an Existing Survey Design**

735 It is not necessary to develop a new survey design for all M&E being investigated. Existing
736 survey designs are often available for routine or repetitive applications. If an existing survey

737 design is identified, the planning team or decision maker should evaluate the applicability of the
738 existing design to the current investigation.

739 Standardized survey designs for operating facilities are often documented in the form of standard
740 operating procedures (SOPs, see Section 4.5.1). In other cases, existing survey designs may
741 have been developed for similar projects. A description of the M&E that can be measured
742 should be included in each existing SOP or survey design. If the description matches the M&E
743 being investigated, the existing SOP or survey design can be used to perform the disposition
744 survey. If the description of the M&E is incomplete or vague, or the M&E do not match the
745 description, a more detailed evaluation may be performed to determine the acceptability of the
746 existing survey design.

747 Personnel familiar with the existing survey design and the proposed application should perform
748 the detailed evaluation of an existing survey design. All supporting documentation used to
749 develop the existing survey design should be available for the evaluator(s), not just the SOP or
750 survey design being reviewed.

751 The detailed evaluation should determine whether the M&E are measurable using the existing
752 survey design. If the M&E are measurable, the existing survey design can be used. Detailed
753 evaluations should include a review of each step in the survey development process, including:

- 754 • Selection of a disposition option (Section 2.5),
- 755 • Identification of action levels (Section 3.3),
- 756 • Specification of the population parameter of interest (Section 3.4),
- 757 • Development of survey unit boundaries (Section 3.6),
- 758 • Selection of measurement methods (Section 3.8 and Section 5.9),
- 759 • Identification of alternative actions (Section 3.5), and
- 760 • Development of a decision rule (Section 3.7 and Section 4.2.6).

761 The results of the evaluation should be documented. The documentation may require a
762 modification to the existing survey design. For example, the description of M&E that can (or
763 cannot) be measured using a specific SOP may be expanded for M&E that are routinely or
764 repeatedly surveyed. Alternatively, the documentation may consist of a notation in a survey log
765 (including a name, title, and date) for unique items.

1 **4 SURVEY DESIGN**

2 **4.1 Introduction**

3 Once a decision rule has been developed, a disposition survey can be designed for the impacted
4 materials and equipment (M&E) being investigated. The disposition survey incorporates all of
5 the available information to determine the quantity and quality of data required to support a
6 disposition decision. This chapter provides information on selecting the type, number, and
7 location of measurements required to support a decision regarding the disposition of the M&E.
8 Facilities or installations can use the process in this chapter and following chapters to develop an
9 SOP so multiple surveys can be performed for similar M&E to avoid costly and time-consuming
10 development of redundant survey designs. The evaluation of existing SOPs for usability is
11 discussed in Section 3.10. The output from this chapter is a documented disposition survey
12 design that integrates measurement, data collection, and data analysis techniques.

13 The information in this chapter builds on the information collected and decisions made in
14 Chapter 2 and Chapter 3. The disposition option selected in Section 2.5 and the action levels
15 identified in Section 3.3 are incorporated into the decision rules developed in Section 3.7. A
16 decision rule is the basis for the disposition survey design. If multiple survey designs address the
17 same decision rule and meet the data quality objectives (DQOs), the decision maker needs to
18 determine the most effective design for that decision rule. If none of the survey designs meet the
19 DQOs for a specific decision rule, it may be necessary to reconsider decisions made earlier in the
20 survey design process and adjust the DQOs.¹ If there are multiple decision rules (e.g., one for
21 total radioactivity and one for removable radioactivity) more than one survey design may need to
22 be developed to meet all of the DQOs for the project or a single survey design may be developed
23 to incorporate all of the decision rules.

¹ Refer to Section 2.3 for information on performing preliminary surveys to help ensure at least one survey design will meet the DQOs.

24 The complexity of a survey design generally reflects the complexity of the statistics used to
25 interpret the results (see Chapter 6). Survey designs range from simple (e.g., scan 100% of the
26 M&E for surface radioactivity at a specified action level) to complex (e.g., develop a
27 MARSSIM-type survey design). Simple survey designs typically require few resources for
28 planning, but may require significant resources to implement. Complex survey designs typically
29 require more resources during planning, with fewer resources required during implementation. If
30 the planning and implementation portions of the data life cycle are performed correctly, the
31 assessment and decision making stages should require few resources. This chapter provides
32 information on statistical decision-making and how it is used during development of survey
33 designs.

34 **4.2 Statistical Decision Making**

35 In Section 3.6, the planning team assumed the levels and distribution of radioactivity associated
36 with the M&E were known with no uncertainty. A theoretical decision rule was developed using
37 this assumption to help focus the attention of the planning team on *how* they would make
38 decisions. In this chapter the planning team accounts for uncertainty in decisions when ideal
39 data are not available by establishing a statistical test to implement the decision rule. Decisions
40 regarding the disposition of M&E are based on data with uncertainties. Through the use of
41 statistics, the disposition survey design attempts to control the probability of making a decision
42 error because of these uncertainties. MARSSIM Section 2.3 provides additional discussions on
43 the use of statistics for making decisions based on environmental data.

44 MARSAME recommends the planning team complete the following steps:

- 45 • Select a null hypothesis (Section 4.2.1),
- 46 • Choose a discrimination limit (Section 4.2.2),
- 47 • Define Type I and Type II decision errors (Section 4.2.5),
- 48 • Set a tolerable Type I decision error rate at the action level (Section 4.2.5), and
- 49 • Set a tolerable Type II decision error rate at the discrimination limit (Section 4.2.5).

50 4.2.1 Null Hypothesis

51 In hypothesis testing, two assertions about the actual level of radioactivity associated with the
52 M&E are formulated. The two assertions are called the null hypothesis (H_0) and the alternative
53 hypothesis (H_1). H_0 and H_1 together describe all possible radionuclide concentrations or levels
54 of radioactivity under consideration. The survey data are evaluated to choose which hypothesis
55 to reject or not reject, and by implication which to accept.² In any given situation, one and only
56 one of the hypotheses must be true. The null hypothesis is assumed to be true within the
57 established tolerance for making decision errors (Section 4.2.5). Thus, the choice of the null
58 hypothesis also determines the burden of proof for the test.

59 If the action level (AL) is not zero, the planning team generally assumes the radionuclide
60 concentration or level of radioactivity (X) exceeds the action level unless the survey results
61 provide evidence to the contrary. In other words, surveys are designed to provide sufficient
62 evidence to disprove H_0 . In this case, the null hypothesis is that the radionuclide concentration
63 or level of radioactivity is greater than or equal to the action level (i.e., $H_0: X \geq AL$). The
64 alternative hypothesis is the radionuclide concentration or level of radioactivity is less than the
65 action level (i.e., $H_1: X < AL$). MARSSIM and NUREG-1505 (NRC 1998a) describe this as
66 Scenario A, and the burden of proof falls on the owner of the M&E. Scenario A is sometimes
67 referred to as “presumed not to comply” or “presumed not clean.”

68 On the other hand, the planning team may choose to assume the action level has not been
69 exceeded unless the survey results provide evidence to the contrary. The null hypothesis
70 becomes $H_0: X \leq AL$, and the alternative hypothesis is $H_1: X > AL$. MARSSIM and NUREG-
71 1505 (NRC 1998a) describe this as Scenario B, and the burden of proof falls on the regulator.
72 Scenario B is sometimes referred to as “indistinguishable from background” or “presumed
73 clean.” This is the only practical approach when the action level is equal to zero (above
74 background); because it is technically impossible to obtain statistical evidence that the

² In hypothesis testing, to “accept” the null hypothesis only means not to reject it. For this reason many statisticians avoid the word “accept.” A decision not to reject the null hypothesis does not imply the null hypothesis has been shown to be true.

75 radionuclide concentration or level of radioactivity is exactly zero. However, Scenario B can be
76 applied to situations other than “indistinguishable from background.” For example, the case
77 study example in Section 7.4 uses Scenario B to support an interdiction decision.

78 **4.2.2 Discrimination Limit**

79 Action levels were defined in Section 3.3 based on the selected disposition option and applicable
80 regulatory requirements. The planning team also chooses another radionuclide concentration or
81 level of radioactivity that can be reliably distinguished from the action level by performing
82 measurements (i.e., direct measurements, scans, in situ measurements, samples and laboratory
83 analyses). This radionuclide concentration or level of radioactivity is called the discrimination
84 limit (DL). An example where the discrimination limit is defined is provided in Section 7.4.5.2.

85 The gray region is defined as the interval between the action level and the discrimination limit
86 (Figures 4.1, 4.2, and 4.3 provide visual descriptions of the gray region). The width of the gray
87 region is called the shift and denoted as Δ . The objective of the disposition survey is to decide
88 whether the concentration of radioactivity is more characteristic of the DL or of the AL, i.e.,
89 whether action should be taken, or if action is not necessary. Both parts of Figure 4.1 show
90 examples that would fall under Scenario A (discussed in Section 4.2.3). In Figure 4.1a (top) the
91 difference in concentration between the AL and the DL (i.e., Δ) is large; but the variability in the
92 measured concentration (i.e., σ) is also large. In Figure 4.1b (bottom) the difference in
93 concentration between the AL and the DL (i.e., Δ) is relatively small. However, the variability in
94 the measured concentration (i.e., σ) is also smaller. Figure 4.1 illustrates that determining the
95 level of survey effort depends not just on the width of the gray region, but also in the ratio of that
96 width to the expected variability of the data. This ratio, Δ/σ , is called the relative shift in
97 MARSSIM. In situations where Δ/σ is small, i.e., less than 1, it may be impracticable to achieve
98 the required accuracy of measurements or the number of samples to meet the Type I error rate in
99 the DQOs. Section 4.4.4 presents options for relaxing project constraints to optimize the survey
100 design in such cases. In Figure 4.1 part (a) Δ/σ is greater than four; while in part (b) Δ/σ is
101 approximately one.

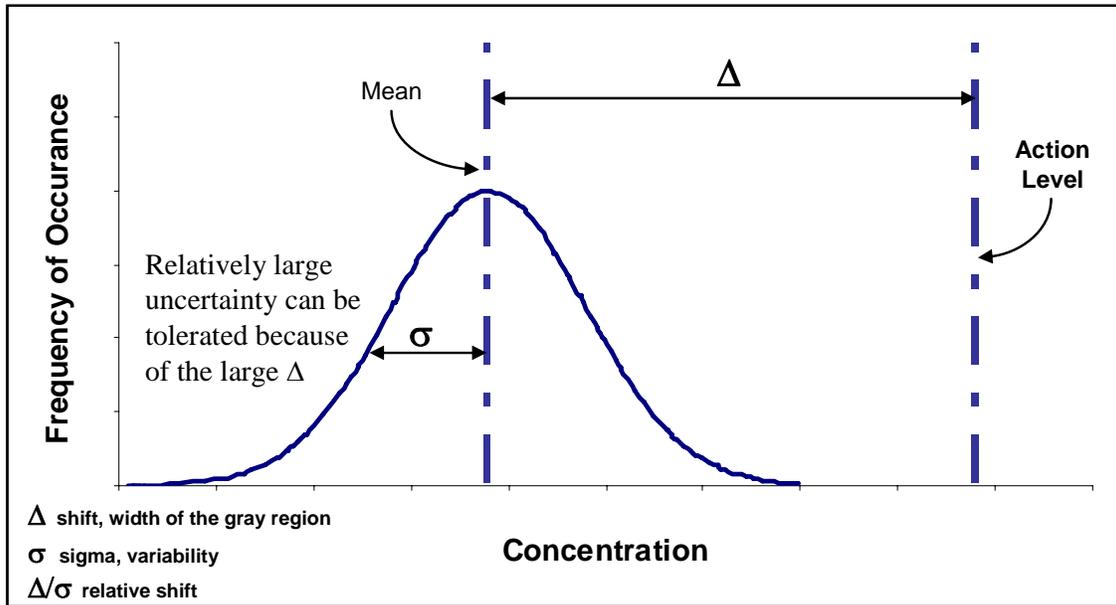


Figure 4.1a σ is Large, but the Large Δ Results in a Large Δ/σ and Fewer Samples

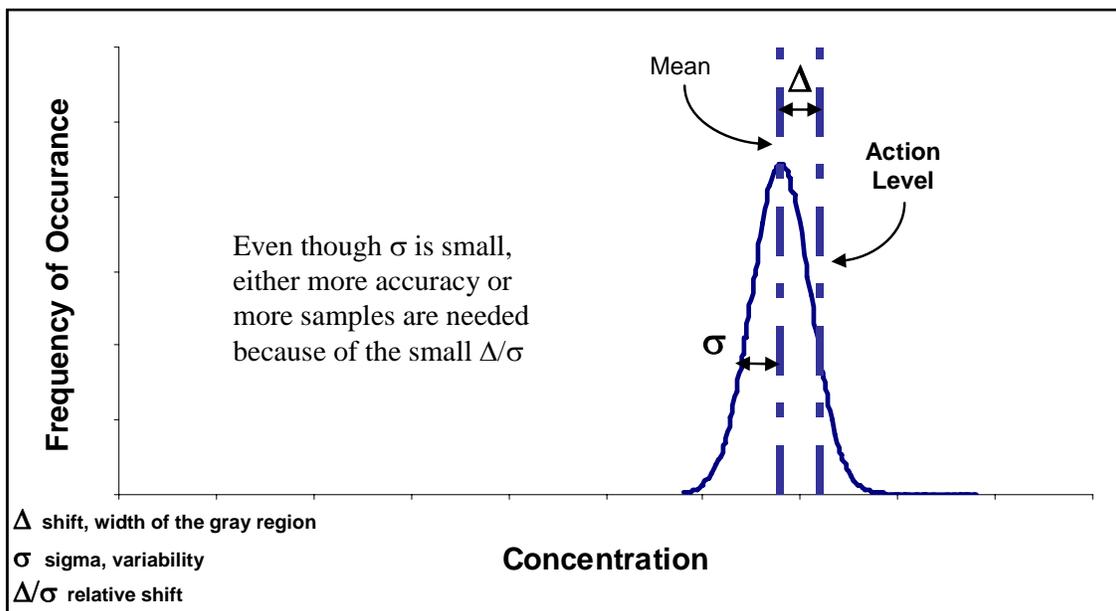


Figure 4.1b σ is Small, but the Small Δ Results in a Small Δ/σ and More Samples

102

103

Figure 4.1 Relative Shift, Δ/σ , Comparison for Scenario A

104 As discussed in MARSSIM, generally, the larger Δ/σ , the easier the survey effort. When Δ/σ is
105 greater than three, the survey effort will be minimal, and any effort to increase it by either
106 widening the gray region or reducing the measurement variability usually would not be
107 worthwhile.

108 On the other hand, when Δ/σ is less than one, the survey effort will become substantial, and any
109 effort to increase it by either widening the gray region or reducing the measurement variability
110 will be worthwhile. The measurement variability is thus just as important as the width of the
111 gray region when designing disposition surveys. In MARSSIM surveys, the total variability had
112 two components: spatial and analytical. For some MARSAME surveys this will also be the case.

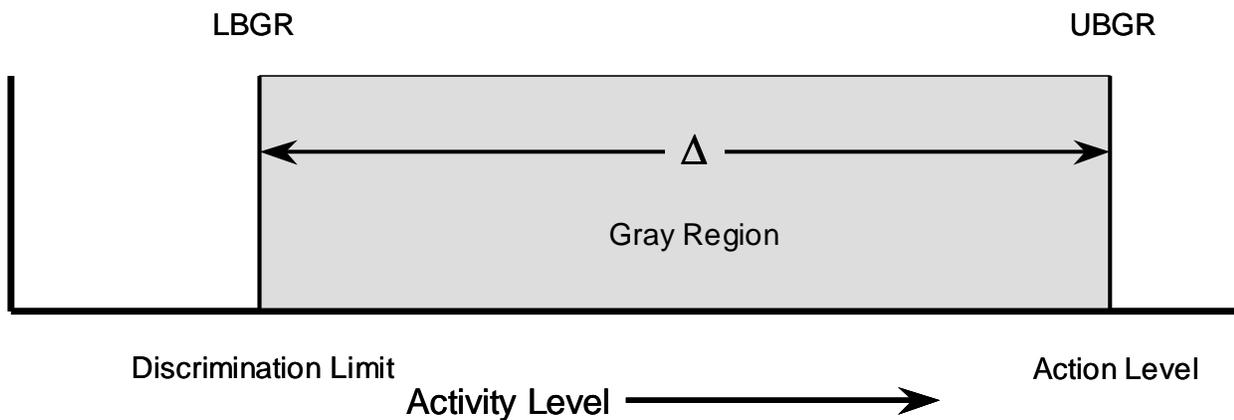
113 However, in many MARSAME surveys the spatial variability will be of less importance, either
114 because 100% of the survey unit is being measured, or because disposition decisions are being
115 made on the basis of single measurements on single items or single locations. In such cases, the
116 required measurement method uncertainty discussed in Section 3.8.1 will be of paramount
117 importance in the survey planning. The details for determining the required measurement
118 method uncertainty and how to determine if it is being met are discussed in detail in Chapter 5.

119 Depending on the survey design, the combination of action levels, expected radionuclide
120 concentrations or levels of radioactivity, instrument sensitivity, and local radiation background
121 contribute to defining the width of the gray region. Reducing the radionuclide concentrations or
122 levels of radioactivity known or assumed to be associated with the M&E can affect the selection
123 of a discrimination limit, so remediation costs may need to be considered. Increasing the
124 sensitivity of a measurement method to reduce the measurement method uncertainty generally
125 involves increased instrument costs or increased counting times.

126 The lower bound of the gray region will be denoted by LBGR and the upper bound of the gray
127 region will be denoted by UBGR. The association of either the UBGR or the LBGR with the DL
128 or AL will depend on the scenario selected (see Sections 4.2.3 and 4.2.4). The width of the gray
129 region (UBGR - LBGR) is denoted by Δ and is called the shift or the required minimum
130 detectable difference in activity or concentration (MARSSIM Section 5.5.2 and Section D.6,
131 MARLAP Section C.2, NRC 1998a, and EPA 2006a,).

132 **4.2.3 Scenario A**

133 The null hypothesis for Scenario A specifies that the radionuclide concentration or level of
 134 radioactivity associated with the M&E is equal to or exceeds the action level. For Scenario A
 135 ($H_0: X \geq AL$), the UBGR is equal to the AL and the LBGR is equal to the DL. As a general rule
 136 for applying Scenario A, the DL should be set no higher than the expected radionuclide
 137 concentration associated with the M&E. The DL and the AL should be reported in the same
 138 units. Figure 4.2 illustrates Scenario A.



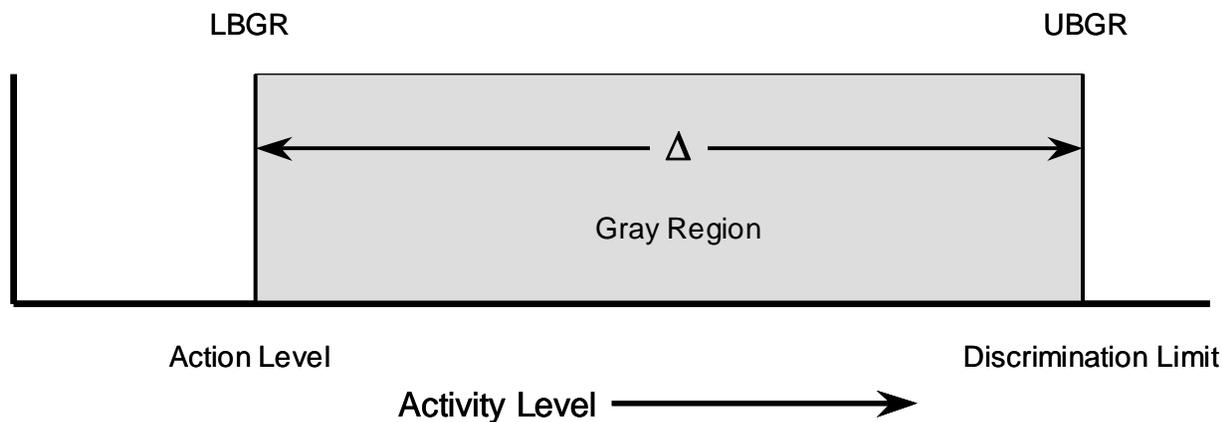
139 **Figure 4.2 Illustration of Scenario A**

140 **4.2.4 Scenario B**

141 The null hypothesis for Scenario B specifies the radionuclide concentration or level of
 142 radioactivity associated with the M&E is less than or equal to the action level. For Scenario B
 143 ($H_0: X \leq AL$), the UBGR is equal to the DL and the LBGR is equal to the AL. The DL defines
 144 how hard the surveyor needs to look, and is determined through negotiations with the regulator.³

145 In some cases the DL will be set equal to a regulatory limit (e.g., 10 CFR 36.57 and DOE 1993).
 146 The DL and the AL should be reported in the same units. Figure 4.3 illustrates Scenario B. This
 147 description of Scenario B is based on information in MARLAP and is fundamentally different
 148 from the description of Scenario B in NUREG 1505 (NRC 1998a).

³ In some cases setting the discrimination limit may include negotiations with stakeholders.



149 **Figure 4.3 Illustration of Scenario B**

150 In NUREG 1505 (NRC 1998a) the gray region is defined to be below the AL in both Scenario A
 151 and Scenario B. In MARSAME and MARLAP the gray region is defined to be above the AL in
 152 Scenario B. The difference lies in how the action level is defined.

153 **4.2.5 Specify Limits on Decision Errors**

154 There are two possible types of decision errors:

- 155 • Type I error: rejecting the null hypothesis when it is true.
- 156 • Type II error: failing to reject the null hypothesis when it is false.

157 Since there is always uncertainty associated with the survey results, the possibility of decision
 158 errors cannot be eliminated. So instead, the planning team specifies the maximum Type I
 159 decision error rate (α) that is allowable when the radionuclide concentration or level of
 160 radioactivity is at or above the action level. This maximum usually occurs when the true
 161 radionuclide concentration or level of radioactivity is exactly equal to the action level. The
 162 planning team also specifies the maximum Type II decision error rate (β) that is allowable when
 163 the radionuclide concentration or level of radioactivity equals the discrimination limit.
 164 Equivalently, the planning team can set the “power” ($1-\beta$) when the radionuclide concentration
 165 or level of radioactivity equals the discrimination limit. See MARSSIM Appendix D, Section
 166 D.6 for a more detailed description of error rates and statistical power.

167 The definition of decision errors depends on the selection of the null hypothesis. For Scenario A
 168 the null hypothesis is that the radionuclide concentration or level of radioactivity exceeds the

169 action level. A Type I error for Scenario A occurs when the decision maker decides the
170 radionuclide concentration or level of radioactivity is below the action level when it is actually
171 above the action level (i.e., mistakenly decides the M&E are clean when they are actually not
172 clean). A Type II error for Scenario A occurs when the decision maker decides the radionuclide
173 concentration or level of radioactivity is above the action level when it is actually below the
174 action level (i.e., mistakenly decides the M&E are not clean when they are actually clean).

175 For Scenario B the null hypothesis is that the radionuclide concentration or level of radioactivity
176 is less than or equal to the action level. A Type I error for Scenario B occurs when the decision
177 maker decides the radionuclide concentration or level of radioactivity is above the action level
178 when it is actually below the action level (i.e., mistakenly decides the M&E are not clean when
179 they are actually clean). A Type II error for Scenario B occurs when the decision maker decides
180 the radionuclide concentration or level of radioactivity is below the action level when it is
181 actually above the action level (i.e., mistakenly decides the M&E are clean when they are
182 actually not clean).

183 It is important to clearly define the scenario (i.e., A or B) and the decision errors for the survey
184 being designed. Once the decision errors have been defined, the planning team should determine
185 the consequences of making each type of decision error. For example, incorrectly deciding the
186 activity is less than the action level may result in increased health and ecological risks.
187 Incorrectly deciding the activity is above the action level when it is actually below may result in
188 increased economic and social risks. The consequences of making decision errors are project
189 specific.

190 Once the consequences of making both types of decision errors have been identified, acceptable
191 decision error rates can be assigned for both Type I and Type II decision errors. Historically a
192 decision error rate of 0.05, or 5%, has been acceptable for decision errors that result in increased
193 health risks. However, assigning the same tolerable decision error rate to all projects does not
194 account for the differences in consequences of making decision errors. This becomes evident
195 with M&E where there are wide ranges of disposition options generating a wide range of
196 consequences. For example, a Type I decision error for Scenario A could have different
197 consequences for a clearance decision compared to a low-level radioactive waste disposal
198 decision. Not all consequences of decision errors are the same, and it is unlikely that applying a

199 fixed value to all decision error rates will result in reasonable survey designs resulting in
200 comparable decisions. Project-specific decision error rates should be selected based on the
201 project-specific consequences of making decision errors.

202 **4.2.6 Develop an Operational Decision Rule**

203 The theoretical decision rule developed in Section 3.6 was based on the assumption that the true
204 radionuclide concentrations in the M&E were known. Since the disposition decision will be
205 made based on measurement results and not the true but unknown concentration, an operational
206 decision rule needs to be developed to replace this theoretical decision rule. The operational
207 decision rule is a statement of the statistical hypothesis test, which is based on comparing some
208 function of the measurement results to some critical value. The theoretical decision rule is
209 developed during Step 5 of the DQO Process (Chapter 3), while the operational decision rule is
210 developed as part of Step 6 and Step 7 of the DQO Process. For example, a theoretical decision
211 rule might be “if the results of any measurement identify surface radioactivity in excess of
212 background, the front loader will be refused access to the site; if no surface radioactivity in
213 excess of background is detected, the front loader will be granted access to the site.” The related
214 operational decision rule might be “any result that exceeds the critical value associated with the
215 MDC set at the discrimination limit will result in rejection of the null hypothesis, and the front
216 loader will not be allowed on the site” (see more examples in Chapter 7).

217 Chapter 6 provides guidance on using statistical tests to evaluate data collected during the
218 disposition survey to support a disposition decision. The planning team should evaluate the
219 statistical tests and possible operational decision rules and select one that best matches the intent
220 of the theoretical decision rule with the statistical assumptions. Each operational decision rule
221 will have a different formula for determining the number of measurements or fraction of M&E to
222 be measured to meet the DQOs.

223 Developing an operational decision rule incorporates all relevant information available
224 concerning the M&E (Section 2.4.3), selected instrumentation and measurement technique
225 (Section 5.9), selected statistical tests (Section 6.2.3), and any constraints on collecting data
226 identified by the planning team. The operational decision rule will need to specify a
227 measurement technique (e.g., scan-only, in situ, sample collection and analysis) and a statistical

228 test. Examples of statistical tests include comparison to the UBGR (Section 6.3), comparison to
229 an upper confidence interval (Section 6.4), the Sign test (Section 6.5), the Wilcoxon Rank Sum
230 test (Section 6.6), and the Quantile test (Section 6.7). At this point in the survey design process
231 it is not necessary to select a specific instrument to perform the measurements. However,
232 selection of a measurement technique will assist the planning team in identifying the appropriate
233 statistical test. For example, if a scan-only measurement method is selected it is not appropriate
234 to select the Wilcoxon Rank Sum test to determine the number of measurements. However, if no
235 scan-only or in situ measurement methods are available that meet the measurement quality
236 objectives (MQOs), a MARSSIM-type survey (which combines scan and static measurements,
237 see Section 4.4.3) should be developed.

238 The planning team uses the combination of the selected instrumentation and measurement
239 technique (see Section 5.9) with a data evaluation method (see Section 6.2.5) to establish an
240 operational decision rule. Then, from the operational decision rule, the planning team can
241 determine the number of measurements or the fraction of the M&E that needs to be measured
242 during the disposition survey. There is no formal structure for stating an operational decision
243 rule. The structure of the operational decision rule is generally defined in terms that meet the
244 needs of a particular project. An operational decision rule can be simple or complex. A simple
245 example could be “If 100% of the surfaces of hand tools are surveyed using a scan-only
246 technique that meets the DQOs, and none of the results exceed the action level for release, then
247 the tools can be released.” The statistical test for this simple example is a comparison of the
248 mean to the action level; however, since all of the values are below the action level, the mean
249 value must also be below the action level. Therefore it is not necessary to perform the actual
250 statistical test. This represents a conservative approach to data interpretation that may not
251 always be appropriate. More complex operational decision rules can:

- 252 • Account for different types of measurements and multiple radionuclides of concern,
- 253 • Specify critical values and test statistics for the statistical tests, and
- 254 • Incorporate multiple decisions (e.g., average and maximum values, fixed and
255 removable radioactivity) depending on the project.

256 **4.3 Classification of Materials and Equipment**

257 Classification is used to determine the level of survey effort for the disposition survey. The level
258 of survey effort is linked to the potential to exceed the action levels (i.e., classification), and is a
259 graded approach to survey design. Impacted M&E with the highest potential to exceed the
260 action levels (i.e., Class 1) receive the greatest effort for the disposition survey, while M&E with
261 a lower potential to exceed the action levels (i.e., Class 2 or Class 3) require less survey effort.
262 Classification in MARSAME is analogous to classification in MARSSIM. The planning team
263 needs to remember that classification is based on estimated radionuclide concentrations or
264 radioactivity relative to the AL.

265 There are tradeoffs (costs and benefits) associated with classification based on estimated⁴ or
266 known radionuclide concentrations or levels of radioactivity relative to the action levels. This
267 means that some knowledge of radionuclide concentrations is required before M&E can be
268 classified. Known radionuclide concentrations or levels of radioactivity may be available from
269 historical data identified during the IA (see Section 2.2), or performance of preliminary surveys
270 (see Section 2.3). Estimates of radionuclide concentrations can be developed based on historical
271 data or process knowledge (see Section 2.2). In the absence of information on the radionuclide
272 concentrations, the default assumption is that all impacted M&E are Class 1.

273 Because classification of impacted M&E is based in part on an action level, classification cannot
274 be performed until potential action levels have been identified (see Section 3.3). For projects
275 where multiple potential action levels have been identified, classification and selection of an
276 appropriate action level may be an iterative process used to reduce the number of survey options.
277 Alternatively, multiple survey designs can be developed to address all potential action levels. In
278 the final step of the DQO Process the most resource efficient survey design that meets the survey
279 objectives is selected (see Section 4.4.4).

⁴ There are risks and tradeoffs associated with using estimated values. The planning team should compare the consequences of potential decision errors with the resources required to improve the quality of existing data to determine the appropriate approach for a specific project.

280 4.3.1 Class 1

281 Class 1 M&E are impacted M&E that have, or had, the following: (1) highest potential for, or
282 known, radionuclide concentration(s) or radioactivity above the action level(s); (2) highest
283 potential for small areas of elevated radionuclide concentration(s) or radioactivity; and (3)
284 insufficient evidence to support reclassification as Class 2 M&E or Class 3 M&E. Such potential
285 may be based on historical information and process knowledge, while known radionuclide
286 concentration(s) or radioactivity may be based on preliminary surveys. This class of M&E might
287 consist of processing equipment, components, or bulk materials that may have been affected by a
288 liquid or airborne release, including, for example, inadvertent effects from spills.

289 Class 1 M&E are those that may have been in direct contact with radioactive materials during
290 operations or may have become activated and are likely to exceed the action level. Additionally,
291 M&E that have been cleaned to remove residual radioactivity above the action level are
292 generally considered to be Class 1. An exception to Class 1 classification may be considered if
293 there are no difficult-to-measure areas and any residual radioactivity is readily removable using
294 cleaning techniques. Examples of such methods may include vacuuming, wipe downs, or
295 chemical etching that quantitatively remove sufficient amounts of radionuclides such that
296 surficial activity levels would be less than the release criteria. Documented process knowledge
297 of cleaning methods directly applicable to the particular M&E should be provided to justify this
298 exception.

299 4.3.2 Class 2

300 Class 2 M&E are impacted M&E that have, or had, the following: (1) low potential for
301 radionuclide concentration(s) or radioactivity above the action level(s); and (2) little or no
302 potential for small areas of elevated radionuclide concentration(s) or radioactivity. Such
303 potential may be based on historical information, process knowledge, or preliminary surveys.
304 This class of materials might consist of electrical panels, water pipe, conduit, ventilation
305 ductwork, structural steel, and other materials that might have come in contact with radioactive
306 materials. Radionuclide concentration(s) and radioactivity above the action level, including
307 small areas of elevated radionuclide concentration(s) or radioactivity, are not expected in
308 Class 2 M&E.

309 4.3.3 Class 3

310 Class 3 M&E are impacted M&E that have, or had, the following: (1) little, or no, potential for
311 radionuclide concentration(s) or radioactivity above background; and (2) insufficient evidence to
312 support categorization as non-impacted. Radionuclide concentration(s) and radioactivity above a
313 specified small fraction of the UBGR are not expected in Class 3 M&E. The specified fraction
314 should be developed by the planning team using a graded approach and approved by the
315 regulatory authority.

316 4.3.4 Other Classification Considerations

317 The planning team should review any historical data used to provide information on radionuclide
318 concentrations or radioactivity and evaluate whether or not the data meet the objectives of the
319 disposition survey, as illustrated in the following examples. Representativeness (see MARSSIM
320 Appendix N) is a key data quality indicator when evaluating historical data. Ideally, the IA
321 should provide information on the radionuclides of potential concern, expected radionuclide
322 concentrations or radioactivity, distribution of radioactivity, and locations where radioactivity is
323 expected (e.g., surficial or volumetric, see Section 2.4.3). In addition, the data should meet the
324 criteria for measurability (e.g., MQC) or detectability (e.g., MDC) established for the project (see
325 Sections 3.8 and 5.5). Historical data that do not meet the objectives of the disposition survey
326 may still be used to provide estimates for radionuclide concentrations or levels of radioactivity.

327 The results of the IA may provide estimated radionuclide concentrations or levels of
328 radioactivity based on process knowledge, historical data, sentinel measurements, or preliminary
329 surveys. In some cases, a survey is performed to develop adequate estimates for levels and
330 variability of radionuclide concentrations or radioactivity. Again, the planning team should
331 evaluate the data used to develop the estimated radionuclide concentrations or levels of
332 radioactivity. In general, estimated data will have a higher associated uncertainty than known
333 data that meet the objectives of the project. The planning team should keep this in mind when
334 developing estimates for radionuclide concentrations or radioactivity to be used in classifying
335 M&E.

336 If the action level is defined in terms of average activity, the average radionuclide concentration
337 or radioactivity should be compared to the action level to determine the appropriate

338 classification. Similar comparisons should be developed for action levels provided in terms of
339 maximum activity or total activity. For example, DOE Order 5400.5 (DOE 1993) provides three
340 surface activity action levels for each group of radionuclides: average total surface activity,
341 maximum total surface activity, and average removable surface activity. These action levels
342 must be evaluated prior to disposition of the M&E. Classification would be determined by
343 comparing the average total surface activity, maximum total surface activity, and average
344 removable surface activity (or appropriate conservative estimates) to the corresponding action
345 level. The overall classification would be determined by the most restrictive case. If the
346 maximum total surface activity indicates the M&E is Class 1, while the average removable
347 surface activity indicates the M&E is Class 3, the M&E should be classified as Class 1.

348 The improper classification of M&E has serious implications, particularly when it leads to the
349 release of material with residual radioactivity in excess of the AL. For example, if material were
350 mistakenly thought to have a very low potential for having residual radioactivity, the material
351 will be subjected to a survey with lesser scrutiny. This misclassification might result in releasing
352 material that should not be released. The opposing possibility (i.e., when M&E is misclassified
353 as impacted when it is non-impacted) involves the stakeholders expending potentially substantial
354 resources involved in unnecessarily surveying non-impacted M&E.

355 **4.4 Disposition Survey Design**

356 MARSAME recommends design of disposition surveys that measure 100% of the M&E being
357 investigated whenever practical. This includes survey designs where all of the M&E are
358 physically measured. Survey designs where physical measurements are performed for less than
359 100% of the M&E may be acceptable if the radioactivity is measurable. Measurable
360 radioactivity is radioactivity that can be quantified and meets the DQOs and MQOs established
361 for the survey. Radioactivity that is quantified using known or predicted relationships developed
362 from process knowledge, historical data, sentinel measurements, or preliminary measurements is
363 considered measurable as long as the relationships are developed and verified as specified in the
364 DQOs and MQOs. An example of such a relationship could be the immobile progeny of the
365 measured radionuclides.

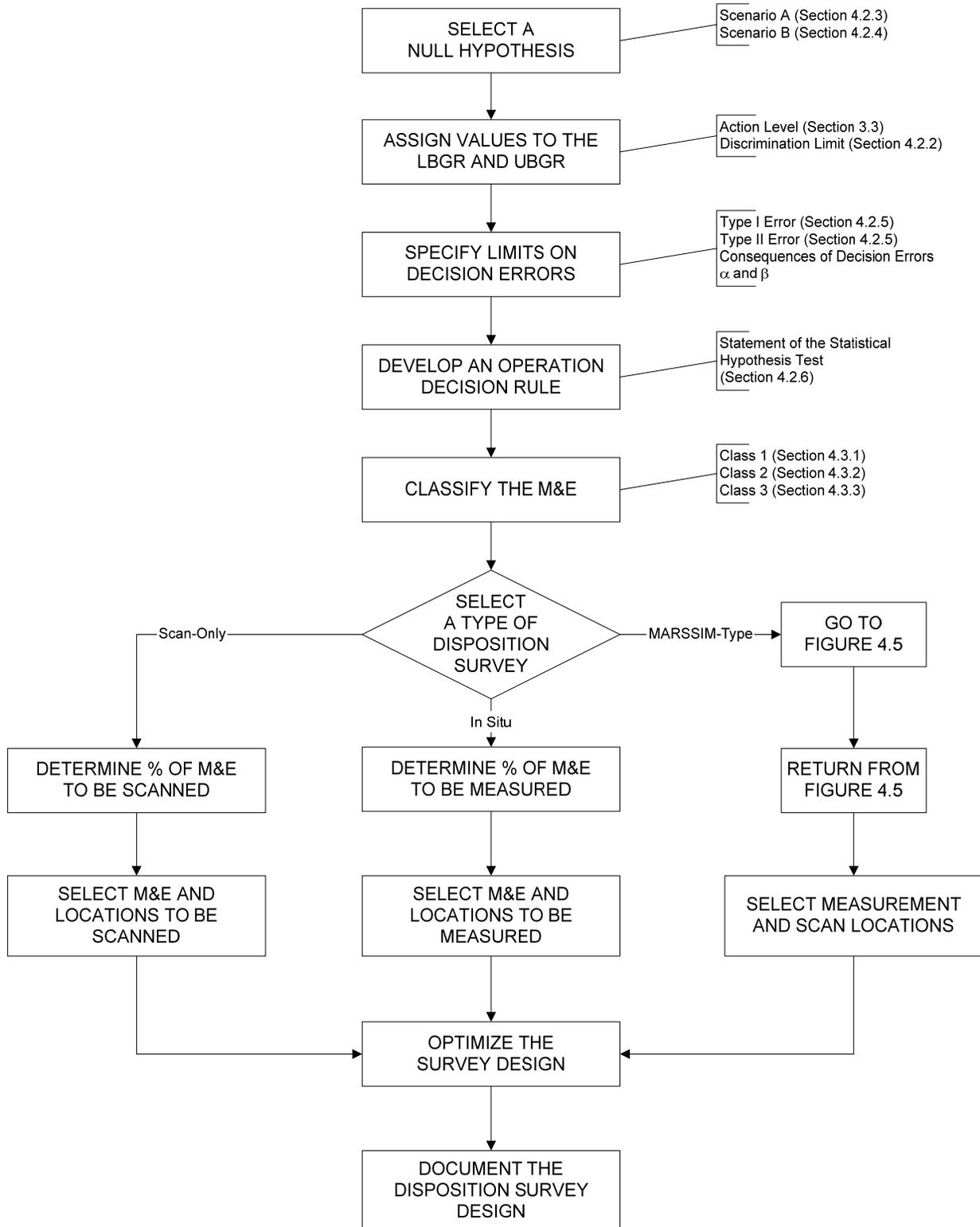
366 Survey designs that measure 100% of the M&E being investigated reduce the uncertainty in the
367 final decision. Because 100% of the M&E are measured, for practical purposes spatial
368 variability can be ignored. Attention should be given to ensure that all impacted surfaces are
369 measured in 100% scan surveys. Surveys that use known or predicted relationships to estimate
370 radionuclide concentrations or levels of radioactivity need to account for the contribution of
371 spatial variability to total uncertainty.

372 To make the best use of limited resources, MARSAME places the greatest level of survey effort
373 on M&E that have, or had, the greatest potential for residual radioactivity (i.e., Class 1). This is
374 referred to as a graded approach. As noted in Section 1.3, survey designs that measure 100% of
375 the M&E are often neither practical nor cost-effective, and could drive the user to dispose of any
376 material that is potentially impacted without considering the benefits of reuse or recycle. The
377 use of a graded approach to ensure that a sensible, commensurate balance is achieved between
378 cost and risk reduction should always be incorporated into MARSAME survey designs.

379 The following sections describe three basic disposition survey designs:

- 380 • Scan-only survey designs,
- 381 • In situ survey designs, and
- 382 • Survey designs that combine scans and static measurements (MARSSIM-type
383 surveys).

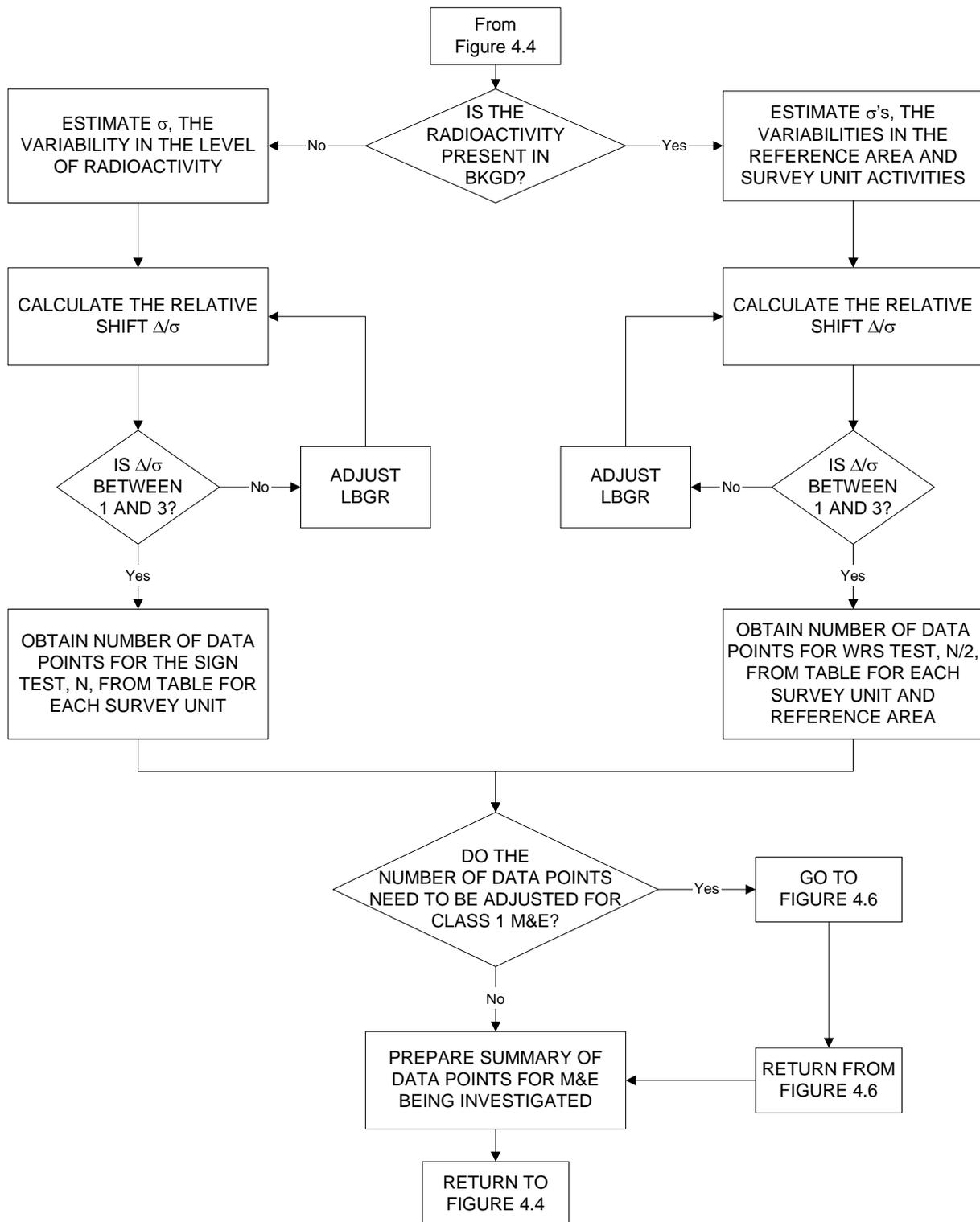
384 Figures 4.4, 4.5, and 4.6 illustrate the process of designing a disposition survey. Classification
385 can be used to provide a graded survey approach to individual survey designs. Information on
386 adjusting the level of survey effort based on classification is provided for each type of survey
387 design. Each survey design can include a variety of survey techniques (see Section 5.9).



388

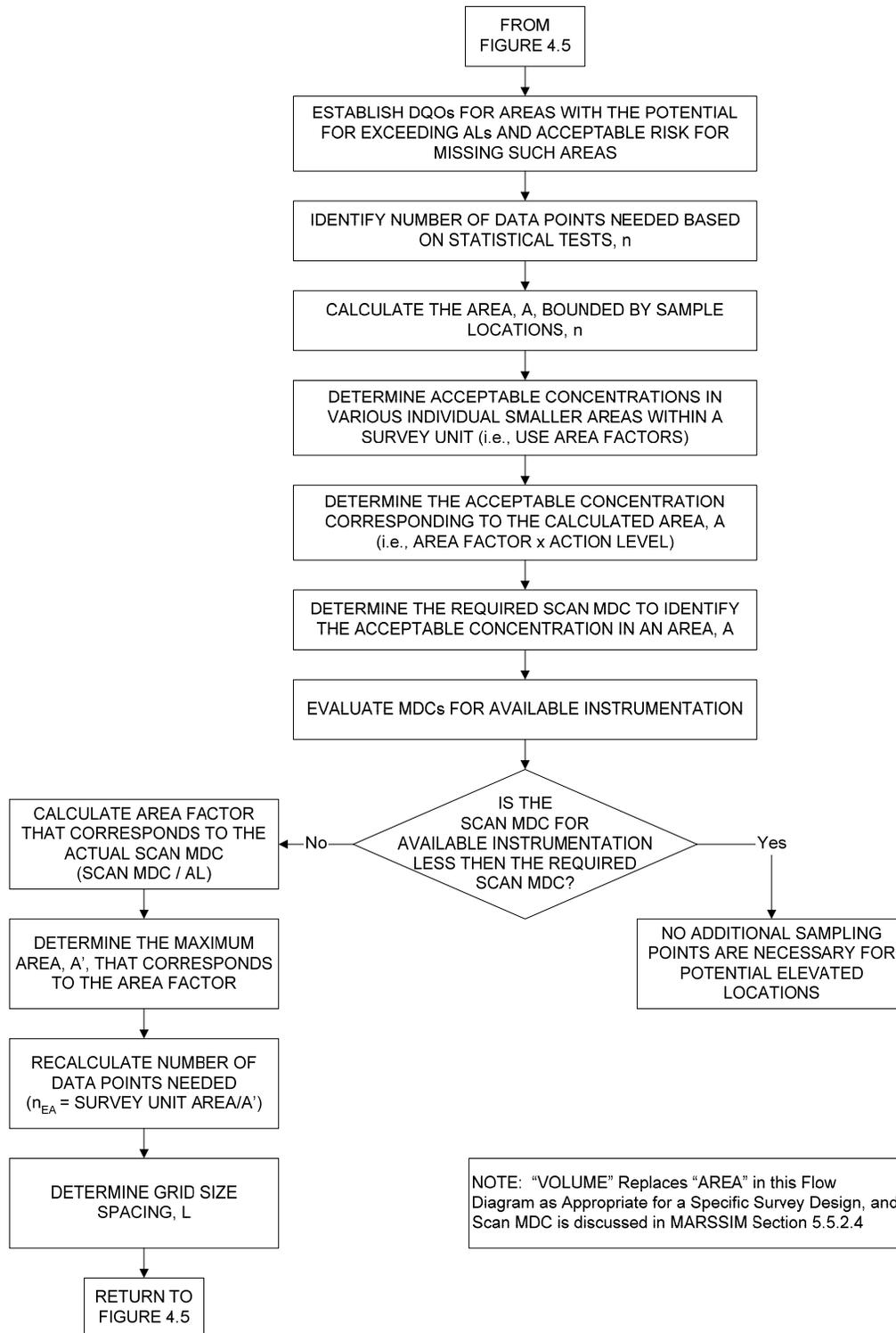
389

Figure 4.4 Flow Diagram for a Disposition Survey Design



390

391 **Figure 4.5 Flow Diagram for Identifying the Number of Data Points for a**
 392 **MARSSIM-Type Disposition Survey**



393

394 **Figure 4.6 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of**
 395 **Elevated Activity in Class 1 Survey Units for MARSSIM-Type Disposition**
 396 **Surveys**

397 **4.4.1 Scan-Only Survey Designs**

398 Scan-only survey designs use scanning techniques to measure the M&E. The detector is moving
399 at a constant speed relative to the M&E being surveyed while maintaining a constant distance
400 relative to the M&E. Scan techniques include hand-held instruments that are moved over the
401 M&E, as well as systems that move the M&E past stationary detectors (e.g., conveyor systems).
402 For example, a scan-only survey may involve the use of a Geiger-Mueller (GM) pancake
403 detector to measure potential surface radioactivity on hand tools. Alternatively, a scan-only
404 survey could involve the use of a conveyORIZED system that measures large quantities of M&E
405 (e.g., bulk material or laundry). Scan-only surveys are generally applicable to all types of
406 disposition surveys.

407 Scan-only surveys are characterized by large numbers of measurements with relatively short
408 count times. Measurement uncertainty should account for variations in source-to-detector
409 distance, scan speed, and surface efficiency that are commonly associated with scanning
410 measurements.

411 Evaluation of scan-only survey data depends on whether or not individual measurement results
412 are recorded (see Section 6.2.5). The decision of whether to record individual measurement
413 results will impact the selection of instrumentation (see Section 5.9) and survey documentation
414 requirements (see Sections 4.5, 5.11, and 6.9), and may impact handling of the M&E (see
415 Section 5.3).

416 4.4.1.1 Class 1 Scan-Only Surveys

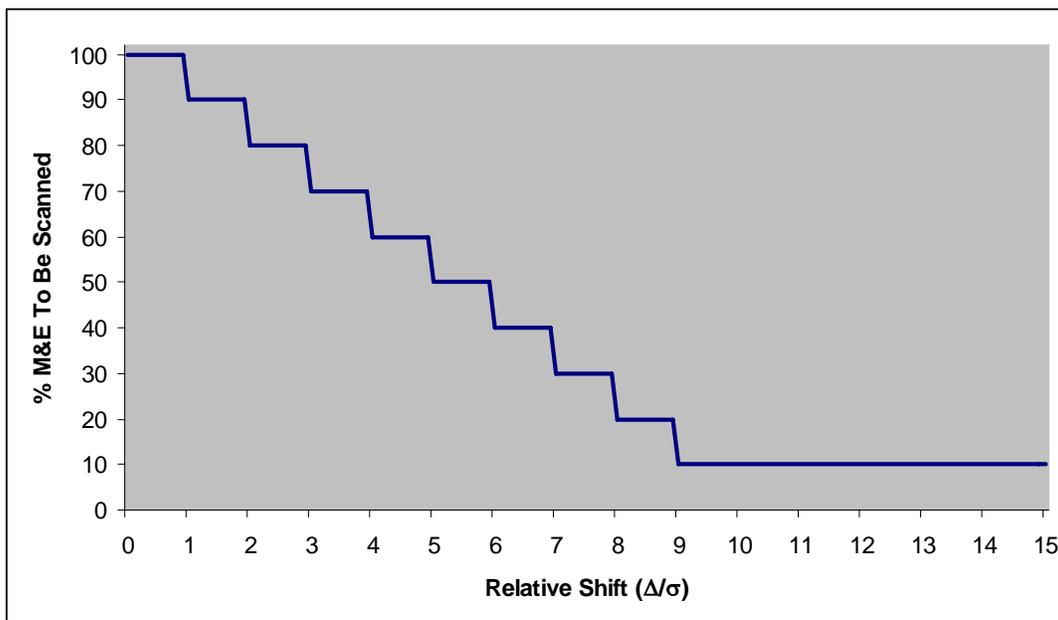
417 Class 1 scan-only surveys require that physical measurements be performed for 100% of the
418 M&E being investigated. For individual items this may require scanning both sides of flat items
419 (e.g., sheet metal, boards) and changing the surveyor's grip on the item to ensure all areas are
420 surveyed (e.g., handles). For conveyor systems this may require flipping or rotating the M&E
421 and performing additional measurements. Conveyor systems can also be designed with detectors
422 surrounding the M&E (e.g., above and below a conveyor belt) to provide 100% measurability.

423 4.4.1.2 Class 2 Scan-Only Surveys

424 Class 2 scan-only surveys use information about the M&E to reduce the total area surveyed
 425 using a graded approach. The amount of the M&E surveyed is calculated based on the relative
 426 shift (i.e., Δ/σ). The percent of the M&E to be surveyed is 10%, or the result using Equation 4-1,
 427 whichever is larger:

$$428 \quad \% \text{ Scan} = \frac{(10 - \frac{\Delta}{\sigma})}{10} \times 100\% \quad (4-1)$$

429 The amount of M&E to be scanned should be rounded up to the next 10 percent, and at least 10%
 430 of the M&E must be surveyed. For example, if the % scan is 51%, then 60% of the M&E will be
 431 surveyed. This means that between 10 to 100% of Class 2 M&E would be measured during the
 432 disposition survey. Figure 4.7 shows the relationship between the relative shift and the amount
 433 of M&E to be scanned.



434

435 **Figure 4.7 Relationship Between the Relative Shift and the Amount of M&E to be Scanned**

436 The scan to release percentages need to represent spatially uniform coverage of the survey unit
 437 and coincide with the conceptual model for the M&E. Consider spatially uniform coverage
 438 when scanning 30% of a desk and 30% of a bucket of bolts. For the desk example, 30%

439 coverage during scanning may be derived from performing scans on the top surface, the legs,
440 inside the drawers, etc., so that essentially 30% of each surface is scanned, yielding 30% total
441 coverage of the entire desk. For the bucket of bolts example, 30% scanning coverage means
442 laying out all the bolts and scanning 30% of them as well as 30% of the bucket itself.
443 Alternatively, if the conceptual model for the desk showed a higher potential for contamination
444 on the top, bottoms of legs, and drawer handles, 100% of these areas could be scanned with
445 smaller amounts of the areas with a lower potential for radioactivity scanned to provide a total of
446 30% coverage for the entire desk. The graded approach should be applied to all aspects of the
447 survey design.

448 The selection of M&E to survey as part of a Class 2 survey is project specific and is determined
449 based on what is known about the M&E. For example, if all of the M&E is accessible and is
450 expected to have uniform radionuclide concentrations or levels of radioactivity, the M&E to be
451 surveyed should be selected randomly. However, there may be areas that are difficult-to-access
452 with the instrumentation selected to perform the survey. If there is a known and accepted
453 relationship between radionuclides in difficult-to-access areas and radionuclides in accessible
454 areas, the Class 2 measurements may be biased to only accessible areas (i.e., representative of
455 measurements in difficult-to-access areas).

456 If elevated radionuclide concentrations or levels of radioactivity are restricted to areas that can be
457 readily identified (e.g., discolored areas, corners, cracks, access points) the Class 2
458 measurements may be designed to concentrate on these biased areas. The Class 2 survey design
459 should include a combination of biased and random areas to check assumptions used to support
460 the survey design.

461 The selection of M&E to survey may also depend on the physical characteristics of the M&E.
462 For example, surveying 40% of the inside of a railroad car would be different from surveying
463 40% of a pile of rubblized concrete. Section 5.3 provides information on handling M&E and
464 determining what will be measured during implementation of the survey design.

465 4.4.1.3 Class 3 Scan-Only Surveys

466 Class 3 scan-only survey designs are identical to Class 2 scan-only survey designs. The planning
467 team may decide that some Class 3 scan-only disposition surveys require that less than 10% of

468 the M&E will be measured. The decision to design a survey requiring less than 10% of the
469 M&E to be measured should be based on the total uncertainty associated with the disposition
470 decision. The determination of total uncertainty should be based on process knowledge,
471 historical data, and the results of preliminary and disposition surveys.

472 In addition, some Class 3 scan-only survey designs may be based solely on biased
473 measurements. In other words, random measurement locations are not required for Class 3 scan-
474 only survey designs. However, if biased measurements are reasonable, they should be
475 performed, keeping in mind that Class 3 M&E have very little or no potential for exceeding the
476 AL.

477 **4.4.2 In situ Survey Designs**

478 In situ survey designs use static measurements to measure 100% of an item. The detector and
479 the item being measured are held in a fixed geometry⁵ for a specified count time to meet the
480 MQOs. There are a wide variety of in situ measurement techniques available. Examples include
481 box counters, portal monitors, and in situ gamma spectrometry systems, as well as direct
482 measurements with hand-held instruments. In situ surveys are generally applied to situations
483 where scan-only surveys are determined to be unacceptable. For example, variations in source-
484 to-detector distance, scan speed, and surface efficiency that are commonly associated with
485 scanning measurements can often be effectively controlled using an in situ survey design.

486 In situ surveys are characterized by limited numbers of measurements with long count times
487 (relative to scan-only surveys). Measurement uncertainty will incorporate spatial uncertainty
488 because of the source geometry assumed in the calibration. Thus, special attention needs to be
489 made to the assumptions made in the calibration of in situ systems. Potential deviations from
490 these assumptions need to be propagated through the calibration equation to assess the total

⁵ There are situations where the levels of radioactivity for M&E being measured are expected to be inhomogeneous. Certain measurement systems can rotate the M&E during a measurement to provide an estimate of the average activity. For the purposes of this section, these are considered fixed geometries. Additional discussion on the limitations of these systems is provided in Chapter 5.

491 measurement uncertainty (see Section 5.6). Count times are determined by the MQOs rather
 492 than the time constant of the measurement system. In situ measurements provide a 100%
 493 measurement for some portion of the M&E being investigated. The M&E may be an individual
 494 item or piece of equipment, or some fraction of a large quantity of material determined by the
 495 solid angle coverage of the detector.

496 In situ surveys may consist of a single measurement, or a series of measurements. Single
 497 measurement surveys are typically performed on individual items or relatively small batches of
 498 M&E. A series of in situ measurements may be used to evaluate larger quantities of M&E. In
 499 some cases, a series of in situ measurements may be performed of a single item or batch of M&E
 500 to provide several estimates of the radionuclide concentrations from different angles. The
 501 planning team may decide to identify survey units and determine a statistically based number of
 502 measurements per survey unit using MARSSIM guidance. MARSAME does not adjust survey
 503 unit sizes based on classification. This means there is no difference between Class 2 and Class 3
 504 in situ surveys utilizing a MARSSIM-type approach.

505 4.4.2.1 Class 1 In situ Surveys

506 Class 1 in situ surveys require that physical measurements be performed for 100% of the M&E
 507 being investigated. Placing an item inside a 4- π measurement system, performing a series of
 508 measurements with overlapping fields of view that incorporate all of the M&E, or rotating the
 509 M&E within the field of view of the detector so 100% of the M&E are measured are examples
 510 where 100% of the M&E are measured.

511 4.4.2.2 Class 2 In situ Surveys

512 Class 2 in situ surveys use information about the M&E to reduce the total area surveyed using a
 513 graded approach. The amount of the M&E surveyed is calculated based on the relative shift (i.e.,
 514 Δ/σ). The percent of the M&E to be surveyed is 10% or the result using Equation 4-2,
 515 whichever is larger:

$$516 \quad \% \text{ Measured or } \% \text{ Solid Angle Coverage} = \frac{(10 - \frac{\Delta}{\sigma})}{10} \times 100\% \quad (4-2)$$

517 The fraction of the M&E or the solid angle coverage of the M&E to be surveyed should be
518 rounded up to the next 10 percent. If the % coverage is 51%, then 60% of the M&E will be
519 surveyed. This means that 10 to 100% of Class 2 M&E would be measured during the
520 disposition survey.

521 The selection of M&E to survey as part of a Class 2 survey is project specific and is determined
522 based on what is known about the M&E. For example, if all of the M&E is accessible and is
523 expected to have uniform radionuclide concentrations or levels of radioactivity, the M&E to be
524 surveyed should be selected randomly. However, there may be areas that are difficult-to-access
525 with the instrumentation selected to perform the survey. If there is a known and accepted
526 relationship between radionuclides in difficult-to-access areas and radionuclides in accessible
527 areas, the Class 2 measurements may be biased to only accessible areas (i.e., representative of
528 measurements in difficult-to-access areas). If elevated radionuclide concentrations or levels of
529 radioactivity are restricted to areas that can be readily identified (e.g., discolored areas, corners,
530 cracks, access points) the Class 2 measurements may be designed to concentrate on these biased
531 areas. The Class 2 survey design should include a combination of biased and random areas to
532 check assumptions used to support the survey design.

533 4.4.2.3 Class 3 In situ Surveys

534 Class 3 in situ survey designs are identical to Class 2 in situ survey designs. The planning team
535 may decide that some Class 3 in situ disposition surveys require that less than 10% of the M&E
536 will be measured. The decision to design a survey requiring less than 10% of the M&E to be
537 measured should be based on the total uncertainty associated with the decision based on process
538 knowledge, historical data, and the results of preliminary and disposition surveys.

539 4.4.3 MARSSIM-Type Survey Designs

540 MARSSIM-type survey designs combine a statistically based number of static measurements to
541 determine average radionuclide concentrations or radioactivity levels with scanning to identify
542 areas of elevated radionuclide concentrations or radioactivity for specified quantities of M&E
543 (i.e., survey units). Identifying survey unit sizes, laying out systematic measurement grids, and
544 calculating project- and item-specific area factors requires a significant effort. Section 5.3
545 discusses considerations for handling M&E, including locating measurements. The planning

546 team should consider that MARSSIM-type survey designs might be more complex and require
547 more resources than scan-only or in situ survey designs that meet the DQOs. Information on
548 designing MARSSIM-type surveys is found in MARSSIM Section 5.5. In general, MARSSIM-
549 type surveys of M&E are only performed on large, complicated M&E with a high inherent value
550 after scan-only and in-situ surveys have been considered and rejected.

551 4.4.3.1 Class 1 MARSSIM-Type Surveys

552 Class 1 MARSSIM-type surveys calculate the required number of measurements in each survey
553 unit based on the shift (i.e., Δ), the variability in the radionuclide concentrations or levels of
554 radioactivity (i.e., σ), and the Type I and Type II decision error rates (i.e., α and β). The number
555 of measurements per survey unit is adjusted to account for small areas of elevated activity using
556 the information in MARSSIM Section 5.5.2.4. In addition, scan measurements are required for
557 100% of the M&E being investigated.

558 The development of survey unit boundaries is discussed in Section 3.3.1. The quantity of M&E
559 in each survey unit should be determined based on the modeling assumptions used to develop the
560 action levels.

561 The variability in the radionuclide concentrations in each survey unit can be estimated using the
562 standard deviation of preliminary measurements or the uncertainties from individual
563 measurements, whichever is larger. Whenever practical, preliminary data should be used to
564 provide estimates of variability. As a last resort when preliminary data are not available,
565 MARSSIM states that assuming a coefficient of variation on the order of 30% may be reasonable
566 (MARSSIM Section 5.5.2.2, Page 5-26). This 30% is used as a starting point for the DQO
567 Process, and should be adjusted iteratively during the development of a final survey design. For
568 M&E, MARSAME recommends using a more conservative assumption.

569 Area factors are specified in a regulation or other guidance, or developed based on the changes in
570 dose or risk associated with changing the area (or volume) of activity to be less than the entire
571 survey unit. For example, DOE Order 5400.5 (DOE 1993) allows use of an area factor of up to
572 3.0 for surficial radioactivity for all radionuclides. NUREG-1640 (NRC 2003a) is only
573 concerned with average activity and total inventory of radioactivity, which implies that within
574 the survey unit relatively high localized concentrations of radioactivity could exist. This

575 implication does not mean that a large part of the survey unit may be used to intentionally
576 “dilute” high concentrations of radioactivity. Rather, in the course of normal processing there is
577 a non-prescriptive flexibility allowed of inhomogeneity of radionuclide concentrations.
578 Nevertheless, mixing different classes of M&E (Class 1, 2, and 3) is not allowed. The physical
579 characteristics of the M&E combined with potential future exposures based on the selected
580 disposition option mean that area factors (and possibly exposure pathway dose or risk models)
581 need to be developed for each project. In the absence of regulation-specific area factors,
582 assuming an area factor of 1.0 for all radionuclides would be the most conservative approach.
583 Depending on the basis of the action level, an area factor may or may not be applicable.
584 MARSSIM uses completely different scenarios to develop area factors than those used in
585 NUREG-1640 (NRC 2003a). Area factors may be derived on a project-specific basis using
586 project-specific scenarios.

587 If the radioactivity being measured is present in background, Table 5.3 in MARSSIM provides
588 the number of measurements required in each survey unit as well as in each reference area.
589 MARSSIM Section 5.5.2.2 and NUREG-1505 (NRC 1998a) Sections 9.4 and 9.5 provide
590 information on calculating the number of required measurements when the radioactivity being
591 measured is present in background.

592 If the radioactivity being measured is not present in background, Table 5.5 in MARSSIM
593 provides the number of measurements required in each survey unit. MARSSIM Section 5.5.2.3
594 and NUREG-1505 (NRC 1998a) Sections 9.2 and 9.3 provide information on calculating the
595 number of required measurements when the radioactivity being measured is not present in
596 background. For convenience, MARSSIM Tables 5.3 and 5.5 and the basics of the MARSSIM
597 approach have been extracted from MARSSIM and are included as Appendix A.

598 Whenever area factors other than 1.0 are used to design the disposition survey, a systematic grid
599 should be used to determine measurement locations. The systematic grid determines the largest
600 area that could be missed by the measurements which is used to determine the required scan
601 MDC. Section 5.3 provides information on handling M&E, including setting up systematic
602 grids.

603 4.4.3.2 Class 2 MARSSIM-Type Surveys

604 Class 2 MARSSIM-type surveys are similar to Class 1 MARSSIM-type surveys. The numbers
605 of measurements in each survey unit are determined in the same manner, although the expected
606 radionuclide concentrations or levels of radioactivity and the decision error rates may change.
607 Unlike MARSSIM, the survey unit size remains the same and does not change based on
608 classification. The portion of the survey unit where scan surveys are required is reduced to
609 between 10 and 100%. The information in Section 4.4.1.2 for Class 2 scan-only surveys should
610 be used to determine the areas to be scanned. This recommendation is provided for M&E only,
611 and is not intended to update the guidance in MARSSIM for surface soils and building surfaces.

612 4.4.3.3 Class 3 MARSSIM-Type Surveys

613 Class 3 MARSSIM-type surveys are similar to Class 1 MARSSIM-type surveys. The numbers
614 of measurements in each survey unit are determined the same way, although the expected
615 radionuclide concentrations or levels of radioactivity and the decision error rates may change.
616 Unlike MARSSIM, the survey unit size does not change based on classification. The portion of
617 the survey unit where scan surveys are required is reduced to less than 10% and is based on
618 professional judgment. The information in Section 4.4.1 for scan-only surveys should be used to
619 determine the areas to be scanned. This recommendation is provided for M&E only, and is not
620 intended to update the guidance in MARSSIM for surface soils and building surfaces.

621 **4.4.4 Optimize the Disposition Survey Design**

622 The disposition survey design process described in this supplement could result in the
623 development of multiple potential disposition survey designs. For example, consider the case
624 when simultaneous compliance with more than one action level is required (e.g., DOE 1993). In
625 other cases the decision resulting from one survey may lead to the requirement of another survey,
626 such as failure to demonstrate compliance with the disposition criterion for release resulting in a
627 survey to comply with radioactive waste acceptance criteria. Multiple survey designs could
628 result from selection of multiple potential disposition options, action levels, survey techniques,
629 measurement systems, decision rules, or some combination of these factors. Before the planning
630 team can proceed, all of the potential disposition survey designs need to be reviewed to select a
631 final disposition survey design.

632 The final step in the DQO Process (Develop the Detailed Plan for Obtaining Data, Step 7) is
633 designed to produce the most resource-efficient survey design that is expected to meet the
634 DQOs. It may be necessary to revisit previous steps in the DQO Process and work through this
635 step more than once.

636 There are five activities included in this step:

- 637 1. Review existing data (e.g., historical data, preliminary survey results). Use existing data
638 to support the data collection design. If no existing data are available, consider
639 performing preliminary surveys to acquire estimates of variability to determine numbers
640 of measurements. Evaluate potential problems regarding detection limits or
641 interferences. If new data will be combined with existing data, determine if there are data
642 gaps that need to be filled or deficiencies that can be mitigated prior to implementing the
643 disposition survey design.
- 644 2. Evaluate operational decision rules. The theoretical decision rules developed in Section
645 3.6 were based on the assumption that the true radionuclide concentrations or
646 radioactivity present in the M&E were known. Operational decision rules based on the
647 statistical tests (see Chapter 6) should replace the theoretical decision rule (see Sections
648 3.5 and 4.2.6). Review the parameter of interest (e.g., maximum measured value, mean
649 or median radionuclide concentration) and the possible statistical tests that could be
650 applied to the data to evaluate the operational decision rules.
- 651 3. Develop general data collection design alternatives. Sections 4.4.1, 4.4.2, and 4.4.3
652 provide information on general data collection design alternatives applicable to
653 disposition surveys. Consider individual instruments and measurements techniques (see
654 Chapter 5) combined with general data collection designs to develop alternative survey
655 approaches.
- 656 4. Calculate the number of measurements or amount of M&E to be surveyed. Sections
657 4.4.1, 4.4.2, and 4.4.3 provide general information on determining the level of survey
658 effort for the general data collection design alternatives based on classification.
659 Determine the estimated resources required for each of the alternative survey approaches.

660 5. Select the most resource-effective survey design. Evaluate each of the survey approaches
661 based on the required resources and the ability to meet the DQO constraints within the
662 tolerable decision error limits. The survey design that provides the best balance between
663 cost and meeting survey objectives while considering the non-technical economic and
664 health factors imposed on the project is usually the most resource-effective. The
665 statistical concept of a power curve (MARSSIM Appendix I.9) is extremely useful in
666 investigating the performance of alternative survey designs.

667 If none of the alternative survey designs meet the survey objectives within the tolerable decision
668 error limits while considering the budget or other constraints, then the planning team will need to
669 relax one or more of the constraints. Examples include:

- 670 • Increasing the budget for implementing the survey,
- 671 • Using exposure pathway modeling to develop site-specific action levels,
- 672 • Increasing the decision error rates, not forgetting to consider the consequences
673 associated with making an incorrect decision,
- 674 • Increasing the width of the gray region for Scenario A surveys by decreasing the
675 average activity associated with the M&E which may require remediation, or
676 negotiating a higher UBGR for Scenario B which may require additional reference
677 area investigations,
- 678 • Relaxing other project constraints—e.g., schedule,
- 679 • Changing the boundaries—it may be possible to reduce measurement costs by
680 changing or eliminating survey units that will require different decisions,
- 681 • Segregating the M&E based on physical or radiological attributes (see Section 5.4),
- 682 • Evaluating alternative measurement techniques with lower detection limits or lower
683 survey costs,
- 684 • Adjusting the list of radionuclides or radiations of concern (Section 3.2), and
- 685 • Considering other disposition options that will result in higher action levels.

686 **4.5 Document the Disposition Survey Design**

687 Documentation of the disposition survey design should provide a complete record of the selected
688 survey design. The documentation should include all assumptions used to develop the survey
689 design, a detailed description of the M&E being investigated, along with the DQOs and MQOs
690 for the survey (e.g., MQC, MDC, count time). The regulatory basis for the disposition criterion
691 and calculations showing the derivation of action levels should also be provided. Sufficient data
692 and information should be provided to enable an independent re-creation and evaluation of the
693 disposition survey design. The documentation should provide information on the following
694 topics:

- 695 • *Who* - information on who developed, reviewed, and approved the survey design, as
696 well as training and qualification requirements for such individuals, should be
697 included, along with any requirements for who can implement the survey design.
- 698 • *What* - information on what M&E were considered when developing the survey
699 design along with a description of M&E to which the survey design applies.
- 700 • *When* - information on when the survey design was developed along with when the
701 survey design will be implemented including restrictions on time of day, time of year,
702 and count times when applicable.
- 703 • *Where* - information on where the survey design can be applied (including restrictions
704 on local background levels) along with measurement locations including fraction of
705 M&E to be surveyed and locations of direct measurements or samples or methods for
706 selecting locations during implementation,
- 707 • *Why* - information on why a survey should be performed including justification for
708 impacted and non-impacted decisions and assignment of classifications,
- 709 • *How* - information on how the survey will be performed including measurement
710 techniques and instruments along with instructions for segregating and handling the
711 M&E during the survey.

712 There are two methods for documenting surveys described in the following sections based on the
713 type of project:

- 714 • Routine or Repetitive Surveys, and
- 715 • Case-Specific Applications.

716 **4.5.1 Routine Surveys and Standard Operating Procedures**

717 Routine (or repetitive) surveys are disposition surveys that are routinely performed on M&E
718 entering or leaving an operating facility. Examples of routine surveys include:

- 719 • Clearance of tools from radiological control areas at a radiation facility,
- 720 • Preparation of low-level radioactive waste for disposal, and
- 721 • Interdiction of scrap metal entering a recycling facility.

722 Documenting routine survey designs, for example as SOPs, can be consistent with MARSAME
723 recommendations. SOPs detail the work processes that are conducted or followed within an
724 organization and document the way activities are performed. SOPs that also meet the DQOs for
725 the disposition survey can be used to document routine survey designs. The development and
726 use of SOPs facilitates consistent conformance to technical and quality system requirements.
727 They promote quality through consistent implementation of a process within an organization,
728 even if there are temporary or permanent personnel changes. The benefits of a valid SOP are
729 reduced work effort combined with improved data comparability, credibility, and legal
730 defensibility (EPA 2001). Additional guidance on developing SOPs, including example SOPs, is
731 provided in EPA QA/G-6 (EPA 2001).

732 4.5.1.1 SOP Process

733 The organization developing the SOP should have a procedure in place for determining what
734 procedures or processes need to be documented. SOPs documenting these procedures or
735 processes should be written by individuals knowledgeable with the activity and the
736 organization's internal structure. For disposition survey designs, a team approach to writing
737 SOPs is often used. This allows input from subject-matter experts with information critical to
738 the survey process, and promotes acceptance of the SOP once it is completed.

739 SOPs should be concise and provide step-by-step instructions in an easy-to-read format. They
740 should provide sufficient detail so that a technician with limited experience, but with a basic
741 understanding of the process, can successfully implement the survey design when unsupervised.

742 Disposition survey SOPs should be reviewed and validated by one or more individuals with
743 appropriate training and experience in performing surveys of M&E before they are implemented.
744 It may be helpful to have the draft SOP field tested by someone not directly involved in the
745 development of the SOP. The review process for disposition surveys should include a regulatory
746 review and appropriate stakeholder involvement.

747 SOPs need to remain current. SOPs should be updated and re-approved whenever survey
748 procedures are changed. SOPs should be systematically reviewed on a periodic basis to ensure
749 that the policies and procedures remain current and appropriate.

750 Many disposition survey activities use checklists or forms to document completed tasks (e.g.,
751 daily instrument checks). Any checklists or forms included as part of the disposition survey
752 should be referenced at the points in the procedure where they are used and attached to the SOP.
753 Remember that the checklist or form is not the SOP, but a part of the SOP.

754 The organization should have a system for developing, reviewing, approving, controlling, and
755 tracking documents. This process is usually documented in the Quality Management Plan.

756 4.5.1.2 General Format for Disposition Survey SOPs

757 In general, disposition survey SOPs consist of five elements:

- 758 • Title Page,
- 759 • Table of Contents,
- 760 • Procedures,
- 761 • Quality Assurance and Quality Control, and
- 762 • References.

763 The title page should include a title that clearly identifies the activity, an identification number,
764 date of issue or revision, and the name of the organization to which the SOP applies. The
765 signatures and signature dates of individuals who prepared and approved the SOP should also be
766 included.

767 The table of contents lists the major section headings and the pages where the information is
768 located. This provides a quick reference for locating the desired information and identifies
769 changes or revisions made to individual sections.

770 The procedures are specific to the disposition survey design and may include some or all of the
771 following topics:

- 772 • Scope and applicability. This section should provide a detailed description of the
773 M&E to which the SOP can be applied. In addition, it is often important to clearly
774 identify M&E to which the SOP does not apply.
- 775 • Summary of method. This section briefly describes the overall survey design,
776 identifies the disposition option, lists the action levels, and provides their regulatory
777 basis. The details on the development of the action levels based on the disposition
778 criterion in the regulations is generally referenced or included as an attachment.
- 779 • Definitions. This section identifies and defines any acronyms, abbreviations, or
780 specialized terms used in the SOP.
- 781 • Health and safety warnings. This section indicates operations that could result in
782 personal injury, loss of life, or uncontrolled release to the environment. Explanations
783 of what could happen if the procedure is not followed or if it is followed incorrectly
784 should appear here as well at the critical steps in the procedure.
- 785 • Cautions. This section identifies activities that could result in equipment damage,
786 degradation of data, or possible invalidation of results. Explanations of what could
787 happen if the procedure is not followed or if it is followed incorrectly should appear
788 here as well as the critical steps in the procedure.
- 789 • Interferences. This section describes any component of the process that may interfere
790 with the final decision regarding disposition of the M&E.

- 791 • Personnel qualifications. This section lists the minimum experience required for
792 individuals implementing the SOP. Any required certifications or training courses
793 should be listed. For many routine surveys the training records of the personnel
794 implementing the survey design are used to document compliance with the SOP.
- 795 • Equipment and supplies. This section lists and specifies the equipment, materials,
796 reagents, and standards required to implement the SOP. At a minimum, this section
797 must identify the model number and manufacturer of instruments that will be used to
798 perform the survey.
- 799 • Procedure. This section provides all pertinent steps, in order, and materials needed to
800 implement the survey design. This section should include:
- 801 • Instrument or method calibration and standardization (generally requires a check of
802 the instrument calibration date and lists the appropriate MQOs such as MQC or MDC
803 and references the details for these processes).
- 804 ○ Type, number, and location of measurements.
- 805 ○ Data acquisition, calculations, and data reduction requirements.
- 806 ○ Troubleshooting.
- 807 ○ Computer hardware and software.
- 808 ○ Data and records management. This section describes the forms to fill out,
809 reports to be written, and data and record storage information. At a minimum
810 routine survey records should identify the personnel performing measurements
811 and the instruments used to perform the measurements (i.e., model and serial
812 number for all components of the measurement system). These records should
813 show that the personnel performing the survey were properly trained and the
814 instruments used to collect the data were calibrated and operating properly. This
815 section should clearly state whether individual measurement results will be
816 recorded, since this information is not always required.

817 The QA/QC section describes the activities required to demonstrate the successful performance
818 of the disposition survey. For many organizations the QC activities for individual instruments
819 are provided in separate SOPs describing the proper use of that instrument, so the daily checks of
820 the instruments are included by reference. The QA/QC section should identify QC requirements

821 for the disposition survey such as blanks, replicates, splits, spikes, and performance evaluation
822 checks. The frequency for each QC measurement should be listed along with a discussion of the
823 rationale for decisions. Specific criteria should be provided for evaluating each type of QC
824 measurement, as well as actions required when the results exceed the QC limits. The procedures
825 for reporting and documenting the results of QC measurements should be listed in the QA/QC
826 section. Section 5.10 provides additional information on QC for disposition surveys.

827 The reference section should list all documents or SOPs that interface with the routine survey
828 SOP. Full references (including SOP versions and dates) should be provided. Published
829 literature and instrument manuals that are not readily available should be attached.

830 **4.5.2 Case Specific Applications**

831 There are M&E that may require a disposition survey that are not covered by routine surveys.
832 These are collectively referred to as case-specific applications. Case-specific applications
833 include project-specific applications such as decommissioning or cleanup surveys, as well as
834 unique applications involving one-time disposition of special equipment from a facility.

835 Ideally, documentation of case-specific survey designs involves a comparable level of effort
836 associated with routine surveys. This is obviously the case for large decommissioning or
837 cleanup projects where survey designs are documented as SOPs using a process analogous to
838 routine surveys. The major differences are seen in the requirements for approval and
839 maintenance of SOPs, which are generally less for decommissioning or cleanup projects
840 compared to operating facilities. Disposition survey designs that will be applied during
841 decommissioning or cleanup activities are typically documented as part of the survey design.
842 However, a survey design needs to provide all of the information supporting the development of
843 the disposition survey design, where SOPs typically focus on one aspect of the survey design or
844 implementation. Historical information, process knowledge, description of the M&E, and
845 assumptions used in the disposition survey design need to be included and not referenced.

846 The assumptions used to develop survey designs for routine surveys cannot be applied to all
847 M&E, so situations will arise where a disposition survey design needs to be developed for
848 special items or unique applications. These types of surveys are often associated with M&E that
849 have a high inherent value (e.g., large quantities of valuable materials, unique or very expensive

850 equipment) to offset the resources required to develop a unique disposition survey design. These
851 special survey designs need to be inclusive, providing all of the information supporting the
852 development of the disposition survey design. Detailed discussions should be provided for all
853 parts of the survey design, including selection of a disposition option, selection and development
854 of action levels, development of MQOs and selection of instruments, and QA/QC requirements
855 for individual measurement systems as well as for the entire disposition survey.

856 For most applications the disposition survey design is expected to be documented as a stand-
857 alone survey plan or as a series of SOPs. However, the planning team may determine that the
858 survey design documentation can be combined with the results of the survey into a single
859 document. At a minimum, instructions on the type, number, and location of measurements
860 should be documented to provide instructions to the technicians performing the survey.

861 Documenting the entire disposition decision process in a single document is most appropriate for
862 unique applications where there is sufficient historical information or survey precedent such that
863 there is little uncertainty associated with the development of a survey design. The benefit of
864 documenting all of the survey decisions (e.g., design, implementation, and assessment) in one
865 document is the savings in resources to develop multiple documents. The risk associated with
866 not documenting the survey design process until after implementation is that the assessment will
867 identify some problems with the survey design requiring additional data collection which could
868 impact project costs and schedule.

1 **5 IMPLEMENTATION OF DISPOSITION SURVEYS**

2 **5.1 Introduction**

3 This chapter discusses the implementation phase of the Data Life Cycle and focuses on
4 controlling measurement uncertainty. The information in this chapter describes approaches for
5 safely implementing the final disposition survey design developed in Chapter 4, methods for
6 controlling uncertainty, and techniques to determine whether the measurement results achieve
7 the survey objectives.

8 Similar to MARSSIM, MARSAME excludes specific recommendations for implementing
9 disposition surveys. Instead, MARSAME provides generic recommendations and information to
10 assist the user in selecting measurement techniques for implementing the survey design. This
11 approach encourages consideration of innovative measurement techniques and emphasizes the
12 flexibility of the information in MARSAME.

13 Implementation begins with health and safety considerations for the disposition survey (Section
14 5.2). Section 5.3 provides information on handling M&E, while Section 5.4 discusses
15 segregating M&E based on physical and radiological attributes. Section 5.5 continues the
16 discussion of measurement quality objectives (MQOs) from Chapters 3 and 4. Measurement
17 uncertainty (Section 5.6), detectability (Section 5.7), and quantifiability (Section 5.8), are three
18 MQOs that are described in greater detail. Combining an instrument with a measurement
19 technique to ensure the MQOs are achieved is discussed in Section 5.9. Section 5.10 provides
20 information on quality control (QC), and information on data reporting is provided in
21 Section 5.11.

22 **5.2 Ensure Protection of Health and Safety**

23 Health and safety is emphasized as an issue potentially affecting the implementation of
24 MARSAME disposition surveys. The focus of minimizing hazards is shifted away from
25 environmental hazards (e.g., confined spaces, unstable surfaces, heat and cold stress) and tailored
26 towards scenarios where health and safety issues may affect how a disposition survey is designed
27 and performed. Work areas and procedures that present potential safety hazards must be

28 identified and evaluated to warn personnel of potential hazards. Personnel must be trained with
29 regards to potential physical and chemical safety hazards (e.g., inhalation, adsorption, ingestion,
30 and injection/puncturing) and the potential for injury (slips, trips, falls, burns, etc.).

31 A job safety analysis (JSA) should be performed prior to implementing a disposition survey.
32 The JSA offers an organized approach to the task of locating problem areas for material handling
33 safety (OSHA 2002). The JSA should be used to identify hazards and provide inputs for drafting
34 a health and safety plan (HASP). The HASP will address the potential hazards associated with
35 M&E handling and movement and should be prepared concurrently with the survey design. The
36 HASP identifies methods to minimize the threats posed by the potential hazards. The
37 information in the HASP may influence the selection of a measurement technique and
38 disposition survey procedures. Radiation work permits (RWPs) may be established to control
39 access to radiologically controlled areas. RWPs contain requirements from the JSA such as
40 dosimetry and personal protective equipment (PPE), as well as survey maps illustrating predicted
41 dose rates and related radiological concerns (e.g., removable or airborne radioactivity). Hazard
42 work permits (HWPs) may be used in place of RWPs at sites with primarily physical or chemical
43 hazards. The Case Study presented in Chapter 7 (see Section 7.3.6.1) provides an example of a
44 JSA.

45 The JSA systematically carries out the basic strategy of accident prevention through the
46 recognition, evaluation, and control of hazards associated with a given job as well as the
47 determination of the safest, most efficient method of performing that job. This process creates a
48 framework for deciding between engineering controls, administrative controls, and PPE for the
49 purpose of controlling or correcting unsafe conditions (Hatch 1978). Examples of these controls
50 include:

- 51 • Engineering controls – physical changes in processes or machinery (e.g., installing guards
52 to restrict access to moving parts during operation), storage configuration (e.g., using
53 shelves in place of piles or stacks).
- 54 • Administrative controls – changes in work practices and organization (e.g., restricted
55 areas where it is not safe to eat, drink, smoke, etc.) including the placement of signs to
56 warn personnel of hazards.

- 57 • Personal protective equipment (PPE) – clothing or devices worn by employees to protect
58 against hazards (e.g., gloves, respirator, full-body suits, etc.).

59 Correction measures may incorporate principles of all of the controls listed above. The preferred
60 method of control is through engineering controls, followed by administrative controls, and then
61 personal protective equipment.

62 Proper handling procedures for hazardous M&E are documented in site-specific health and
63 safety plans. Compliance with all control requirements is mandatory to maintain a safe working
64 environment. Personnel must regard control requirements as a framework to facilitate health and
65 safety, while still taking responsibility for their own well being. Being wary of safety hazards
66 remains an individual responsibility, and personnel must be aware of their surroundings at all
67 times in work areas.

68 **5.3 Consider Issues for Handling M&E**

69 Materials and equipment handling is addressed in this document as a process control issue.
70 M&E handling requirements are determined by the final integrated survey design (see Section
71 4.4) and the combination of instrumentation and measurement technique used to perform the
72 survey (see Section 5.9). M&E may also require handling to more closely match the
73 assumptions used to develop instrument calibrations used to determine measurement uncertainty
74 (see Section 5.6), measurement detectability (see Section 5.7), and measurement quantifiability
75 (see Section 5.8).

76 Typically, M&E will be handled to:

- 77 • Prepare a measurement grid or arrange M&E to perform a survey.
78 • Provide access for performing measurements.
79 • Transport the M&E to a different location.

80 **5.3.1 Prepare M&E for Survey**

81 Depending on the survey design, or assumptions used to develop the survey design, it may be
82 necessary to prepare the M&E for survey. The amount of preparation required is determined by

83 the DQOs and MQOs, and ranges from identifying measurement locations to adjusting the
84 physical characteristics of the M&E (e.g., disassembly, segregation, physical arrangement).

85 The performance of a MARSSIM-type survey requires determining the location where the
86 measurements are to be performed. The DQOs will determine the level of effort required to
87 identify, mark, and record measurement locations.

88 Identifying measurement locations can be problematic because MARSSIM-type surveys
89 recommend samples to be located either randomly (Class 3) or on a systematic grid (Class 1 and
90 Class 2). Class 2 and Class 3 scan-only and in situ surveys do not require 100% of the M&E to
91 be measured, so a method of identifying which portions will be measured is required.

92 Bulk materials or M&E consisting of many small, regularly shaped objects can be spread out in a
93 uniform layer, and a two-dimensional grid can be superimposed on the surface to identify
94 measurement locations. However, it is virtually impossible to identify random or systematic
95 locations on M&E that consist of relatively few, large, irregularly shaped objects. The reason is
96 that it is virtually impossible to establish a reference grid for these M&E. It is important to note
97 that the objective for random locations is to allow every portion of the survey unit the same
98 opportunity to be measured. Alternatively, the objective of systematic locations is to distribute
99 the measurement locations equally. It is only necessary to establish a reference grid to
100 sufficiently identify the measurement locations to meet the survey objectives.

101 One way to approximate a reference grid for locating measurements is to establish a grid in the
102 area where the survey will be performed. The M&E to be surveyed are laid out in a single layer
103 within the grid. The grid can then be used to identify measurement locations. Another option
104 for locating measurements involves superimposing a grid on top of the M&E. A net could be
105 laid over the M&E to be surveyed, ropes could be laid over the M&E to form a grid, or lights on
106 a grid could be directed onto the M&E to approximate a grid and identify measurement
107 locations.

108 If measurement locations cannot be identified with a grid, there may be no alternative but to
109 perform biased measurements. Measurements would be preferentially performed in locations
110 more likely to contain radionuclides or radioactivity, based on the results of the IA (see Section
111 2.5). This process involves professional judgment and may result in overestimating the average

112 radionuclide concentration or level of radioactivity. In all cases, it is important to document the
113 criteria used for identifying measurement locations and to document that these criteria were
114 followed.

115 Marking measurement locations, once they have been identified, should be done in a way that
116 will not interfere with the measurement. For example, using paint to mark the location of an
117 alpha measurement could end up masking the presence of alpha activity. Using arrows, marking
118 borders, or using an alternate method for marking locations (e.g., encircling with chalk) should
119 be considered for these types of situations.

120 Recording measurement locations may be required as part of the survey objectives if the
121 measurements may need to be repeated. For example, a large piece of equipment is surveyed
122 prior to use on a decommissioning or cleanup project. If the exact same locations will be
123 surveyed at the completion of the project, it will be necessary to record the measurement
124 locations. Permanent or semi-permanent markings can be used to identify the measurement
125 locations. Video or photographic records of measurement locations can also be used to return to
126 a specific measurement location.

127 **5.3.2 Provide Access**

128 Large pieces of equipment may require special handling considerations. Large, mobile
129 equipment (e.g., front loader, bulldozer, or crane) typically requires a specially trained operator.
130 The operator may need to be available during the disposition survey to provide access to all areas
131 requiring survey (e.g., move the equipment to provide access to the bottom of tires or treads).
132 Other large items may require special equipment (e.g., a crane or lift) to provide access to all
133 areas requiring survey. Special health and safety issues (Section 5.2) may be required to ensure
134 protection of survey personnel from physical hazards (e.g., personnel or items falling from
135 heights, or large items dropping on personnel or equipment). It may be necessary to partially or
136 totally disassemble large pieces of equipment to provide access and ensure measurability.

137 Piles of M&E may involve special handling precautions. Piles of dispersible M&E (e.g., soil or
138 concrete rubble) may need to be rearranged to match the assumptions used to develop the
139 instrument efficiency. For example, a conical pile of soil may need to be flattened to a uniform
140 thickness to ensure measurability. If the M&E consists of or contains a significant amount of

141 dust, precautions against generating an airborne radiation hazard may be necessary. Since many
142 dust control systems use liquids to prevent the dust from becoming airborne, it may be necessary
143 to account for dust control impacts on measurability of the M&E. For example, adding water to
144 control dust will make it more difficult to measure alpha radioactivity. Piles of scrap may also
145 present other health and safety concerns along with issues related to measurability. Sharp edges,
146 pinch points, and unstable piles are examples of handling problems that may need to be
147 addressed.

148 Small pieces of M&E may be surveyed individually or combined into groups for survey. Care
149 should be taken when combining items to prevent mixing impacted and non-impacted items, or
150 mixing items with different physical or radiological attributes (see Section 2.2 and Section 5.4).

151 The moving of materials at a given site may require labeling as a quality control measure to
152 ensure M&E movement is tracked and documented. Labeling will help avoid the commingling
153 of impacted and non-impacted materials, and facilitate the staging and storage of impacted and
154 non-impacted M&E in appropriate areas.

155 **5.3.3 Transport the M&E**

156 Identification of impacted and non-impacted areas within a facility will assist in selecting areas
157 for storing, staging, and surveying impacted M&E. In general, impacted M&E should be stored,
158 staged, and surveyed in impacted areas. Care should be taken when moving or handling
159 impacted M&E to prevent the spread of radionuclides to non-impacted areas. M&E in areas with
160 airborne radioactivity issues should be moved to protect the personnel conducting surveys and
161 reduce the possibility of contaminating survey instruments.

162 Disposition surveys can be performed with the M&E in place, or the M&E can be moved to
163 another location. For example, work areas with high levels of radioactivity may make it difficult
164 or resource intensive to meet the MQOs for measurement detectability (Section 5.7) or
165 quantifiability (Section 5.8). Moving the M&E to areas with lower levels of radioactivity will
166 help reduce radiation exposure for personnel conducting surveys and facilitate meeting the
167 survey objectives.

168 **5.4 Segregate the M&E**

169 The purpose of segregation is to separate M&E based on the estimated total measurement
170 uncertainty, ease of handling, and disposition options. Segregation is based on the physical and
171 radiological attributes determined during the Initial Assessment (IA, see Chapter 2), not only on
172 radionuclide concentrations or radiation levels (i.e., classification).

173 In general, segregation based on measurement uncertainty should consider the physical and
174 radiological attributes that affect efficiency (i.e., geometry and fluence rate). M&E with simple
175 geometries, such as drums (cylinder) and flat surfaces (plane), should be separated from M&E
176 with complex geometries. Fluence rate is affected by location of the radioactivity (i.e., surficial
177 or volumetric) as well as surface effects (e.g., rough or smooth), density of the M&E, and type
178 and energy of radiation. High fluence rates are associated with surface radioactivity with high
179 energy on flat smooth surfaces made from materials with high atomic number (due to increased
180 backscatter). Volumetric activity, shielded surfaces, alpha or low energy or beta radiations,
181 irregular shapes, or rough surfaces can cause lower fluence rates. All of these factors should be
182 considered when segregating M&E.

183 Segregation of M&E should be performed conservatively. This means that the user should
184 separate M&E when they are not obviously similar. It is always possible to combine M&E but it
185 is not always practical or possible, to separate M&E once they have been combined. For
186 example, consider a facility where all the waste materials (e.g., paper, wood, metal, broken
187 equipment) are combined into a single “trash pile.” When the planning team considers different
188 measurement methods and disposition options, they identify an innovative measurement method
189 that only applies to non-ferrous scrap metal. This would allow for recycling of these materials
190 with significant cost recovery as opposed to disposal. If the cost of re-segregating the M&E is
191 not offset by the value of recycling these materials, it may not be practical to segregate the non-
192 ferrous metals.

193 It is important to note that segregation does not require physical separation. Consider a generic
194 large box geometry, such as an empty shipping container or railroad car. The large, flat sides
195 could be considered separate survey units from the corners. Therefore, separate surveys would
196 be designed for the corners and the sides even though the entire railroad car would remain intact

197 throughout implementation of the disposition survey. Alternatively (or additionally), obvious
198 flaws, corrosion areas, or damaged areas could be segregated from the areas in good condition.
199 Even if the entire object is eventually surveyed using a single in situ measurement (e.g., in situ
200 gamma spectrometry) it is important to segregate the M&E (at least conceptually) so an adequate
201 evaluation of alternate measurement methods can be performed (see Section 5.9).

202 Handling of M&E during disposition surveys should also be considered during segregation (see
203 Section 5.3). Physical characteristics of the M&E should be considered when segregating based
204 on handling requirements. Small, light items are easier to move and gain access to all surfaces
205 than large, massive items. M&E that will require preparation (e.g., disassembly, crushing,
206 chopping) prior to survey should be segregated from M&E that can be surveyed in their present
207 form. Disposition options should also be considered when segregating M&E. M&E that can be
208 reused or recycled should be segregated from M&E that is being considered for disposal.
209 Selection of disposition options was discussed in Section 2.4.

210 **5.5 Set Measurement Quality Objectives**

211 A number of terms with specific statistical meanings are used in this and subsequent sections.
212 These terms are defined in Appendix G. The concept of Measurement Quality Objectives
213 (MQOs) and in particular the required measurement method uncertainty was introduced in
214 Section 3.8. These ideas are discussed in greater detail in the Multi-Agency Radiological
215 Laboratory Analytical Protocols Manual (MARLAP 2004) Chapter 3 and Appendix C. While
216 MARLAP is focused on radioanalytical procedures, these concepts are applicable on a much
217 broader scale and will be used in MARSAME to guide the selection of measurement methods for
218 disposition surveys for materials and equipment.

219 Section 4.2 discussed the DQO process for developing statistical hypothesis tests for the
220 implementation of disposition decision rules using measurement data. This included formulating
221 the null and alternative hypotheses, defining the gray region using the action level and
222 discrimination limit, and setting the desired limits on potential Type I and Type II decision error
223 probabilities that a decision maker is willing to accept for project results. Decision errors are
224 possible, at least in part, because measurement results have uncertainties. The effect of these
225 uncertainties is expressed in the size of the relative shift, Δ/σ , introduced in Section 4.2.2. The

226 overall uncertainty, σ , has components that may be due to spatial variability in radioactivity
227 concentration, σ_s , but also because of uncertainty in the measurement method σ_M . Because
228 DQOs apply to both sampling and measurement activities, what are needed from a measurement
229 perspective are method performance characteristics specifically for the measurement process of a
230 particular project. These method performance characteristics (see Section 3.8) are the
231 measurement quality objectives (MQOs).

232 DQOs define the performance criteria that limit the probabilities of making decision errors by:

- 233 • Considering the purpose of collecting the data
- 234 • Defining the appropriate type of data needed
- 235 • Specifying tolerable probabilities of making decision errors

236 DQOs apply to both sampling and measurement activities.

237 MQOs can be viewed as the measurement portion of the overall project DQOs (see Section 3.8).

238 MQOs are:

- 239 • the part of the project DQOs that apply to the measured result and its associated
240 uncertainty.
- 241 • statements of measurement performance objectives or requirements for a particular
242 measurement method performance characteristic, for example, measurement method
243 uncertainty and detection capability.
- 244 • used initially for the selection and evaluation of measurement methods.
- 245 • are subsequently used for the ongoing and final evaluation of the measurement data.

246 Measurement method uncertainty refers to the predicted uncertainty of a measured value that
247 would be calculated if the method were applied to a hypothetical sample with a specified
248 concentration. Measurement method uncertainty is a characteristic of the measurement method
249 and the measurement process. Measurement uncertainty, as opposed to spatial uncertainty, is a
250 characteristic of an individual measurement.

251 The true measurement method standard deviation, σ_M , is a theoretical quantity and is never
252 known exactly, but it may be estimated using the methods described in Section 5.6. The estimate
253 of σ_M will be denoted here by u_M and called the “measurement method uncertainty.” The
254 measurement method uncertainty, when estimated by uncertainty propagation, is the predicted
255 value of the combined standard uncertainty (“one-sigma” uncertainty) of the measurement for
256 material with concentration equal to the UBGR. Note that the term “measurement method
257 uncertainty” and the symbol u_M actually apply not just to the measurement method but also to the
258 entire measurement process, that is, it should include uncertainties in how the measurement
259 method is actually implemented.

260 The true standard deviation of the measurement method, σ_M , is unknown but σ_{MR} is intended to
261 be an upper bound for σ_M . In practice, σ_{MR} is actually used as an upper bound for the method
262 uncertainty, u_M , which is an estimate of σ_M . Therefore, the value of σ_{MR} will be called the
263 “required measurement method uncertainty” and denoted by u_{MR} .

264 The principal MQOs in any project will be defined by the required measurement method
265 uncertainty, u_{MR} , at and below the UBGR and the relative required measurement method
266 uncertainty, ϕ_{MR} , at and above the UBGR, $\phi_{MR} = u_{MR} / \text{UBGR}$. See Section 5.5.2 for further
267 discussion.

268 When making decisions about individual measurement results u_{MR} should ideally be 0.3Δ , and
269 when making decisions about the mean of several measurement results u_{MR} should ideally be
270 0.1Δ , where Δ is the width of the gray region, $\Delta = \text{UBGR} - \text{LBGR}$. In developing these results, a
271 number of new and sometimes only subtly different definitions and symbols are used. For the
272 convenience of the reader, many of these are summarized in the tables in Appendix G.1.

273 **5.5.1 Determine the Required Measurement Method Uncertainty at the UBGR**

274 This section provides the rationale and guidance for establishing project-specific MQOs for
275 controlling σ_M . This control is achieved by establishing a desired maximum measurement
276 method uncertainty at the upper boundary of the gray region. This control also will assist in both

277 the measurement method selection process and in the evaluation of measurement data.
 278 Approaches applicable to several situations are detailed below.

279 Three basic survey designs were described in Chapter 4: scan-only, in situ, and MARSSIM-type.
 280 The relative shift, Δ/σ , is important in determining the level of survey effort required in all three
 281 designs. For a given width of the gray region, Δ , the relative shift, Δ/σ , can only be controlled
 282 by controlling σ . The standard deviation, σ , may have both a measurement component, σ_M , and
 283 a sampling component, σ_S . Segregation and classification may help in controlling σ_S (see
 284 Sections 4.3 and 5.4).

285 For 100% scan-only surveys, the decision uncertainty associated with σ_S is essentially eliminated
 286 because the entire survey unit is measured. In class 2 survey units, the scan coverage can vary
 287 from 10% to nearly 100% depending on the value of Δ/σ . This is a reflection of the fact that for
 288 a fixed measurement variability, σ_M , smaller values of Δ/σ imply larger spatial variability.
 289 Larger spatial variability demands higher scan coverage to reduce the decision uncertainty. That
 290 is, more of the survey unit must be measured to lower the standard deviation of the mean. In such
 291 cases, it will be desirable to reduce σ_M until it is negligible in comparison to σ_S . σ_M can be
 292 considered negligible if it is no greater than $\sigma_S/3$. Therefore, MARSAME recommends the
 293 requirement $u_{MR} \leq \sigma_S/3$.

294 For in situ survey designs, either the entire survey unit, or a large portion of it, is covered with a
 295 single measurement. Thus, spatial variability will tend to be averaged out. When decisions are to
 296 be made by comparing such single measurements to an action level, the total variance of the data
 297 equals the measurement variance, σ_M^2 , and the data distribution in most instances should be
 298 approximately normal. In these cases the DQOs will be met if

$$299 \quad u_{MR} \leq \frac{\text{UBGR-LBGR}}{z_{1-\alpha} + z_{1-\beta}} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}}$$

300 where $z_{1-\alpha}$, is the $(1 - \alpha)$ -quantile of the standard normal distribution and $z_{1-\beta}$, is the $(1 - \beta)$ -
 301 quantile of the standard normal distribution.

302 If $\alpha = \beta = 0.05$, then

$$303 \quad u_{MR} \leq \frac{\Delta}{z_{0.95} + z_{0.95}} = \frac{\Delta}{1.645 + 1.645} = \frac{\Delta}{3.29} \sim 0.3 \Delta$$

304 Therefore, MARSAME recommends the requirement $u_{MR} \leq 0.3\Delta$. The details are discussed in
305 Appendix G.1.2.

306 For the special case where the LBGR = 0, then $\Delta = UBGR$ and $\sigma_{MR} = \Delta / (z_{1-\alpha} + z_{1-\beta})$ implies

$$307 \quad u_{MR} \leq \frac{UBGR}{z_{0.95} + z_{0.95}} = \frac{UBGR}{1.645 + 1.645} = \frac{UBGR}{3.29} \sim 0.3 UBGR .$$

308 This is equivalent to requiring that the MDC (see Appendix G.3.2) be less than the action level.
309 The MDC is defined as the concentration at which the probability of detection is $1 - \beta$ and the
310 probability of false detection in a sample with zero concentration is at most α .

311 **Example 1:** Suppose the action level is 10,000 Bq/m² and the lower bound of the gray region is
312 5,000 Bq/m², $\alpha = 0.05$, and $\beta = 0.10$. If decisions are to be made about individual items, then the
313 required measurement method uncertainty at 10,000 Bq/m² is

$$314 \quad u_{MR} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}} = \frac{10,000 \text{ Bq/m}^2 - 5,000 \text{ Bq/m}^2}{z_{0.95} + z_{0.90}} = \frac{5,000 \text{ Bq/m}^2}{1.645 + 1.282} = 1,700 \text{ Bq/m}^2$$

315 When a decision is to be made about the mean of a sampled population, generally the average of
316 a set of measurements on a survey unit is compared to the disposition criterion. For MARSSIM-
317 type designs, the ratio Δ/σ , called the “relative shift,” determines the number of measurements
318 required to achieve the desired decision error rates α and β . The target range for this ratio should
319 be between 1 and 3, as explained in MARSSIM (MARSSIM 2002) and NUREG-1505 (NRC
320 1998a). Ideally, to keep the required number of measurements low, the DQOs are aimed at
321 establishing $\Delta/\sigma \approx 3$. The cost in number of measurements rises rapidly as the ratio Δ/σ falls
322 below 1, but there is little benefit from increasing the ratio much above 3. One of the main
323 objectives in optimizing survey design is to achieve a relative shift, Δ/σ , of at least one and
324 ideally three. Values of Δ/σ greater than three, while desirable, should not be pursued at

325 additional cost. If Δ/σ is 3 and σ_M is negligible in comparison to σ_S , then σ_M will be $\Delta/10$. The
 326 details are discussed in Appendix G.1.1.

327 Therefore, MARSAME recommends the requirement $u_{MR} \leq \Delta / 10$ by default when decisions are
 328 being made about the mean of a sampled population. If the LBGR is zero, this is equivalent to
 329 requiring that the MQC be less than the action level (see Appendix G.1.1).

330 **Example 2:** Suppose the action level is 10,000 Bq/m² and the lower bound of the gray region is
 331 2,000 Bq/m². If decisions are to be made about survey units based on measurements at several
 332 locations, then the required measurement method uncertainty (u_{MR}) at 10,000 Bq/m² is

$$333 \quad \frac{\Delta}{10} = \frac{10,000 - 2,000}{10} = 800 \text{ Bq/m}^2$$

334

335 **Example 3:** Suppose the action level is 10,000 Bq/m², but this time assume the lower bound of
 336 the gray region is 0 Bq/m². In this case the required method measurement uncertainty, u_{MR} , at
 337 10,000 Bq/m² is

$$338 \quad u_{MR} = \frac{\Delta}{10} = (10,000 - 0)/10 = 1,000 \text{ Bq/m}^2$$

339 The recommended values of u_{MR} are based on the assumption that any known bias in the
 340 measurement process has been corrected and that any remaining bias is well less than 10% of the
 341 shift, Δ , when a concentration near the gray region is measured.

342 Achieving a required measurement method uncertainty u_{MR} less than the recommended limits
 343 may be difficult in some situations. When the recommended requirement for u_{MR} is too difficult
 344 to meet, project planners may allow u_{MR} to be larger. In this case, project planners may choose
 345 σ_{MR} to be as large as $\Delta/3$ or any calculated value that allows the data quality objectives to be met
 346 at an acceptable effort. Two situations that may make this possible are if σ_S is believed to be less
 347 than $\Delta/10$ or if it is not difficult to make the additional measurements required by the larger
 348 overall data variance ($\sigma_M^2 + \sigma_S^2$).

349 **Example 4:** Suppose the uncertainty in Example 2 of $u_{MR} = 800 \text{ Bq/m}^2$ cannot be achieved
 350 because of the variability in instrument efficiency with surface roughness. A required
 351 measurement method uncertainty, u_{MR} , as large as $\Delta / 3 \approx 2,700 \text{ Bq/m}^2$ may be possible if σ_S is
 352 small or if more measurements are taken per survey unit.

353 **5.5.2 Determine the Required Measurement Method Uncertainty at Concentrations** 354 **Other Than the UBGR**

355 The most important MQO for data evaluation is the one for measurement method uncertainty at a
 356 specified concentration. This MQO is expressed as the required measurement method
 357 uncertainty (u_{MR}) at the UBGR. However, to properly evaluate the data usability of
 358 measurement results at concentrations other than the UBGR, the implications of this requirement
 359 must be extended both above and below the UBGR.

360 When the concentration is less than or equal to the UBGR, the combined standard uncertainty,
 361 u_c , (CSU) of a measured result should not exceed the required measurement method uncertainty,
 362 u_{MR} , specified at the UBGR. When the concentration is greater than the UBGR, the relative
 363 combined standard uncertainty (RCSU), ϕ_{MR} , of a measured result should not exceed the
 364 required relative measurement method uncertainty at the UBGR. This is illustrated in Example 5
 365 and Figure 5.1.

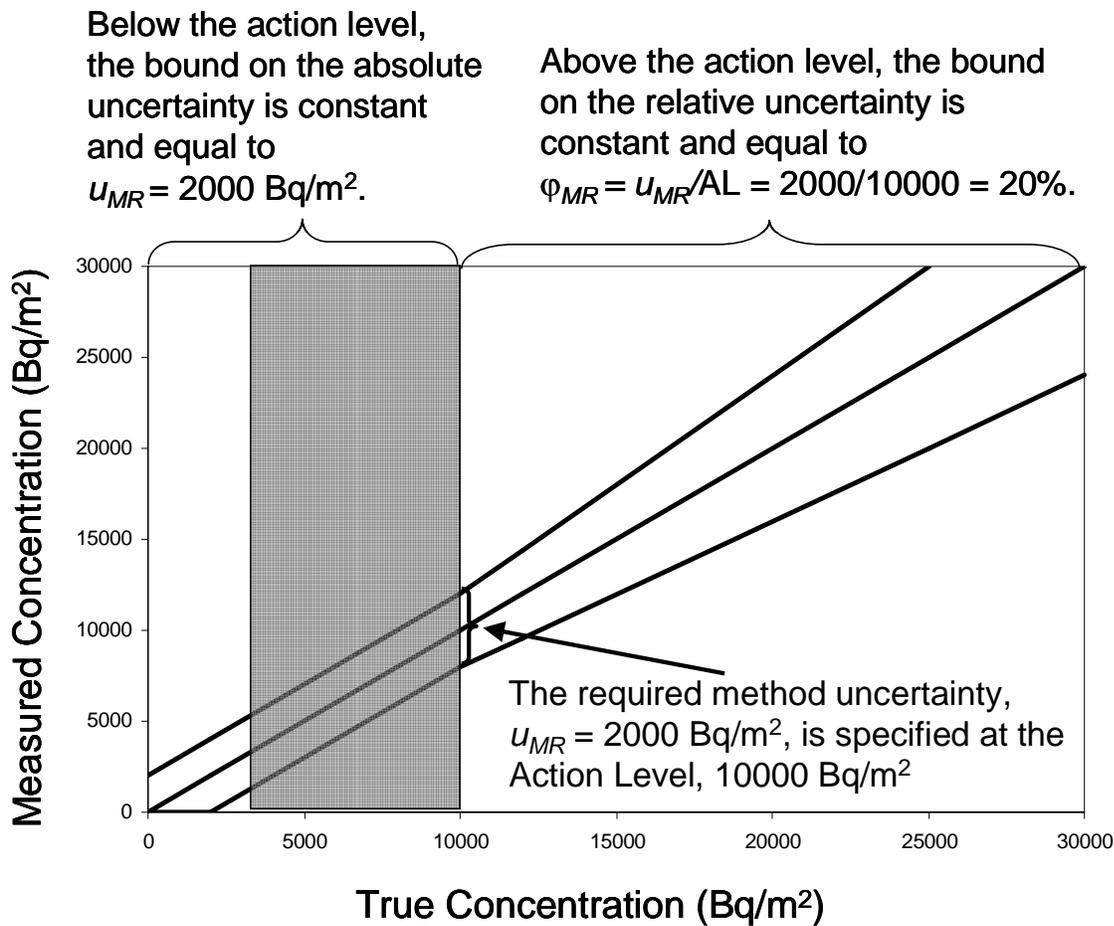
366 **Example 5:** Suppose the action level is $10,000 \text{ Bq/m}^2$ and the discrimination limit is $3,000$.
 367 Scenario A is used, so the UBGR = AL = $10,000 \text{ Bq/m}^2$ and the LBGR = DL = $3,000 \text{ Bq/m}^2$.
 368 Thus the width of the gray region, $\Delta = 10,000 - 3,000 = 7,000$. If decisions are to be made about
 369 individual items, $\alpha = 0.05$, and $\beta = 0.05$, then the required measurement uncertainty at $10,000$
 370 Bq/m^2 is

$$371 \quad u_{MR} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}} = \frac{10,000 \text{ Bq/m}^2 - 3,000 \text{ Bq/m}^2}{z_{0.95} + z_{0.95}} = \frac{7,000 \text{ Bq/m}^2}{1.645 + 1.645} \approx 2,000 \text{ Bq/m}^2$$

372 The required measurement method uncertainty, u_{MR} , is $2,000 \text{ Bq/m}^2$ at $10,000 \text{ Bq/m}^2$. Thus, for
 373 any measured result less than $10,000 \text{ Bq/m}^2$, the reported combined standard uncertainty, u_c ,
 374 should be less than or equal to $2,000 \text{ Bq/m}^2$. For example, a reported result of $4,500 \text{ Bq/m}^2$ with

375 a CSU of 1,900 Bq/m² would meet the requirement. A reported result of 7,700 Bq/m² with a
 376 CSU 2,500 Bq/m² would not meet the requirement.

377 The required relative measurement method uncertainty (ϕ_{MR}) is 2,000 Bq/m² / 10,000 Bq/m² =
 378 20% at 10,000 Bq/m². Thus, for any measured result greater than 10,000 Bq/m², the reported
 379 RCSU should be less than or equal to 20%. For example, a reported result of 14,500 Bq/m² with
 380 a CSU of 2,900 Bq/m² would meet the requirement because 2,900/14,500 = 20%. A reported
 381 result of 18,000 Bq/m² with a CSU 4,500 Bq/ cm² would not meet the requirement because
 382 4,500/18,000 = 25%.



383
 384 **Figure 5.1 Example of the Required Measurement Uncertainty at Concentrations other**
 385 **than the UBGR. In this Example the UBGR Equals the Action Level.**
 386 **(see Example 5)**

387 This check of measurement quality against the required measurement method uncertainty relies
388 on having realistic estimates of the measurement uncertainty. Often reported measurement
389 uncertainties are underestimated, particularly if they are confined to the estimated Poisson
390 counting uncertainty (see Appendix G.2). Tables of results are sometimes presented with a
391 column listing simply “±” without indicating how these numbers were obtained. Often it is
392 found that they simply represent the square root of the number of counts obtained during the
393 measurement. The method for calculating measurement uncertainty, approved by both the
394 International Organization for Standardization (ISO) and the National Institute of Standards and
395 Technology (NIST) is discussed in the next section.

396 **5.6 Determine Measurement Uncertainty**

397 This section discusses the evaluation and reporting of measurement uncertainty. Measurements
398 always involve uncertainty, which must be considered when measurement results are used as part
399 of a basis for making decisions. Every measured and reported result should be accompanied by
400 an explicit uncertainty estimate. One purpose of this section is to give users of data an
401 understanding of the causes of measurement uncertainty and of the meaning of uncertainty
402 statements; another is to describe procedures that can be used to estimate uncertainties. Much of
403 this material is derived from MARLAP Chapter 19.

404 In 1980, the Environmental Protection Agency published a report entitled “Upgrading
405 Environmental Radiation Data,” which was produced by an ad hoc committee of the Health
406 Physics Society (EPA 1980). Two of the recommendations of this report were that:

- 407 1. Every reported measurement result (x) should include an estimate of its overall
408 uncertainty (u_x) that is based on as nearly a complete an assessment as possible.
- 409 2. The uncertainty assessment should include every significant source of inaccuracy in the
410 result.

411 The concept of traceability is also defined in terms of uncertainty. Traceability is defined as the
412 “property of the result of a measurement or the value of a standard whereby it can be related to
413 stated references, usually national or international standards, through an unbroken chain of
414 comparisons all having stated uncertainties” (ISO 1996). Thus, to realistically make the claim

415 that a measurement result is “traceable” to a standard, there must be a chain of comparisons
416 (each measurement having its own associated uncertainty) connecting the result of the
417 measurement to that standard.

418 This section considers only measurement variability, σ_M . Reducing spatial variability, σ_S , by
419 segregating M&E was discussed in Section 5.4. Spatial variability due to field sampling
420 uncertainties is often larger than measurement uncertainties. Although this statement may be true
421 in some cases, this is not an argument for failing to perform a full evaluation of the measurement
422 uncertainty. A realistic estimate of the measurement uncertainty is one of the most useful data
423 quality indicators for a result (see Section 3.8).

424 Although the need for reporting uncertainty has sometimes been recognized, often it consists of
425 only the estimated component due to Poisson counting statistics. This is done because it is easier
426 than a full uncertainty analysis, but it can be misleading because it is at best only a lower bound
427 on the uncertainty and may lead to incorrect decisions based on overconfidence in the
428 measurement. Software is available to perform the mathematical operations for uncertainty
429 evaluation and propagation, eliminating much of the difficulty in implementing the mathematics
430 of uncertainty calculations. There are several examples of such software (McCroan 2006, GUM
431 Workbench 2006, Kragten 1994, and Vetter 2006).

432 **5.6.1 Use Standard Terminology**

433 The methods, terms, and symbols recommended by MARSAME for evaluating and expressing
434 measurement uncertainty are described in the Guide to the Expression of Uncertainty in
435 Measurement, abbreviated as GUM, which was published by ISO (ISO 1995). The ISO
436 methodology is summarized in the NIST Technical Note TN-1297 (NIST 1994).

437 The result of a measurement is generally used to estimate some particular quantity called the
438 measurand. The difference between the measured result and the actual value of the measurand is
439 the error of the measurement. Both the measured result and the error may vary with each
440 repetition of the measurement, while the value of the measurand (the true value) remains fixed.
441 The error of a measurement is unknowable, because one cannot know the error without knowing
442 the true value of the quantity being measured (the measurand). For this reason, the error is
443 primarily a theoretical concept. However, the uncertainty of a measurement is a concept with

444 practical uses. According to the GUM and NIST Technical Note 1297, the term “uncertainty of
 445 measurement” denotes the values that could reasonably be attributed to the measurand. In
 446 practice, there is seldom a need to refer to the error of a measurement, but an uncertainty should
 447 be stated for every measured result.

448 The first step in defining a measurement process is to define the measurand clearly. The
 449 specification of the measurand is always ambiguous to some extent, but it should be as clear as
 450 necessary for the intended purpose of the data. For example, when measuring the activity of a
 451 radionuclide on a surface, it is generally necessary to specify the activity, the date and time, what
 452 area of the surface was measured, and where.

453 Often the measurand is not measured directly but instead an estimate is calculated from the
 454 measured values of other input quantities, which have a known mathematical relationship to the
 455 measurand. For example, input quantities in a measurement of radioactivity may include the
 456 gross count, blank or background count, counting efficiency and area measured. The
 457 mathematical model measurement process specifies the relationship between the output quantity,
 458 Y , and measurable input quantities, X_1, X_2, \dots, X_N , on which its value depends:

$$459 \quad Y = f(X_1, X_2, \dots, X_N).$$

460 The mathematical model for a radioactivity measurement may have the simple form:

$$461 \quad \text{Measurement} = \frac{(\text{Gross Instrument Signal}) - (\text{Blank Signal})}{\text{Efficiency}}$$

462 Each of the quantities shown here may actually be a more complicated expression. For example,
 463 the efficiency may be the product of factors such as surveyor efficiency, surface roughness
 464 efficiency correction, and the instrument counting efficiency. Interferences may be due to
 465 ambient background or other radionuclides that have interactions with the detector in a manner
 466 that contributes spuriously to the gross instrument signal.

467 When a measurement is performed, a specific value x_i is estimated for each input quantity, X_i ,
 468 and an estimated value, y , of the measurand is calculated using the relationship $y = f(x_1, x_2, \dots, x_N)$.
 469 Since there is an uncertainty in each input estimate, x_i , there is also an uncertainty in the output
 470 estimate, y . Determining the uncertainty of the output estimate y requires that the uncertainties

471 of all the input estimates x_i be determined and expressed in comparable forms. The uncertainty
 472 of x_i is expressed in the form of an estimated standard deviation, called the standard uncertainty
 473 and denoted by $u(x_i)$. The ratio $u(x_i)/|x_i|$ is called the relative standard uncertainty of x_i , where
 474 $|x_i|$ is the absolute value of x_i .

475 The partial derivatives, $\partial f / \partial x_i$, are called sensitivity coefficients, usually denoted c_i . The c_i
 476 measure how much f changes when x_i changes. The standard uncertainties are combined with
 477 sensitivity coefficients to obtain the component of the uncertainty in y due to x_i , $c_i u(x_i)$. The
 478 square of the combined standard uncertainty, denoted by $u_c^2(y)$, is called the combined variance.
 479 It is obtained using the formula for the propagation of uncertainty¹:

480
$$u_c^2(y) = \sum_{i=1}^N \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) = \sum_{i=1}^N c_i^2 u^2(x_i)$$
 . The square root of the combined variance is the

481 combined standard uncertainty of y , denoted by $u_c(y)$. Further details of this process are given in
 482 Appendix G.2.1.

483 **5.6.2 Consider Sources of Uncertainty**

484 The following sources of uncertainty should be considered:

- 485 • Radiation counting
- 486 • Instrument calibration (e.g., counting efficiency)
- 487 • Variable instrument backgrounds
- 488 • Variable counting efficiency (e.g., due to the instrument or to source geometry and
 489 placement)
- 490 • Interferences, such as crosstalk and spillover

¹ If the input estimates are potentially correlated, covariance estimates $u(x_i, x_j)$ must also be determined. The covariance $u(x_i, x_j)$ is often recorded and presented in the form of an estimated correlation coefficient, $r(x_i, x_j)$, which is defined as the quotient $u(x_i, x_j) / u(x_i)u(x_j)$. See Appendix G.2.

491 Other sources of uncertainty could include:

- 492 • Temperature and pressure
- 493 • Volume and mass measurements
- 494 • Determination of counting time and correction for dead time
- 495 • Time measurements used in decay and ingrowth calculations
- 496 • Approximation errors in simplified mathematical models
- 497 • Published values for half-lives and radiation emission probabilities

498 There are a number of sources of measurement uncertainty in gamma-ray spectroscopy,
499 including:

- 500 • Poisson counting uncertainty;
- 501 • Compton baseline determination;
- 502 • Background peak subtraction;
- 503 • Multiplets and interference corrections;
- 504 • Peak-fitting model errors;
- 505 • Efficiency calibration model error;
- 506 • Summing;
- 507 • Density-correction factors; and
- 508 • Dead time.

509 Additional discussion of some major sources of uncertainty may be found in Appendix G.2.2.

510 **Example 6:** Consider a simple measurement of a sample. The activity will be calculated from

511
$$y = \frac{(N_S / t_S) - (N_B / t_B)}{\epsilon}$$

512 Where:

513 y is the sample activity (Bq),

514 ϵ is the counting efficiency 0.4176 (s⁻¹/Bq),

515 N_S is the gross count observed during the measurement of the source, (11578).

516 t_S is the source count time (300 s),

517 N_B is the observed background count (87),

518 t_B is the background count time (6,000 s),

519 The combined standard uncertainty of ε is given by $u_c(\varepsilon) = 0.005802$. This is shown in Example
 520 2 in Appendix G.2.2.2. Assume the radionuclide is long-lived; so, no decay corrections are
 521 needed. The uncertainties of the count times are also assumed to be negligible. The standard
 522 uncertainties in N_S and N_B will be estimated as $\sqrt{N_S}$ and $\sqrt{N_B}$ using the Poisson assumption.

523 Then
$$y = \frac{(N_S/t_S) - (N_B/t_B)}{\varepsilon} = \frac{(11578/300) - (87/6000)}{0.4179} = 92.316$$

524
$$u_c^2(y) = \sum_{i=1}^N \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) = \sum_{i=1}^N c_i^2 u^2(x_i)$$

525
$$= \left(\frac{\partial \frac{(N_S/t_S) - (N_B/t_B)}{\varepsilon}}{\partial N_S} \right)^2 u^2(N_S) + \left(\frac{\partial \frac{(N_S/t_S) - (N_B/t_B)}{\varepsilon}}{\partial N_B} \right)^2 u^2(N_B) + \left(\frac{\partial \frac{(N_S/t_S) - (N_B/t_B)}{\varepsilon}}{\partial \varepsilon} \right)^2$$

526
$$= \left(\frac{1/t_S}{\varepsilon} \right)^2 u^2(N_S) + \left(\frac{-1/t_B}{\varepsilon} \right)^2 u^2(N_B) + \left(\frac{-(N_S/t_S) - (N_B/t_B)}{\varepsilon^2} \right)^2 u^2(\varepsilon)$$

527
$$= \left(\frac{1/300}{0.4176} \right)^2 \sqrt{11578}^2 + \left(\frac{-1/6000}{0.4176} \right)^2 \sqrt{87}^2 + \left(\frac{-(11578/300) - (87/6000)}{0.4176^2} \right)^2 0.005802^2$$

528 $= 0.7379 + 0.00001 + 1.6384 = 2.3851$. Note that these calculations show which input quantities
 529 are contributing the most to the combined variance. N_S contributes $0.7379/2.3851 \sim 31\%$. N_B
 530 contributes virtually nothing. The uncertainty in the efficiency contributes $1.6384/2.3851 \sim$
 531 69% . An analysis such as this is called an uncertainty budget, and quickly points out where
 532 improvements in the measurement may be made.

533 Taking the square root of the combined variance we find $u_c(y) = 1.54439$. Usually the combined
 534 standard uncertainty is rounded to two significant figures and the result is rounded to match the
 535 same number of decimal places. So the result would be reported as 92.3 Bq with a combined
 536 standard uncertainty of 1.5 Bq.

537 Note that if the uncertainty in the efficiency had been neglected, the combined standard
538 uncertainty would have been underestimated as 0.86 Bq, and would have been attributed entirely
539 to the uncertainty in the sample counts. This illustrates the importance of including all
540 significant sources of uncertainty in the calculations. Many of these calculations can be done
541 using computer software programs mentioned earlier.

542 A much more detailed and involved example is given in Appendix G.2.3

543 **5.6.3 Summary of Uncertainty Calculation and Reporting**

- 544 • Use the terminology and methods of the Guide to the Expression of Uncertainty in
545 Measurement (ISO 1995) for evaluating and reporting measurement uncertainty.
- 546 • Follow QC procedures that ensure the measurement process remains in a state of
547 statistical control, which is a prerequisite for uncertainty evaluation.
- 548 • Account for possible blunders or other spurious errors. Spurious errors indicate a loss of
549 statistical control of the process and are not part of the uncertainty analysis described
550 above.
- 551 • Report each measured value with either its combined standard uncertainty (or its
552 expanded uncertainty, see Appendix G.2.1.7).
- 553 • Reported measurement uncertainties should be clearly explained. (In particular, when an
554 expanded uncertainty is reported, the coverage factor should be stated and the basis for
555 the coverage probability should also be given, see Appendix G.2.1.7).
- 556 • Consider all possible sources of measurement uncertainty and evaluate and propagate the
557 uncertainties from all sources believed to be potentially significant in the final result.
- 558 • Each uncertainty should be rounded to either one or two significant figures, and the
559 measured value should be rounded to the same number of decimal places as its
560 uncertainty.
- 561 • Results should be reported as obtained together with their uncertainties (whether positive,
562 negative, or zero).

563 **5.7 Determine Measurement Detectability**

564 This section is a summary of issues related to measurement detection capabilities. Much of this
565 material is derived from the MARLAP Chapter 20. More detail may be found in Appendix G.3.

566 Environmental radioactivity measurements may involve material with very small amounts of the
567 radionuclide of interest. Measurement uncertainty often makes it difficult to distinguish such
568 small amounts from zero. Therefore, an important MQO of a measurement process is its
569 detection capability, which is usually expressed as the smallest concentration of radioactivity that
570 can be reliably distinguished from zero. Effective project planning requires knowledge of the
571 detection capabilities of the measurement method that will be or could be used. This section
572 explains a MQO called the minimum detectable concentration (MDC) and describes
573 radioactivity detection capabilities, as well as methods for calculating it.

574 The method most often used to make a detection decision about radiation or radioactivity
575 involves the principles of statistical hypothesis testing. It is a specific example of a Scenario B
576 hypothesis testing procedure described in Section 4.2.4. To “detect” the radiation or
577 radioactivity requires a decision on the basis of the measurement data that the radioactivity is
578 present. The detection decision involves a choice between the null hypothesis (H_0): There is no
579 radiation or radioactivity present (above background), and the alternative hypothesis (H_1): There
580 is radiation or radioactivity present (above background). In this context, a Type I error is to
581 conclude that radiation or radioactivity is present when it actually is not, and a Type II error is to
582 conclude that radiation or radioactivity is not present when it actually is.² Making the choice
583 between these hypotheses requires the calculation of a critical value. If the measurement result
584 exceeds this critical value, the null hypothesis is rejected and the decision is that radiation or
585 radioactivity is present.

² Note that in any given situation only one of the two types of decision error is possible. If the sample *does not* contain radioactivity, a Type I error is possible. If the sample *does* contain radioactivity, a Type II error is possible.

586 5.7.1 Calculate the Critical Value

587 The critical value defines a region where the net instrument signal (count) is too large to be
588 compatible with the premise that there is no radioactivity present. It has become standard
589 practice to make the detection decision by comparing the net instrument count to its critical
590 value, S_C . The net count is calculated from the gross count by subtracting the estimated
591 background and any interferences.³

592 The mean value of the net instrument count typically is positive when there is radioactivity
593 present (i.e., above background). The gross count must be corrected by subtracting an estimate
594 of the count produced under background conditions. See section G.2.2 (Instrument
595 Background).

596 Table 5.1 lists some formulas that are commonly used to calculate the critical value, S_C , together
597 with the major assumptions made in deriving them. Note specifically that the Stapleton formulas
598 given in rows 3-5 are especially appropriate when the total background is less than 100 counts.

599 These formulas depend on N_B (the background count), t_B (the background count time), t_S (the
600 sample count time), and $z_{1-\alpha}$ (the $(1 - \alpha)$ -quantile of the standard normal distribution). The value
601 of α determines the sensitivity of the test. It is the probability that a detection decision is made
602 when no radioactivity above background is actually present.

603 More detail on the calculation of critical values is given in Appendix G.3.3. Software (Strom
604 1999) is available for calculating S_C using the equations recommended here, among others.

³ The presence of other radiation or radioactivity that hinder the ability to analyze for the radiation or radioactivity of interest.

605

Table 5.1 Recommended Approaches for Calculating the Critical Net Signal, S_C ⁴

	Critical Value Equation	Assumptions	Background Count
1	$S_C = z_{1-\alpha} \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$	Poisson	> 100
2	$S_C = 2.33 \sqrt{N_B}$	Poisson $\alpha = 0.05$ $t_B = t_S$	> 100
3	$S_C = d \times \left(\frac{t_S}{t_B} - 1\right) + \frac{z_{1-\alpha}^2}{4} \times \left(1 + \frac{t_S}{t_B}\right) + z_{1-\alpha} \sqrt{(N_B + d) \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$	Stapleton $t_B \neq t_S$	< 100
4	$S_C = 0.4 \times \left(\frac{t_S}{t_B} - 1\right) + \frac{1.645^2}{4} \times \left(1 + \frac{t_S}{t_B}\right) + 1.645 \sqrt{(N_B + 0.4) \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$	Stapleton $t_B \neq t_S$ $\alpha = 0.05$ $d = 0.4$	< 100
5	$S_C = 1.35 + 2.33 \sqrt{N_B + 0.4}$	Stapleton $t_B = t_S$ $\alpha = 0.05$ $d = 0.4$	< 100

606

⁴ These expressions for the critical net count depends for its validity on the assumption of Poisson counting statistics. If the variance of the blank signal is affected by interferences, or background instability, then the Equation 20.7 of MARLAP may be more appropriate.

607 **Example 7:** A 600-second background measurement is performed on a proportional counter and
 608 108 beta counts are observed. A sample is to be counted for 300 s. Estimate the critical value of
 609 the net count when $\alpha = 0.05$.

$$610 \quad S_C = z_{1-\alpha} \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B} \right)}$$

$$611 \quad S_C = 1.645 \sqrt{108 \times \left(\frac{300 \text{ s}}{600 \text{ s}} \right) \left(1 + \frac{300 \text{ s}}{600 \text{ s}} \right)} = 14.8 \text{ net counts}$$

612 Therefore, if 15 or more net counts are observed, the decision will be made that the sample
 613 contains radioactivity above background. Values of S_C should be rounded up when necessary to
 614 make sure that the specified Type I error probability, α , is not exceeded.

615 5.7.2 Calculate the Minimum Detectable Value of the Net Count

616 Table 5.2 lists some formulas that are commonly used to calculate the minimum detectable net
 617 count, S_D , together with the major assumptions made in deriving them. S_D , is defined as the mean
 618 value of the net count that gives a specified probability, $1 - \beta$, of yielding an observed count
 619 greater than its critical value S_C . Therefore S_C must be calculated before S_D . Note specifically
 620 that the Stapleton formulas given in rows 4 and 5 are especially appropriate when the total
 621 background is less than 100 counts. Generally, the Stapleton methods may be used for both high
 622 and low total background counts as they agree well with the more traditional methods when the
 623 background counts are over 100. The simpler more familiar formulas have been included for
 624 completeness.

625 It is important that the assumptions used to calculate S_D are consistent with those that were used
 626 to calculate S_C . The equations for S_D depend on the same variables as S_C , namely N_B , t_B , and t_S .
 627 Notice that neither α nor $z_{1-\alpha}$ appears explicitly, rather they enter the calculation through S_C .
 628 However, β now enters the calculation of S_D through $z_{1-\beta}$. The value of β , like α , is usually
 629 chosen to be 0.05 or is assumed to be 0.05 by default if no value is specified.

630 **Table 5.2 Recommended Approaches for Calculating the Minimum Detectable Net**
 631 **Count.**⁵

	Minimum Detectable Net Signal Equation	Assumptions	Background Count
1	$S_D = S_C + \frac{z_{1-\beta}^2}{2} + z_{1-\beta} \sqrt{\frac{z_{1-\beta}^2}{4} + S_C + N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$	Poisson $t_B \neq t_S$	> 100
2	$S_D = z_{1-\beta}^2 + 2S_C$	Poisson $t_B \neq t_S$ $\alpha = \beta$	> 100
3	$S_D = 2.71 + 2S_C = 2.71 + 2(2.33\sqrt{N_B}) = 2.71 + 4.66\sqrt{N_B}$	Poisson $\alpha = \beta = 0.05$ $t_B = t_S$	> 100
4	$S_D = \frac{(z_{1-\alpha} + z_{1-\beta})^2}{4} \left(1 + \frac{t_S}{t_B}\right) + (z_{1-\alpha} + z_{1-\beta}) \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$	Stapleton	< 100
5	$S_D = 5.41 + 4.65\sqrt{N_B}$	Stapleton $\alpha = \beta = 0.05$ $t_B = t_S$	< 100

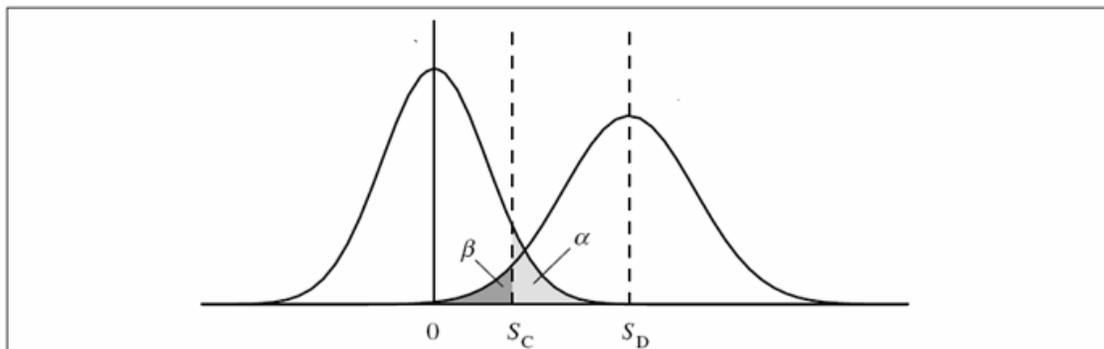
632

⁵ These expressions for the critical value net count depend for their validity on the assumption of Poisson counting statistics. If the variance of the blank signal is affected by interferences, or background instability, then Equation 20.7 of MARLAP may be more appropriate.

633 **Example 8** A 600-second background measurement on a proportional counter produces 108
 634 beta counts and a source is to be counted for 300 s. Assume the background measurement gives
 635 the available estimate of the true mean background count rate and use the value 0.05 for Type I
 636 and Type II error probabilities. From section 5.7.5, Example 7, the critical net count, S_C , equals
 637 14.8, so $S_D = z_{1-\beta}^2 + 2S_C = 1.645^2 + 2(14.8) = 32.3$ net counts. Values of S_D should be rounded
 638 up when necessary to make sure that the specified Type II error probability, β , is not exceeded.

639 The relationship between the critical value of the net count, S_C , and the minimum detectable net
 640 count, S_D , is shown in Figure 5.2. The net counts obtained for a blank sample will usually be
 641 distributed around zero as shown. Occasionally, a net count rate above S_C may be obtained by
 642 chance. The probability that this happens is controlled by the value of α , shown as the lightly
 643 shaded area in Figure 5.2. Smaller values of α result in larger values of S_C and vice versa. The
 644 minimum detectable value of the net count S_D is that value of the mean net count that results in a
 645 detection decision with probability $1 - \beta$. That is, there is only a β , shown as the more darkly
 646 shaded area in Figure 5.2, of yielding an observed count less than S_C . Smaller values of β result
 647 in larger values of S_D and vice versa.

648 More information detail on the calculation of the minimum detectable value of the net instrument
 649 signal, S_D , is given in Appendix G.3.4.



650

651 **Figure 5.2 The critical net signal (S_C) and the minimum detectable net signal (S_D).**
 652 **(Adapted from Figure 20.1 of MARLAP)**

653 5.7.3 Calculate the MDC

654 The MDC is usually obtained from the minimum detectable value of the net instrument count,
 655 S_D . The MDC is by definition an estimate of the true concentration of the radiation or
 656 radioactivity required to give a specified high probability that the measured response will be
 657 greater than the critical value. The common practice of comparing a measured concentration to
 658 the MDC, instead of to the S_C , to make a detection decision is incorrect.

659 To calculate the MDC, the minimum detectable value of the net count, S_D , must first be
 660 converted to the detectable value of the net count rate, S_D/t_S (s^{-1}). This in turn must be divided
 661 by the counting efficiency, ε (s^{-1})/(Bq) to get the minimum detectable activity, y_D . Finally, the
 662 minimum detectable activity can be divided by the sample volume or mass to obtain the MDC.
 663 At each stage in this process, additional uncertainty may be introduced by the uncertainties in
 664 time, efficiency, volume, mass, etc. Thus prudently conservative values of these factors should
 665 be used so that the desired detection power, $1 - \beta$, at the MDC is maintained. Another approach
 666 would be to recognize that y_D itself has an uncertainty which can be calculated using the methods
 667 of Section 5.6. Thus any input quantity that is used to convert from S_D to y_D that has significant
 668 uncertainty can be incorporated to assess the overall uncertainty in the MDC. Additional
 669 discussion of the calculation of the MDCs is given in Appendix G.3.5.

670 **Example 9:** Continuing example 8, $S_D = 32.3$ net counts.

671 Assuming negligible uncertainty in the count time, the net count rate is

672
$$S_D/t_S = 32.3/300 = 0.1077 \text{ (s}^{-1}\text{)} .$$

673 The mean efficiency from Example 6 in Section 5.6.3 was $0.4176 \text{ (s}^{-1}\text{)}/(\text{Bq})$ with a combined
 674 standard uncertainty of $u_c(\varepsilon) = 0.005802$.

675 In Example 8 the value 0.05 was specified for both Type I and Type II error probabilities. So the
 676 specified power was $1 - \beta = 1 - 0.05 = 0.95$.

677 Assume a normal distribution for ε , to obtain a 95% probability of detection for the MDC.

678 To account for the variability in the efficiency, the value used for ε should be the 5th percentile,
 679 i.e., $0.4176 - 1.645(0.005805) = 0.4081$.

680 Thus the minimum detectable activity, $y_D = \frac{S_D/t_S}{\varepsilon} = 0.1077 / 0.4081 = 0.2639 \text{ Bq}$.

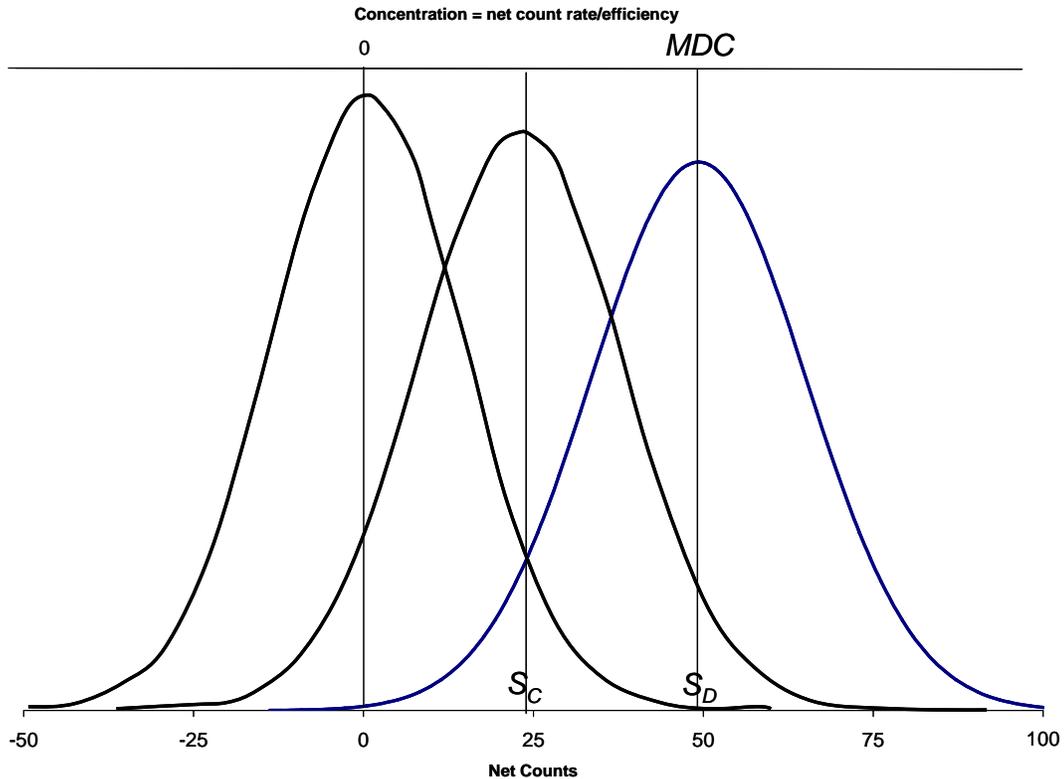
681 Using the mean value of the efficiency would potentially underestimate the minimum detectable
 682 activity as $y_D = \frac{S_D/t_s}{\varepsilon} = 0.1077/0.4176 = 0.2578 \text{ Bq}$.
 683 These values for y_D would then be divided by the mass or volume of the sample to yield the
 684 MDC.

685 5.7.4 Summary of Measurement Detectability

686 The concepts surrounding the MDC and the critical value are illustrated in Figure 5.3, using
 687 familiar formulae for S_C and S_D discussed above, assuming a background count of $N_B = 100$ with
 688 $\alpha = \beta = 0.5$. In this case, the equation in row 2 of Table 5.1 was used to obtain $S_C = 23.3$, and the
 689 corresponding equation in row 3 of Table 5.2 to obtain $S_D = 49.3$. The use of these equations
 690 implies $\alpha = \beta = 0.05$ and $t_B = t_S$.

691 Note, the upper abscissa scale is in concentration and the lower abscissa scale is in net count.
 692 These are related by the efficiency at the point where the MDC corresponds to the minimum
 693 detectable net count, S_D . Each of the curves illustrates the distribution of mean net counts (or
 694 concentration) that may exist for a measurement. The width of these curves represents the
 695 variation due to counting statistics. The variability due to other factors is associated with
 696 uncertainty in ε . Changes in the relationship between the lower and the upper scales result from
 697 changes in ε . This illustrates the importance of choosing realistic, or even conservative, values
 698 of ε . Note that the probability of making a detection decision (which is proportional to the area
 699 of each curve to the right of S_C) depends on the concentration, increasing from 5% at background
 700 to 95% at the MDC, passing through 50% at S_C . This is perhaps more clearly shown in
 701 Figure 5.4, which plots the probability of making a detection decision as a function of net count
 702 (or concentration).

703 Figure 5.4 shows that for concentrations corresponding to net counts between 0 and S_C the
 704 probability of a non-detect is greater than 50%. For concentrations corresponding to net counts
 705 between S_C and S_D the probability of detection is greater than 50%, but less than 95%.
 706 Concentrations above the MDC (with net counts greater than S_D) are highly likely to be detected,
 707 but will have relative standard uncertainties that are somewhat large.

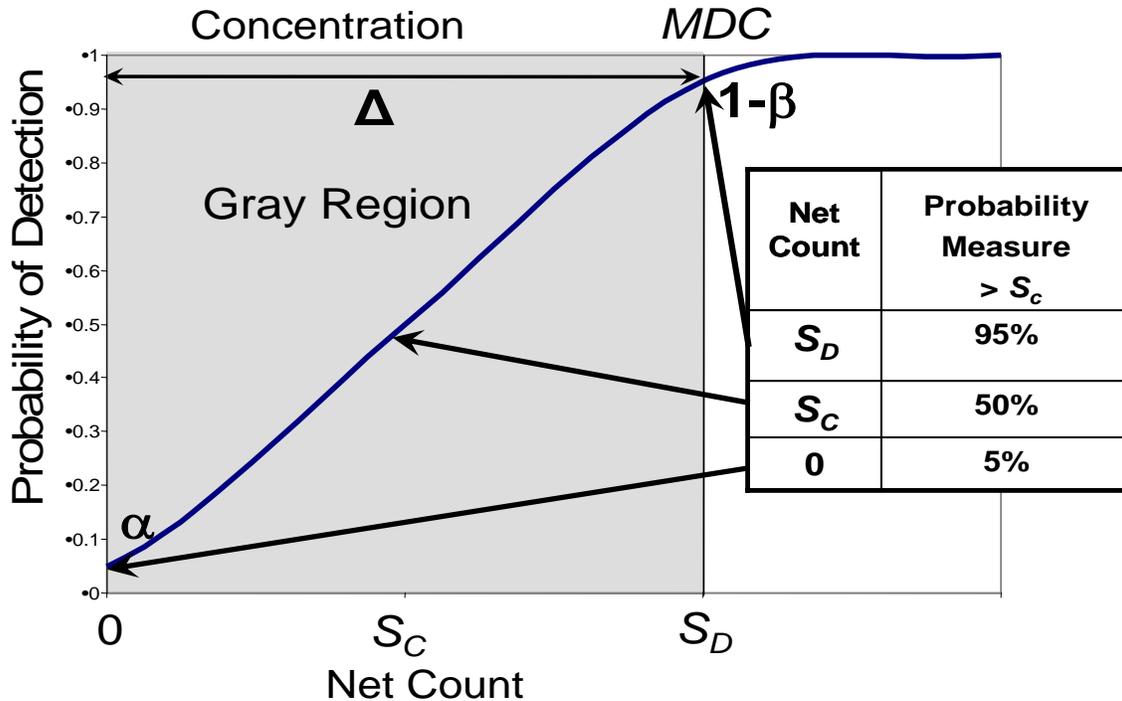


708

709 **Figure 5.3 Relationship Between the Critical Value, the Minimum Detectable Net Counts**
 710 **and the MDC (upper x-axis in units of concentration, lower x-axis in units of**
 711 **net counts)**

712 5.7.5 Measurement Detectability Recommendations

- 713 • When a detection decision is required, it generally should be made by comparing the net
 714 count to its corresponding critical value.
- 715 • Expressions for the critical value and minimum detectable value should be chosen that
 716 are appropriate for the structure and statistics of the measurement process.
- 717 • An appropriate background should be used to predict the count produced when there is no
 718 radioactivity present in the sample.
- 719 • The minimum detectable value (MDC) should be used only as a MQO for the
 720 measurement method. To make a detection decision, a measurement result should be
 721 compared the critical value and never to the MDC.



722

723 **Figure 5.4 Probability of Detection as a Function of Net Count (lower x-axis) and**
 724 **Concentration (upper x-axis)**

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- The validity of the Poisson approximation for the measurement process should be confirmed using the methods described in MARLAP Chapter 20 before using an expression for the critical value that is based on Poisson statistics. When the Poisson approximation is inappropriate for determining the critical value, estimating σ by the sample standard deviation of replicated background measurements is preferable to using the square root of the number of counts.

731

732

- Consider all significant sources of variance in the instrument signal (or other response variable) when calculating the critical value, S_C , and minimum detectable value, S_D .

733

734

- Report each measurement result and its uncertainty as obtained even if the result is less than zero. Never report a result as “less than MDC” or “less than S_C .”

735

736

737

738

- The MDC should not be used for projects where the issue is a quantitative comparison of the average of several measurements to a limit rather than just a detection decision made for a single measurement. For these projects, the minimum quantifiable concentration is a more relevant MQO for the measurement process (see Section 5.8).

739 **5.8 Determine Measurement Quantifiability**

740 This section discusses issues related to measurement quantifiability. Much of this material is
741 derived from the MARLAP Chapter 20.

742 Action levels are frequently stated in terms of a quantity or concentration of radioactivity, rather
743 than in terms of detection. In these cases, project planners may need to know the quantification
744 capability of a measurement method, or its capability for precise measurement. The
745 quantification capability is expressed as the smallest concentration of radiation or radioactivity
746 that can be measured with a specified relative standard deviation. This section explains an MQO
747 called the minimum quantifiable concentration (MQC), which may be used to describe
748 quantification capabilities.

749 The MQC of the concentration, y_Q , is defined as the concentration at which the measurement
750 process gives results with a specified relative standard deviation $1/k_Q$ where k_Q is usually
751 chosen to be 10 for comparability.

752 Historically much attention has been given to the detection capabilities of radiation and
753 radioactivity measurement processes, but less attention has been given to quantification
754 capabilities. For some projects, quantification capability may be a more relevant issue. For
755 example, suppose the purpose of a project is to determine whether the ^{226}Ra concentration on
756 material at a site is below an action level. Since ^{226}Ra can be found in almost any type of
757 naturally occurring material, it may be assumed to be present in every sample, making detection
758 decisions unnecessary. The MDC of the measurement process obviously should be less than the
759 action level, but a more important question is whether the MQC is less than the action level.

760 A common practice in the past has been to select a measurement method based on the minimum
761 detectable concentration (MDC), which is defined in Section 5.7. For example, the Multi-
762 Agency Radiation Survey and Site Investigation Manual (MARSSIM 2002) says:

763 During survey design, it is generally considered good practice to select a measurement
764 system with an MDC between 10-50% of the DCGL [action level].

765 Such guidance implicitly recognizes that for cases when the decision to be made concerns the
 766 mean of a population that is represented by multiple measurements, criteria based on the MDC
 767 may not be sufficient and a somewhat more stringent requirement is needed. The requirement
 768 that the MDC (approximately 3-5 times σ_M) be 10% to 50% of the action level is tantamount to
 769 requiring that σ_M be 0.02 to 0.17 times the action level – in other words, the relative standard
 770 deviation should be approximately 10% at the action level. However, the concentration at which
 771 the relative standard deviation is 10% is the MQC when k_Q assumes its conventional value of
 772 10. Thus, a requirement that is often stated in terms of the MDC may be more naturally
 773 expressed in terms of the MQC, e.g. by saying that the MQC should not exceed the action level.

774 5.8.1 Calculate the MQC

775 The minimum quantifiable concentration, when there are no interferences can be calculated
 776 from:

$$777 \quad y_Q = \frac{k_Q^2}{2t_S \varepsilon (1 - k_Q^2 \phi_{\hat{\varepsilon}}^2)} \left(1 + \sqrt{1 + \frac{4(1 - k_Q^2 \phi_{\hat{\varepsilon}}^2)}{k_Q^2} \left(N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B} \right) \right)} \right)$$

778 Where:

779 t_S is the count time for the source, s,

780 t_B is the count time for the background, s,

781 N_B is the background count,

782 $\phi_{\hat{\varepsilon}}^2$ is the relative variance of the measured efficiency, $\hat{\varepsilon}$. (See for example
 783 Appendix G.2.2.2)

784 k_Q assumes its conventional value of 10

785 **Example 10:** Continuing example 9, $t_S = 300$, $t_B = 600$, $N_B = 108$, $\phi_{\hat{\varepsilon}}^2 = (0.005805/0.4176)^2 =$
 786 0.0001932 , and $k_Q = 10$. So,

$$787 \quad y_Q = \frac{k_Q^2}{2t_S \varepsilon (1 - k_Q^2 \phi_{\hat{\varepsilon}}^2)} \left(1 + \sqrt{1 + \frac{4(1 - k_Q^2 \phi_{\hat{\varepsilon}}^2)}{k_Q^2} \left(N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B} \right) \right)} \right)$$

$$788 \quad = \frac{100}{2(300)(0.4176)(1-100(0.0001932))} \left(1 + \sqrt{1 + \frac{4(1-100(0.0001932))}{100} \left(108 \frac{300}{600} \left(1 + \frac{300}{600} \right) \right)} \right)$$

789 = 1.239 Bq. This value for y_Q would then be divided by the mass or volume of the sample to
790 yield the MQC.

791 The next example is given to verify that the equation for y_Q does indeed produce a value with a
792 relative uncertainty of 10%. It also provides an opportunity to give another illustration of the
793 methodology for the calculation of measurement uncertainty developed in Section 5.6.
794 Additional information on the calculation of MQCs is given in Appendix G.4.

795 **Example 11:** The calculations of Example 10 can be verified by calculating the uncertainty of a
796 measurement made at the MQC. The expected number of counts for a sample at the MQC
797 counted for 300 s:

$$798 \quad N_S = y_Q t_S \varepsilon + N_B (t_S / t_B) = (1.239 \text{ Bq})(300 \text{ s})(0.4176) + (108 \text{ s}^{-1})(300 / 600) = 209,$$

799 rounded to the nearest whole number.

800 The model equation is the same as was used in Example 6, Section 5.6.3:

$$801 \quad y = \frac{(N_S / t_S) - (N_B / t_B)}{\varepsilon}, \text{ so the equation for the combined standard uncertainty is the same:}$$

$$802 \quad u_c^2(y) = \left(\frac{1/t_S}{\varepsilon} \right)^2 u^2(N_S) + \left(\frac{-1/t_B}{\varepsilon} \right)^2 u^2(N_B) + \left(\frac{-(N_S/t_S) - (N_B/t_B)}{\varepsilon^2} \right)^2 u^2(\varepsilon)$$

$$803 \quad = \left(\frac{1/300}{0.4176} \right)^2 (209) + \left(\frac{-1/600}{0.4176} \right)^2 (108) + \left(\frac{-(209/300) - (108/600)}{0.4176^2} \right)^2 (0.005805)^2$$

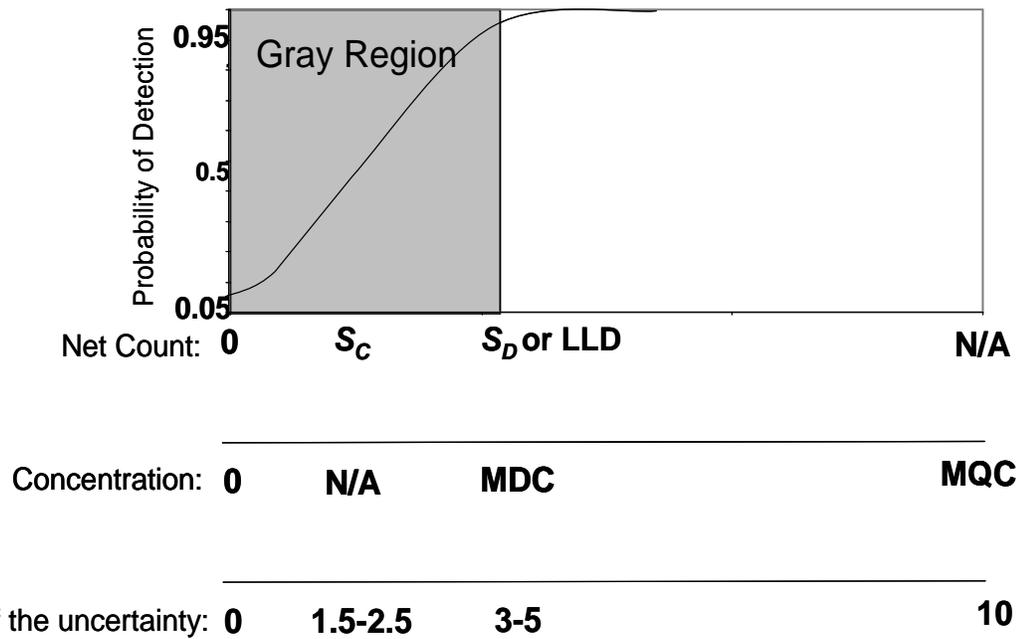
$$804 \quad = 1.332 \times 10^{-2} + 1.72 \times 10^{-3} + 8.5 \times 10^{-4} = 1.589 \times 10^{-2}$$

$$805 \quad u_c(y) = \sqrt{1.59 \times 10^{-2}} = 0.126. \text{ Thus the relative uncertainty at the MQC is } 0.126/1.239 = 0.1017.$$

806 This means, apart from some small difference due to rounding, the relative measurement
807 uncertainty at y_Q is 10%, as should be the case for the MQC.

808 **5.8.2 Summary of Measurement Quantifiability**

809 Figure 5.5 is a modification of Figure 5.4, illustrating the relationships between the critical value,
 810 the MDC, the MQC and the probability of exceeding the critical value. As can be seen, the issue
 811 of detection is almost moot at the MQC. The probability of detection is near 100%. However,
 812 the MQC specifies a concentration with a defined relative standard uncertainty, making
 813 comparisons between measurements or comparisons between measurements and regulatory
 814 criteria meaningful.



815

816 **Figure 5.5 Relationships Among the Critical Value, the MDC, the MQC and the**
 817 **Probability of Exceeding the Critical Value**

818 Three x-axis scales are shown in Figure 5.5, for net count, concentration, and multiple of
 819 measurement uncertainty. This emphasizes, for example, that the minimum detectable net count,
 820 S_D , corresponds to the minimum detectable concentration (MDC), but has different units. It also
 821 shows that the minimum quantifiable concentration (MQC) is by definition 10 times the
 822 measurement uncertainty at that concentration. The critical value of the net count, S_C , has no
 823 corresponding common term in concentration units. This is because detection decisions are
 824 usually made on the basis of the net counts (instrument reading). These are inherently qualitative
 825 “yes or no” decisions. The relationship between S_C and S_D and the multiple of the uncertainty

826 varies according to which set of assumptions are used and which equations in Table 5.2 and
827 Table 5.3 are appropriate to those assumptions. Therefore an approximate range is shown for
828 these quantities on the multiple of uncertainty axis.

829 **5.9 Select a Measurement Technique and Instrumentation Combination**

830 The combination of a measurement technique with instrumentation is used to select a
831 measurement method to implement a disposition survey design based on the ability to meet the
832 MQOs (see Section 3.3.2 and 5.5). A realistic determination of the measurement method
833 uncertainty (see Section 5.6) is critical to demonstrating a method meets the MQOs. Other
834 considerations when selecting a measurement method include:

- 835 • Health and safety concerns (Section 5.2),
- 836 • M&E handling issues (Section 5.3),
- 837 • Segregation (Section 5.4),
- 838 • Measurement detectability (Section 5.7), and
- 839 • Measurement quantifiability (Section 5.8).

840 The measurement techniques discussed in Section 5.9.1 can all be classified as scanning
841 measurements (constant motion involved in the surveying procedure) or fixed measurements
842 (surveying discrete locations without motion). Fixed measurements consist of in situ
843 measurements (the detection instrument moves to the M&E or measures the M&E in its
844 entirety), and sampling (removing part of the M&E for separate analysis).

845 Instrumentation for performing radiological measurements is varied and constantly being
846 improved. The discussions in Section 5.9.2 provide an overview of some commonly used types
847 of instruments and how they might be applied to disposition surveys. The purpose of the
848 discussions on instrumentation is not to provide an exhaustive list of acceptable instruments, but
849 to provide examples of how instrumentation and measurement techniques can be combined to
850 meet the survey objectives. Additional information on instrumentation is found in Appendix D.

851 Section 5.9.3 provides information on selecting a combination of instrumentation and survey
852 technique to provide a measurement method. It is necessary that the selected measurement
853 method meet the MQOs established during survey design (see Section 3.8). Selection of

854 instrumentation can be an iterative process. The appropriate MQO (e.g., MDC, MQC) may not
855 be attainable with some measurement methods. In some cases selection of a different instrument
856 may be all that is necessary, while in other cases a different measurement technique or an
857 entirely different measurement method will need to be considered.

858 **5.9.1 Measurement Techniques**

859 A measurement technique describes how a measurement is performed. The detector can be
860 moved relative to the M&E (i.e., scanning), used to perform static measurements of the M&E in
861 place (i.e., in situ or direct measurements), or some representative portion of the M&E can be
862 removed for analysis in a different location (i.e., sampling).

863 5.9.1.1 Scanning Techniques

864 Scanning techniques generally consist of moving portable radiation detectors at a specified
865 distance above the physical surface of a survey unit at some specified speed to meet the MQOs.
866 Alternatively, the M&E can be moved past a stationary instrument at a specified distance and
867 speed (e.g., conveyORIZED systems or certain portal monitors). Scanning techniques can be used
868 alone to demonstrate compliance with a disposition criterion (i.e., scan-only surveys, Section
869 4.4.1), or combined with sampling in a MARSSIM-type survey design (see Section 4.4.3).
870 Scanning is used in MARSSIM-type surveys to locate radiation anomalies by searching for
871 variations in readings, indicating gross radioactivity levels that may require further investigation
872 or action. Scanning techniques can more readily provide thorough coverage of a given survey
873 unit and are often relatively quick and inexpensive to perform. Scanning often represents the
874 simplest and most practical approach for performing MARSAME disposition surveys.

875 Maintaining the specified distance and speed during scanning can be difficult, especially with
876 hand-held instruments and irregularly shaped M&E. Variations in source-to-detector distance
877 and scan speed can result in increased total measurement method uncertainty. Determining a
878 calibration function for situations other than surficial radionuclides uniformly distributed on a
879 plane can be complicated, and may also contribute to the total measurement method uncertainty.

880 5.9.1.2 In Situ Measurements

881 In situ measurements are taken by placing the instrument in a fixed position at a specified
882 distance⁶ from the surface of a given survey unit of M&E and taking a discrete measurement for
883 a pre-determined time interval. Single in situ measurements can be performed on individual
884 objects or groups of M&E. Multiple in situ measurements can be combined to provide several
885 different views of the same object, or used to provide measurements for a specified fraction of
886 the M&E. In situ measurements can also be performed at random or systematic locations,
887 combined with scanning measurements, in a MARSSIM-type survey design. In situ
888 measurements are generally used to provide an estimate of the average radionuclide
889 concentration or level of radioactivity over a certain area or volume defined by the calibration
890 function.

891 Determining a calibration function for situations other than radionuclides uniformly distributed
892 on a plane or through a regularly shaped volume (e.g., a disk or cylinder) can be complicated,
893 and may contribute to the total measurement method uncertainty. In situ techniques are not
894 typically used to identify small areas or volumes of elevated radionuclide concentration or
895 activity.

896 5.9.1.3 Sampling

897 Sampling consists of removing a portion of the M&E for separate analysis. This measurement
898 technique surpasses the detection capabilities of measurement techniques that may be
899 implemented with the M&E left in place, enabling the analysis of complicated radioisotope
900 mixtures, difficult-to-measure radionuclides, and extremely low concentrations of residual
901 radioactivity. Sampling is used to provide an estimate of the average radionuclide concentration
902 or level of radioactivity for a specified area or volume. The sample locations may be located
903 using a random or systematic grid, depending on the objectives of the survey. Sampling is

⁶ Measurements at several distances may be needed. Near-surface or surface measurements provide the best indication of the size of the area of elevated radionuclide concentrations or radioactivity, and are useful for model implementation. Gamma measurements at one meter provide a good estimate of potential direct external exposure (MARSSIM 2002).

904 typically combined with scanning in a MARSSIM-type survey design, where sampling is used to
905 evaluate the average concentration or activity and scanning is used to identify small areas or
906 volumes with elevated radionuclide concentrations or radioactivity. Sampling may also be used
907 to validate data collected using other measurement techniques.

908 Sampling (combined with laboratory analysis) typically requires the most time for data
909 generation of all the surveying techniques discussed in this chapter and is often the most
910 expensive. Sampling is not an effective technique for identifying small areas or volumes of
911 elevated radionuclide concentrations or levels of radioactivity.

912 **5.9.2 Select Instrumentation**

913 This section briefly describes the typical types of instrumentation that may be used to conduct
914 MARSAME disposition surveys. More detailed information relevant to each type of instrument
915 and measurement method is provided in Appendix D.

916 5.9.2.1 Hand-Held Instruments

917 Hand-held instruments are typically composed of a detection probe (utilizing a single detector)
918 and an electronic instrument to provide power to the detector and to interpret data from the
919 detector to provide a measurement display. They may be used to perform scanning surveys or in
920 situ measurements. Hand-held measurements also allow the user the flexibility to constantly
921 vary the source-to-detector geometry for obtaining data from difficult-to-measure areas.

922 5.9.2.2 Volumetric Counters (Drum, Box, Barrel, 4π Counters)

923 Box counting systems typically consist of a counting chamber, an array of detectors configured
924 to provide 4π counting geometry, and microprocessor-controlled electronics that allow
925 programming of system parameters and data-logging. Volumetric counters are used to perform
926 in situ measurements on entire pieces of small M&E.

927 5.9.2.3 Conveyorized Survey Monitoring Systems

928 Conveyorized survey monitoring systems automate the routine scanning of M&E. Conveyorized
929 survey monitoring systems typically perform scanning surveys by moving M&E through a
930 detector array on a conveyor belt. Conveyorized survey monitoring systems may be utilized to

931 take in situ measurements by halting the conveyor and continuing the measurement to improve
932 the detection efficiency.

933 5.9.2.4 In Situ Gamma Spectroscopy

934 Some in situ gamma spectroscopy (ISGS) systems consist of a small hand-held unit that
935 incorporates the detector and counting electronics into a single package. Other ISGS systems
936 consist of a semiconductor detector, a cryostat, a multi-channel analyzer (MCA) electronics
937 package that provides amplification and analysis of the energy pulse heights, and a computer
938 system for data collection and analysis. ISGS systems are typically applied to perform in situ
939 measurements, but they may be incorporated into innovative detection equipment set-ups to
940 perform scanning surveys.

941 5.9.2.5 Portal Monitors

942 Portal monitors utilize a fixed detector array through which M&E are passed to typically perform
943 scanning surveys (objects may also remain stationary within the detector array to perform in situ
944 measurements). Portal monitors are typically used to perform scanning surveys of vehicles.⁷ In
945 situ measurements may be utilized with portal monitors by taking motionless measurements to
946 improve the detection efficiency.

947 5.9.2.6 Laboratory Analysis

948 Laboratory analysis consists of analyzing a portion or sample of the M&E. The laboratory will
949 generally have recommendations or requirements concerning the amount and types of samples
950 that can be analyzed for radionuclides or radiations. Communications should be established
951 between the field team collecting the samples and the laboratory analyzing the samples. More
952 information on sampling is provided in Section 5.9.1.3. Laboratory analyses can be developed
953 for any radionuclide with any material, given sufficient resources. Laboratory analyses typically
954 require more time to complete than field analyses. The laboratory may be located onsite or

⁷ Specialized vehicle monitors are available that monitor rates of change in ambient background to account for differences in vehicles being scanned to improve measurement detectability.

955 offsite. The quality of laboratory data is typically greater than data collected in the field because
956 the laboratory is better able to control sources of measurement method uncertainty. The
957 planning team should consider the resources available for laboratory analysis (e.g., time, money),
958 the sample collection requirements or recommendations, and the requirements for data quality
959 (e.g., MDC, MQC) during discussions with the laboratory.

960 **5.9.3 Select a Measurement Method**

961 Table 5.3 and Table 5.4 illustrate the potential applications and associated size restrictions for
962 combinations of the instrument and measurement techniques discussed in Sections 5.9.1 and
963 5.9.2, respectively. Sampling followed by laboratory analysis is not included in these tables, but
964 is considered “GOOD” for all applications. Please note the following qualifiers:

GOOD The measurement technique is well-suited for performing this application

FAIR The measurement technique can adequately perform this application

POOR The measurement technique is poorly-suited for performing this application

NA The measurement technique cannot perform this application

965 Table 5.3 illustrates that most measurement techniques can be applied to almost any M&E and
966 type of radioactivity. The quantity of M&E to be surveyed becomes a major factor for the
967 selection of measurement instruments and techniques described in this chapter. Hand-held
968 measurements and techniques are generally the most efficient technique for surveying small
969 quantities of M&E.

970 **Table 5.3 Potential Applications for Instrumentation and Measurement Technique**
 971 **Combinations**

Radiation Type	Hand-Held Instruments	Volumetric Counters	Portal Monitors	In Situ Gamma Spectroscopy	Conveyorized Survey Monitoring Systems
In Situ Measurements					
Alpha	FAIR	FAIR	POOR	NA	FAIR
Beta	GOOD	FAIR	FAIR	NA	GOOD
Photon	GOOD	GOOD	GOOD	GOOD	GOOD
Neutron	GOOD	FAIR	GOOD	NA	GOOD
Scanning Surveys					
Alpha	POOR	NA	POOR	NA	POOR
Beta	GOOD	NA	FAIR	NA	FAIR
Photon	GOOD	NA	GOOD	GOOD	GOOD
Neutron	FAIR	NA	FAIR	NA	FAIR

972 **Table 5.4 Survey Unit Size and Quantity Restrictions for Instrumentation and**
 973 **Measurement Technique Combinations**

Size of Items	Number of Survey Units or Items	Hand-Held Instruments	Volumetric Counters	Portal Monitors	In Situ Gamma Spectroscopy	Conveyorized Survey Monitoring Systems
In Situ Measurements						
> 10 m ³	Few	GOOD	NA	FAIR	GOOD	POOR
	Many	POOR	NA	FAIR	GOOD	POOR
1 to 10 m ³	Few	GOOD	FAIR	FAIR	GOOD	FAIR
	Many	POOR	FAIR	FAIR	GOOD	FAIR
< 1 m ³	Few	GOOD	GOOD	POOR	GOOD	GOOD
	Many	FAIR	GOOD	POOR	GOOD	GOOD
Scanning Surveys						
> 10 m ³	Few	GOOD	NA	GOOD	FAIR	POOR
	Many	FAIR	NA	GOOD	FAIR	POOR
1 to 10 m ³	Few	GOOD	NA	FAIR	FAIR	FAIR
	Many	FAIR	NA	FAIR	FAIR	FAIR
< 1 m ³	Few	GOOD	NA	POOR	FAIR	GOOD
	Many	GOOD	NA	POOR	FAIR	GOOD

974 Facilities that conduct routine surveys on substantial quantities of specific types of M&E may
975 benefit financially from investing in measurement instruments and techniques that require less
976 manual labor to conduct disposition surveys. For example, it will require significantly more time
977 for a health physics technician to survey a toolbox of tools and equipment used in a
978 radiologically-controlled area using hand-held surveying techniques and instruments than the
979 time to complete the surveying using a box counting system. Use of such automated systems will
980 also reduce the potential for ergonomic injuries, and attendant costs, associated with routine,
981 repetitive surveys performed using hand-held instruments. Hand-held surveying remains the
982 more economical choice for a small quantity of tools and toolboxes, but as the quantity of tools
983 and toolboxes increases, the cost of a box counting system becomes an increasingly worthwhile
984 investment to reduce manual labor costs associated with surveying. Note that some M&E have
985 no survey design options that are described as “GOOD” in these two tables (e.g., a large quantity
986 of M&E impacted with residual alpha radioactivity with survey unit sizes greater than 10 m³).
987 The planning team should revisit earlier DQO selections to see if a different approach is more
988 acceptable (e.g., review selection of disposition options in Section 2.4). Each type of
989 measurement technique has associated advantages and disadvantages, some of which are
990 summarized in Table 5.5. All the measurement techniques described in this table include source-
991 to-detector geometry and spatial variability as common disadvantages.

992 **5.10 Quality Control**

993 The purpose of QC is to ensure that measurement and other data-producing systems operate
994 within defined performance limits as specified in planning. QC programs can lower the chances
995 of making an incorrect decision and help the decision maker understand the level of uncertainty
996 that surrounds the decision. QC operations help identify where errors are occurring, what the
997 magnitude of that error is, and how that error might impact the decision-making process.

998 This section discusses QC in the context of implementation. Information is provided on
999 measurement performance indicators as well as instrument performance indicators. Evaluation
1000 of QC data is discussed in Section 6.2.2.1.

1001 **Table 5.5 Advantages and Disadvantages of Instrumentation and Measurement Technique**
 1002 **Combinations**

Instrument	Measurement Technique	Advantages	Disadvantages
Hand-Held Instruments	In Situ	<ul style="list-style-type: none"> • Generally allows flexibility in media to be measured • Detection equipment is usually portable • Detectors are available to efficiently measure alpha, beta, gamma, x-ray, and neutron radiation • Generally acceptable for performing measurements in difficult-to-measure areas • Measurement equipment is relatively low cost • May provide a good option for small quantities of M&E 	<ul style="list-style-type: none"> • Requires a relatively large amount of manual labor as a surveying technique; may make surveying large quantities of M&E labor-intensive • Detector windows may be fragile • Most do not provide nuclide identification
Hand-Held Instruments	Scanning	<ul style="list-style-type: none"> • Generally allows flexibility in media to be measured • Detection equipment is usually portable • Detectors are available to efficiently measure beta, gamma, x-ray, and neutron radiation • Generally good for performing measurements in difficult-to-measure areas • Measurement equipment is relatively low cost • May provide a good option for small quantities of M&E 	<ul style="list-style-type: none"> • Requires a relatively large amount of manual labor as a surveying technique; may make surveying large quantities of M&E labor-intensive • Detector windows may be fragile • Most do not provide nuclide identification • Incorporates more potential sources of uncertainty than most instrument and measurement technique combinations • Potential ergonomic injuries and attendant costs associated with repetitive surveys.

1003 **Table 5.5 Advantages and Disadvantages of Instrumentation and Measurement Technique**
 1004 **Combinations (continued)**

Instrument	Measurement Technique	Advantages	Disadvantages
Volumetric Counters	Sampling	<ul style="list-style-type: none"> • Able to measure small items • Designs are available to efficiently measure gamma, x-ray, and alpha radiation • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • May not be suited for measuring radioactivity in difficult-to-measure areas • Size of instrumentation may discourage portability
Portal Monitors	In situ	<ul style="list-style-type: none"> • Able to measure large objects • Designs are available to efficiently measure gamma, x-ray, and neutron radiation • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Not ideal for measuring alpha or beta radioactivity • May not be ideal for measuring radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability
Portal Monitors	Scanning	<ul style="list-style-type: none"> • Able to measure large objects • Efficient designs available for gammas, X-rays, and neutron radiation • Residence times are generally short • May not require objects to remain stationary during counting • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Not ideal for measuring alpha or beta radioactivity • Source geometry is an important consideration • May not be ideal for measuring radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability
In Situ Gamma Spectroscopy (ISGS)	In situ	<ul style="list-style-type: none"> • Provides quantitative measurements with flexible calibration • Generally requires a moderate amount of labor • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain • May require liquid nitrogen supply (with ISGS semiconductor systems) • Size of detection equipment may discourage portability

1005 **Table 5.5 Advantages and Disadvantages of Instrumentation and Measurement Technique**
 1006 **Combinations (continued)**

Instrument	Measurement Technique	Advantages	Disadvantages
In Situ Gamma Spectroscopy (ISGS)	Scanning	<ul style="list-style-type: none"> • Provides quantitative measurements with flexible calibration • Generally requires a moderate amount of labor • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain • May require liquid nitrogen supply (with ISGS semiconductor systems) • Size of detection equipment may discourage portability
Conveyorized Survey Monitoring Systems	In situ	<ul style="list-style-type: none"> • Requires relatively small amount of labor after initial set up • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain • May not be ideal for assessing radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability • Typically does not provide nuclide identification
Conveyorized Survey Monitoring Systems	Scanning	<ul style="list-style-type: none"> • Requires relatively small amount of labor after initial set up • May be cost-effective for measuring large quantities of M&E 	<ul style="list-style-type: none"> • Instrumentation may be expensive and difficult to set up and maintain • May not be ideal for assessing radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability • Typically does not provide nuclide identification

1007 **Table 5.5 Advantages and Disadvantages of Instrumentation and Measurement Technique**
 1008 **Combinations (continued)**

Instrument	Measurement Technique	Advantages	Disadvantages
Laboratory Analysis	Sampling	<ul style="list-style-type: none"> • Generally provides the lowest MDCs and MQCs, even for difficult-to-measure radionuclides • Allows positive identification of radionuclides without gammas 	<ul style="list-style-type: none"> • Most costly and time-consuming measurement technique • May incur increased overhead costs while personnel are waiting for analytical results • Great care must be taken to ensure samples are representative • Detector windows may be fragile

1009 **5.10.1 Measurement Performance Indicators**

1010 Measurement performance indicators are used to evaluate the performance of the measurement
 1011 method. These indicators describe how the measurement method is performing to ensure the
 1012 survey results are of sufficient quality to meet the survey objectives.

1013 5.10.1.1 Blanks

1014 Blanks are measurements of materials with little or no radioactivity and none of the
 1015 radionuclide(s) of concern present. Blanks are performed to determine whether the measurement
 1016 process introduces any increase in count rate that could impact the measurement method
 1017 detection capability. Blanks should be representative of all measurements performed using a
 1018 specific method (i.e., combination of instrumentation and measurement technique). When
 1019 practical, the blank should consist of the same or equivalent material(s) as the M&E being
 1020 surveyed.

1021 Blanks are typically performed before and after a series of measurements to demonstrate the
 1022 measurement method was performing adequately throughout the survey. At a minimum, blanks
 1023 should be performed at the beginning and end of each shift. When large quantities of data are
 1024 collected (e.g., scanning measurements) or there is an increased potential for radionuclide
 1025 contamination of the instrument (e.g., removable or airborne radionuclides), blanks may be

1026 performed more frequently. In general, a blank should be collected whenever enough
1027 measurements have been performed such that it is not practical to repeat those measurements if a
1028 problem is identified.

1029 A sudden change in a blank result indicates a condition requiring immediate attention. Sudden
1030 changes are caused by the introduction of a radionuclide, a change in ambient background, or
1031 instrument instability. Gradual changes in blank values indicate a need to inspect all survey
1032 areas for sources of radionuclides or radioactivity. Gradual build up of removable radionuclides
1033 over time or instrument drift and deterioration can result in slowly increasing blank values. High
1034 variability in blank values can result from instrument instability or improper classification (i.e.,
1035 high activity and low activity M&E combined into a single survey unit. It is important to correct
1036 any problems with blanks to ensure measurement detectability (see Section 5.7) is not
1037 compromised.

1038 5.10.1.2 Replicate Measurements

1039 Replicate measurements are two or more measurements performed on the same M&E.
1040 Replicates are performed primarily to provide an estimate of precision for the measurement
1041 method. The reproducibility of measurement results should be evaluated by replicates to
1042 establish this component of measurement uncertainty (see Section 5.6).

1043 Replicates are typically performed at specified intervals during a survey (e.g., 5% of all
1044 measurements or once per day). Replicates should be used to evaluate each batch of data used to
1045 support a disposition decision (e.g., one replicate per survey unit). For single measurement
1046 surveys or scan-only surveys where decisions are made based on every measurement, typically
1047 5% of all measurements are replicated.

1048 Precision exhibits a range of values and depends in part on the material being measured and the
1049 activity level. Small changes in precision are expected, and the acceptable range of variability
1050 should be established prior to initiating data collection activities. The main causes for lack of
1051 precision include problems with repeating measurements on irregularly shaped M&E, the
1052 material being measured, counting statistics when the activity levels are low, and instrument
1053 contamination.

1054 5.10.1.3 Spikes, Standards, and Certified Reference Materials

1055 Spikes, standards, and certified reference materials are materials with known composition and
1056 known radionuclide content. Materials with known radionuclide concentrations are used to
1057 evaluate bias in the measurement method. It is unlikely that certified reference materials will be
1058 available for most field applications.

1059 Measurements of materials with known radionuclide concentrations are typically performed at
1060 specified intervals during a survey (e.g., 5% of all measurements or once per day). At a
1061 minimum, these measurements should be used to evaluate each batch of data used to support a
1062 disposition decision (i.e., at least one spike or standard per survey unit).

1063 M&E cover a broad range of physical forms and materials that can change a measurement
1064 method's expected bias. Tracking results of measurements with known activity can provide an
1065 indication of the magnitude of bias. However, M&E can be very complex and subject to large
1066 variability, so care should be taken in interpreting these results. The activity level associated
1067 with the standards should be considered. In general, activity levels close to the action levels (or
1068 discrimination limits) will provide adequate information on the performance of the measurement
1069 system.

1070 **5.10.2 Instrument Performance Indicators**

1071 Instrument performance indicators provide information on how an instrument is performing.
1072 Evaluation of these indicators provides information on the operation of the instruments.

1073 5.10.2.1 Performance Tests

1074 Performance tests should be performed periodically and after maintenance to ensure that the
1075 instruments continue to meet performance requirements for measurements. An example of a
1076 performance test is a test for response time. Performance requirements should be met as
1077 specified in the applicable sections of ANSI N323A (ANSI 1997), ANSI N42.17A (ANSI
1078 2003b), and ANSI N42.17C (ANSI 1989). These tests may be conducted as part of the
1079 calibration procedure.

1080 5.10.2.2 Functional Tests

1081 Functional tests should be performed prior to initial use of an instrument. These functional tests
1082 should include:

- 1083 • General condition
- 1084 • Battery condition
- 1085 • Verification of current calibration (i.e., check to see that the date due for calibration has
1086 not passed)
- 1087 • Source and background response checks (and other tests as applicable to the instrument)
- 1088 • Constancy check

1089 The effects of environmental conditions (temperature, humidity, etc.) and interfering radiation on
1090 an instrument should be established prior to use. The performance of functional tests should be
1091 appropriately documented. This may be as simple as a checklist on a survey sheet, or may
1092 include more detailed statistical evaluation such as a chi-square test.

1093 5.10.2.3 Instrument Background

1094 All radiation detection instruments have a background response, even in the absence of a sample
1095 or radiation source (see Section 3.4.2). Inappropriate background correction will result in
1096 measurement error and increase the uncertainty of data interpretation.

1097 5.10.2.4 Efficiency Calibrations

1098 Detector efficiency is critical for converting the instrument response to activity (MARSAME
1099 Section 6.4, MARSSIM Section 6.5.4, MARLAP Chapter 16). Routine performance checks may
1100 be used to demonstrate the system's operational parameters are within acceptable limits, and
1101 these measurements are typically included in the assessment of bias. The system's operational
1102 parameters may be tracked using control charts.

1103 5.10.2.5 Energy Calibrations (Spectrometry Systems)

1104 Spectrometry systems identify radionuclides based on the energy of the detected radiations. A
1105 correct energy calibration is critical to accurately identify radionuclides. An incorrect energy

1106 calibration may result in misidentification of peaks, or failure to identify radionuclides present in
1107 the M&E being investigated.

1108 5.10.2.6 Peak Resolution and Tailing (Spectrometry Systems)

1109 The shape of the full energy peak is important for identifying radionuclides and quantifying their
1110 activity with spectrometry systems. Poor peak resolution and peak tailing may result in larger
1111 measurement uncertainty, or in failure to identify the presence of peaks based on shape.
1112 Consistent problems with peak resolution indicate the presence of an analytical bias.

1113 5.10.2.7 Voltage Plateaus (Gas Proportional Systems)

1114 The accuracy of results using a gas proportional system can be affected if the system is not
1115 operated with its detector high voltage adjusted such that it is on a stable portion of the operating
1116 plateau.

1117 5.10.2.8 Self Absorption, Backscatter, and Crosstalk

1118 Alpha and beta measurement results can be affected by the M&E through self-absorption and
1119 backscatter. Measurement systems simultaneously detecting alpha and beta particles using an
1120 electronic discriminator (e.g., gas flow proportional detectors) can be affected by crosstalk (i.e.,
1121 identification of alpha particles as beta particles and vice versa). Accurate differentiation
1122 between alpha and beta activity depends on the assessment and maintenance of information on
1123 self-absorption and crosstalk.

1124 **5.11 Report the Results**

1125 Once the instruments have been checked to ensure proper operation, the data should be collected
1126 in a manner consistent with the survey design. Any field changes and deviations from survey
1127 design should be documented and described in sufficient detail to enable an independent re-
1128 creation and evaluation at some future time.

1129 The reported measurements should comprise raw data that includes background radioactivity
1130 (i.e., gross measurement data). Electronic instruments with data logging capabilities should be
1131 used when applicable. Electronic data should be exported and backed up periodically to
1132 minimize the chance of losing data and the need for re-surveying.

1133 Use of a measurement identification system should be considered. If required by the objectives
1134 of the survey, the identification system should be developed and used such that each
1135 measurement is assigned and labeled with a unique (preferably sequential) identifying number,
1136 the collection date and time, the measurement location, and any applicable comments.

1137 While MARSAME does not make specific recommendations with regard to approved media
1138 formats for storing documentation, some users of MARSAME (e.g., private industry nuclear
1139 power plants) may be required to retain documentation in media formats prescribed by State and
1140 Federal rules of evidence. Similarly, State and Federal rules of evidence may specify retention
1141 periods for documentation that exceed internal facility requirements. Compliance with State and
1142 Federal rules of evidence is intrinsic to maintaining legally defensible records for insurance and
1143 litigation-related purposes.

1144 Documentation of the survey measurements should provide a complete and unambiguous record
1145 of the data collected. Documentation should also include descriptions of variability and other
1146 conditions pertaining to the M&E that may have affected the measurement capabilities of the
1147 survey procedure, and photographs where applicable. The documentation itself should be clear,
1148 legible, retained, retrievable, and to the level of detail required..

1149 Negative results (net activity below zero) can be obtained when an instrument background is
1150 subtracted from the measurement of a low activity sample. In the case where the activity is close
1151 to zero, the measurement uncertainty will result in a distribution of results where approximately
1152 one half are less than zero and one half are greater than zero. As long as the magnitude of
1153 negative values is comparable to the estimated measurement uncertainties and there is no
1154 discernible negative bias, negative results should be accepted as legitimate estimates of
1155 radionuclide concentrations or levels of radioactivity associated with the M&E. A
1156 preponderance of negative results, even if they are close to zero may indicate a bias or systematic
1157 error.

1158 The inclusion of the information described above is important in creating comprehensive
1159 documentation to make disposition surveys technically and legally defensible. The collection of
1160 all necessary data prepares the MARSAME user to assess the results of the disposition survey,
1161 which is discussed in Chapter 6.

1 **6 ASSESS THE RESULTS OF THE DISPOSITION SURVEY**

2 **6.1 Introduction**

3 The assessment phase of the Data Life Cycle involves the interpretation of survey results.
4 Interpretation of survey results is very straightforward when all of the data are below or all of the
5 data are above the action level, and the correct decision regarding disposition of the M&E is
6 obvious. In these cases very little data interpretation is required. However, formal statistical
7 tests provide a valuable tool when the survey results are neither clearly above nor entirely below
8 the action level. In either case, statistical tests are always used to support the survey design in
9 helping to ensure the quantity and quality of data meet the data quality objectives (DQOs) and
10 measurement quality objectives (MQOs).

11 **6.2 Conduct Data Quality Assessment**

12 Data Quality Assessment (DQA) is a scientific and statistical evaluation that determines whether
13 data are the right type, quality and quantity to support their intended use (EPA 2006b). There are
14 five steps in the DQA Process:

- 15 1. Review the DQOs and survey design.
- 16 2. Conduct a preliminary data review.
- 17 3. Select the statistical test.
- 18 4. Verify the assumptions of the statistical test.
- 19 5. Draw conclusions from the data.

20 The effort applied to DQA should be consistent with the graded approach used to develop the
21 survey design. More information on DQA can be found in *Data Quality Assessment: A User's*
22 *Guide* (EPA QA/G-9R, EPA 2006b) and *Data Quality Assessment: Statistical Tools for*
23 *Practitioners* (EPA QA/G-9S, EPA 2006c). Data should be verified and validated as described
24 in the quality assurance project plan (QAPP). Guidance on data verification and validation can
25 be found in MARSSIM Section 9.3 and MARLAP Chapter 8. Guidance on developing a QAPP
26 is available in EPA QA/G-5 (EPA 2002a) and MARLAP Chapter 4.

27 **6.2.1 Review the Data Quality Objectives and Survey Design**

28 The first step in the DQA Process is a review of the DQO outputs used to develop the survey
29 design to ensure they are still applicable. The review of the DQOs and survey design should also
30 include the MQOs (e.g., measurement uncertainty, detectability, and quantifiability). For
31 example, if the data show the measurement uncertainty exceeds the estimate used to design the
32 survey, the DQOs and MQOs should be revisited.

33 The survey design should be reviewed for consistency with the DQOs. For example, the review
34 should verify that the appropriate number or amount of measurements were performed in the
35 correct locations and were analyzed using measurement methods with adequate sensitivity.

36 In cases where the survey did not involve taking discrete measurements or samples (i.e., scan-
37 only, conveyor systems, or in situ surveys), it is imperative that the minimum detectable
38 concentrations (MDCs) be calculated realistically and they truly reflect at least 95 percent
39 probability that concentrations at or about the MDC were detected. Clearly, MDCs must be
40 capable of detecting radionuclide concentrations or levels of radioactivity at or below the upper
41 bound of the gray region (UBGR). When detection decisions are made for individual items (i.e.,
42 Scenario B) the MDC should be less than or equal to the UBGR.

43 The minimum quantifiable concentration (MQC) is defined as the radionuclide concentration or
44 level of radioactivity at which the measurement method gives results with a specified relative
45 standard deviation $1/k_Q$, where k_Q is usually chosen to be 10 (see Section 5.8, MARLAP Section
46 19.4.5, MARLAP Section 19.7.3). MARSAME recommends that the MQC should be no larger
47 than the upper bound of the gray region (UBGR) when making quantitative comparisons of the
48 mean survey data to the action level (i.e., Scenario A). This is an expression of the fact that the
49 MQC, unlike the MDC used for a simple detection decision, addresses the relative uncertainty of
50 the data value obtained. If the objective of the disposition survey is to quantify radionuclide
51 concentrations near the UBGR, the MQC should be no larger than the UBGR.¹

¹ The UBGR is either the action level for Scenario A or the discrimination limit for Scenario B (see Section 4.2).

52 For MARSSIM-type surveys (see Section 4.4.3) it is important to collect sufficient data to
53 support a disposition decision. This is particularly important in cases where the radionuclide
54 concentrations are near the action level. This can be done prospectively during survey design to
55 test the efficacy of a proposed survey design (see Chapter 4), or retrospectively during
56 interpretation of survey results to demonstrate the objectives of the survey design have been
57 achieved. The procedure for generating power curves for the Sign Test and the Wilcoxon Rank
58 Sum test are provided in Appendix I of MARSSIM. Note that the accuracy of a prospective
59 power curve depends on estimates of data variability and the planned number of measurements.
60 After the data are analyzed, the sample standard deviation provides an estimate of data
61 variability and the actual number of valid measurements are known, and these two parameters
62 are used to generate a retrospective power curve (see MARSSIM Appendix I). The consequence
63 of inadequate power is an increased Type II decision error rate. For Scenario A, this means
64 M&E that actually meet the release criteria have a higher probability of being incorrectly
65 determined not to meet the release criterion. For Scenario B, this means M&E that actually do
66 not meet the release criterion have a higher probability of being incorrectly determined to meet
67 the release criterion.

68 **6.2.2 Conduct a Preliminary Data Review**

69 A preliminary data review is performed to learn more about the structure of the data by
70 identifying patterns, relationships, or potential anomalies. The preliminary data review includes
71 reviewing quality assurance (QA) and quality control (QC) reports, performing a graphical data
72 review, and calculating basic statistical quantities.

73 **6.2.2.1 Review Quality Assurance and Quality Control Reports**

74 Quality assurance reports describing data collection and reporting processes provide valuable
75 information about potential problems with or anomalies in the data. EPA QA/G-9R (EPA
76 2006b) recommends a review of (1) data validation reports that document the data collection,
77 handling, analysis, reduction, and reporting procedures; (2) QC reports from laboratories or field
78 stations that document measurement system performance including data from blanks, replicates,
79 spikes, standards, and certified reference materials, or other internal QC measures; and (3)
80 technical systems reviews, performance evaluation audits, and audits of data quality including

81 data from performance evaluation measurements. EPA QA/G-9R (EPA 2006b) also suggests
82 paying particular attention to information that can be used to check assumptions made during
83 survey design using the DQO Process, especially any anomalies in recorded data, missing values,
84 deviations from SOPs, or the use of nonstandard data collection methods (e.g., new, emerging, or
85 “cutting edge” technology). Verification of instrument calibrations and review of MQOs are
86 particularly important to disposition surveys. Periodic measurements must be made to ensure the
87 measurement systems remain within acceptable calibration and control limits.

88 Quality control measurements are performed during implementation of the survey design to
89 monitor performance of the measurement methods, identify problems, and initiate corrective
90 actions when necessary. The evaluation of QC measurements used to control measurement
91 methods is distinct from the evaluation from survey results. MARLAP Section 18.3 (Evaluation
92 of Performance Indicators), Attachment 18A (Control Charts), and Attachment 18B (Statistical
93 Tests for QC Results) provide information on the evaluation of quality control measurements.

94 Reviewing QA and QC reports is the only preliminary data review performed for surveys where
95 individual measurements are not recorded (e.g., scan-only surveys with hand-held instruments).
96 This increases the importance of the QA and QC reports and should be considered during survey
97 planning to ensure data quality is adequate to meet the survey objectives.

98 6.2.2.2 Perform a Graphical Data Review

99 Preparing and evaluating graphs and other visual depictions of the data may identify trends in the
100 data that go unnoticed using purely numerical methods. The graphical data review may include
101 posting plots, frequency plots, quantile plots, or other methods for visually interpreting data.
102 General guidance on performing a graphical data review and exploratory data analysis is
103 provided in EPA QA/G-9R (EPA 2006b) and by the National Institute of Science and
104 Technology (NIST 2006). A graphical data review cannot be performed unless the measurement
105 results are recorded. Surveys where recording individual measurement results is not required
106 (e.g., scan-only surveys with hand-held instruments) do not receive a graphical data review.

107 A posting plot is simply a map of the survey unit with the data values entered at the measurement
108 locations. This type of plot potentially reveals heterogeneities in the data, especially possible

109 patches of elevated radionuclide concentrations. For a reference material survey a posting plot
110 can reveal spatial trends in background data that might affect the results of the statistical tests.

111 If the posting plot reveals systematic spatial trends in the M&E, the cause of the trends should be
112 investigated. In some cases the trends could be attributable to residual radioactivity, but they
113 may also be caused by inhomogeneities in the ambient background in the area the survey is
114 performed. EPA QA/G-9S (EPA 2006c) provides additional diagnostic tools for examining
115 spatial trends. The role of a posting plot for a conveyorized system would be a time series
116 display of the data showing any trends between adjacent batches of M&E conveyed past the
117 detector.

118 The geometric configuration of most M&E survey units composed of a few large irregularly
119 shaped pieces of M&E is transitory. The arrangement of tools and piles of scrap metal, for
120 example, changed as volumes of material were moved, or even as individual pieces were handled
121 during the survey (see Section 5.3). In these cases some identifying marks, numbers, or bar-code
122 labels should have been used to identify and track where measurements were made, at least until
123 it is determined that the M&E meet the disposition criteria. Such marking and labeling need not
124 be permanent, but may be made with materials such as chalk or removable labels.

125 A frequency plot, or histogram, is a useful tool for examining the general shape of a distribution.
126 This plot is a bar chart of the number of data points within a certain range of values. A
127 frequency plot reveals any obvious departures from symmetry, such as skewness or bimodality
128 (two peaks), in the data distributions for the M&E or reference material.

129 The presence of two peaks in the M&E data set frequency plot may indicate the presence of
130 small areas of elevated activity. In some cases it may be possible to identify an appropriate
131 background distribution within the M&E data set. This type of data interpretation generally
132 depends on site-specific considerations and should only be pursued after consultation with the
133 responsible regulatory agency.

134 The presence of two peaks in the M&E or reference material frequency plots may also indicate a
135 mixture of materials with different intrinsic radiation backgrounds. The greater variability in the
136 data caused by the presence of such a mixture reduces the power of the statistical tests. These

137 situations should be avoided whenever possible through segregation of M&E (see Section 5.4)
138 and carefully matching the reference materials to the M&E being surveyed.

139 When data are obtained from scan-only surveys incorporating data loggers, large quantities of
140 data are usually recorded. In essence, 100 percent of Class 1 M&E are measured. While the
141 survey coverage may be less than 100 percent for Class 2 and Class 3 M&E, the number of data
142 points is still likely be large. As long as there was no bias in the selection of areas that were
143 scanned, the frequency plot will be close to the population distribution of radioactivity levels in
144 the M&E. The mean and standard deviation calculated from these logged values should be very
145 close to the corresponding population values.

146 For conveyORIZED survey monitors, the data may be interpreted batch-by-batch as it is scanned.
147 In this case, the data treatment would be most similar to a single in situ measurement used to
148 evaluate all of the M&E. If, on the other hand, the data were logged continuously the data
149 treatment would be similar to a scan-only survey using data loggers.

150 6.2.2.3 Calculate Basic Statistical Quantities

151 Radiological survey data are usually obtained in units (e.g., counts per unit time) that have no
152 intrinsic meaning relative to the action levels. For comparison of survey data to action levels,
153 survey data from laboratory and field analyses are converted into action level units. MARSSIM
154 Section 6.6 provides guidance on data conversion. Any uncertainty associated with data
155 conversion should be included in the estimate of measurement uncertainty (see Section 5.6). For
156 surveys where individual results are not recorded (e.g., scan-only surveys with hand-held
157 instruments) the uncertainty is associated with converting the action level into the units provided
158 by the instrument in the field. Since individual results are not recorded, no statistical quantities
159 can be calculated.

160 Basic statistical quantities that should be calculated for the sample data set include the mean,
161 standard deviation, and the median. Other statistical quantities may be calculated based on the
162 survey objectives. For example, suppose the following 10 measurement results are obtained
163 from a disposition survey:

164 9.1, 10.7, 13.6, 3.4, 13.3, 7.9, 4.5, 7.7, 8.3, 10.4

165 The mean of the data (μ) is 8.89 and the standard deviation (σ) is 3.3231.²

166 The next 10 measurement results are from an appropriate matching reference material:

167 6.2, 13.8, 15.2, 9.3, 6.7, 4.9, 7.1, 3.6, 8.8, 8.9

168 The mean of the reference data (μ) is 8.45 and the standard deviation (σ) is 3.6713.

169 The means of the two data sets can be compared to provide a preliminary indication of the
170 survey unit status. The difference is 0.44, with the M&E being investigated having a higher
171 mean concentration. If the mean for the M&E exceeds the mean for the reference material by
172 more than the action level, the M&E clearly do not meet the disposition criterion. On the other
173 hand, if the difference between the largest M&E measurement (13.6 for this example) and the
174 smallest reference material measurement (3.6 for this example) is below the action level, the
175 M&E will pass the WRS test (Section 6.6) but will have to meet other criteria as well.

176 The value of the sample standard deviation is especially important. If the standard deviation is
177 too large compared to what was assumed for variability during development of the survey
178 design, this may indicate an insufficient number of samples were collected to achieve the desired
179 power for the statistical test. As previously mentioned, inadequate power can lead to an increase
180 in the Type II decision error rate.

181 The median is the middle value of the data set when the number of data points is odd or the mean
182 of the two middle values when the number of data points is even. A large difference between the

² Note the use of significant digits in this example. Since all of the numbers in the text are interim values in calculating the difference between two means, they are not rounded. If the mean and standard deviation values were to be reported as results they would be rounded to two significant digits because the original data is a mixture of numbers with two and three significant digits. If the data were rounded after each calculation, the difference in the rounded means appears to be 0.4 (i.e., 8.9 minus 8.5), but the actual difference is 0.44 based on the un-rounded means (i.e., 8.89 minus 8.45). This is an example of how rounding numbers too early in the process can result in additional uncertainty.

183 mean and the median indicate a potential skew in the data. This would also be evident in a
184 histogram of the data.

185 Examining other statistical quantities such as the maximum, minimum, and range may provide
186 additional useful information. For the example M&E data set the minimum is 3.4 and the
187 maximum is 13.6. The range is $13.6 - 3.4 = 10.2$. The range is equal to 3.1 standard deviations
188 (i.e., $10.2/3.3$). When there are thirty or fewer data points, range values greater than 4 or 5
189 standard deviations would be unusual. Thus, the range for this example data set is not unusually
190 large. The range may be greater for larger data sets.

191 **6.2.3 Select the Statistical Tests**

192 In most cases the selection of a statistical test is determined by the survey design used to collect
193 the data. The most appropriate procedure for summarizing and analyzing the data is chosen
194 based on the preliminary data review. If the preliminary data review indicates that the
195 assumptions used to develop the survey design are valid, the statistical tests and evaluation
196 methods determined should then be applied. If the assumptions used to develop the survey
197 design are determined to be invalid, it may be necessary to consult a statistician to determine the
198 most appropriate statistical test for evaluating the survey results.

199 6.2.3.1 Scan-Only Surveys

200 Scan-only surveys generate large amounts of data. Class 1 surveys measure all of the M&E.
201 When less than 100 percent of the M&E are measured (i.e., Class 2 or Class 3 surveys) the areas
202 that are measured are assumed representative of the areas that are not measured. This
203 assumption should be checked during the preliminary data review (Section 6.2.2). The
204 radionuclide concentrations or radioactivity in the areas that are not measured can be inferred
205 based on the measurement results in the areas that are measured. Data indicating this inference
206 may not be reasonable should result in re-evaluation of the survey design. For example, suppose
207 the survey design specifies that ^{137}Cs is the radionuclide of concern and scanning 50% of the
208 M&E is appropriate based on the expected distribution of radionuclide concentrations, expected
209 levels of radioactivity, and the beta-gamma emissions from the radionuclide of concern. If

210 additional historical data is found showing ^{239}Pu is also a radionuclide of concern, the survey
211 design should be re-evaluated based on the presence of an alpha emitting radionuclide as well.

212 If disposition decisions will be made for individual items or based on individual measurement
213 results, all of the results should be compared to the action level. Comparison to the action level
214 based on a detection decision or measurement (see Section 5.7) is discussed in Section 6.3.

215 Individual measurement results can be recorded for scan-only surveys. The benefit of logging
216 individual measurement results is the ability to statistically evaluate the data (e.g., calculate a
217 mean and an upper confidence limit). If disposition decisions will be made based on the mean of
218 logged data, an upper confidence level for the mean is calculated and compared to the UBGR.
219 This means that compliance with the disposition criterion can be demonstrated for the entire
220 survey unit, even if some of the results exceed the UBGR. Evaluations using the upper
221 confidence limit are discussed in Section 6.4. When less than 100% of the M&E are measured
222 (i.e., Class 2 and Class 3 surveys), the total uncertainty includes both spatial and measurement
223 uncertainty. Measuring 100% of the M&E (i.e., Class 1 survey) accounts for spatial variability,
224 but there is still an uncertainty component resulting from variability in the measurement process.

225 Conveyorized systems that continually log the survey results also generate large amounts of data.
226 An upper confidence level for the mean can be used for the evaluation of data from these types
227 of systems (see Section 6.4) in the same manner as logged scan data. Conveyorized systems that
228 operate in a batch mode are essentially treated as single in situ measurements of small batches of
229 M&E. The results generated by these types of systems are evaluated as a series of comparisons
230 to the UBGR; using detection decisions based on the MDC (see Section 6.3).

231 6.2.3.2 In Situ Surveys

232 In situ surveys may consist of a series of isolated measurements covering all or part of the M&E
233 (i.e., MARSSIM-type survey design), a series of measurements with overlapping fields of view
234 incorporating all (Class 1) or a portion (Class 2 or Class 3) of the M&E, or a single measurement
235 incorporating all of the M&E (see Section 4.4.2). Different assumptions are used to design each
236 of these types of in situ surveys, and different methods are used to evaluate the results of these
237 surveys.

238 Similar to scan-only surveys, if disposition decisions will be made for individual items or based
239 on individual measurement results, all of the results should be compared to the action level.
240 Comparison to the action level based on a detection decision (see Section 5.7) is discussed in
241 Section 6.3. Unlike scan-only surveys, in situ surveys are likely based on a limited number of
242 data points. To perform in situ measurements, assumptions were made about the distribution of
243 radioactivity within the volume of M&E being measured. These assumptions are inherent in the
244 calibration of in situ measurement systems and the validity of these assumptions determines the
245 appropriateness of the measurement. It is important to account for uncertainty in these
246 assumptions when calculating the MDC and to evaluate these assumptions using QC
247 measurements performed during the survey. If there is uncertainty about the true MDC or
248 critical value, use conservative values for the efficiency as described in Chapter 5.

249 6.2.3.3 MARSSIM-Type Survey Designs

250 MARSSIM-type survey designs are generally used when instrumentation for scan-only or in situ
251 measurement surveys does not provide sufficient sensitivity (e.g., the MDC is greater than the
252 UBGR). A statistically based number of measurements is used to provide an estimate of the
253 mean activity in each survey unit, and scanning is used to identify small areas of elevated
254 activity between sample locations.

255 The number of measurements is determined by the statistical test. In most cases the statistical
256 tests used in MARSSIM are appropriate for Scenario A. The criteria for choosing between the
257 Sign test and the Wilcoxon Rank Sum (WRS) test are described in MARSSIM Section 8.2.3. In
258 general, when the radionuclide is not present in background (or its background concentration is
259 negligible compared to the action level) and radionuclide-specific measurements are made, the
260 Sign test (Section 6.5) is used. Otherwise, the WRS (Section 6.6) test should be used. The Sign
261 test is designed to detect whether there is radioactivity in the M&E above the action level. The
262 WRS test is used to compare measurements of the M&E to measurements performed on the
263 reference material.

264 When Scenario B is used, the statistical tests described in NUREG-1505 (NRC 1998a) are
265 generally used. The Sign test and the WRS test are still used, but the application of the test is
266 adjusted to account for the difference in the null hypothesis. When using Scenario B, there is a

267 potential for the WRS test to miss non-uniform radioactivity (i.e., slightly elevated radionuclide
268 concentrations or levels of radioactivity over a portion of the survey unit). Randomization of the
269 M&E through mixing or homogenization can eliminate this possibility. If randomization is not
270 practical, the Quantile test (Section 6.7) should be used to evaluate survey units when the WRS
271 test fails to reject the null hypothesis.

272 The results of scanning measurements performed as part of a MARSSIM-type survey are
273 evaluated using the elevated measurement comparison (EMC). The EMC is simply a
274 comparison to an action level (see Section 6.3). The action level used for the EMC is the action
275 level for small areas of elevated activity. If there is no action level for elevated activity, the
276 scanning results are compared to the action level for the mean activity in the survey unit.
277 Additional information on the EMC is available in MARSSIM Section 8.5.1 and NUREG-1505
278 Chapter 8 (NRC 1998a).

279 **6.2.4 Verify the Assumptions of the Tests**

280 An evaluation to determine the data are consistent with the underlying assumptions of the
281 statistical tests helps to validate the use of a particular test. One may also determine that certain
282 departures from these assumptions are acceptable when given the actual data and other
283 information about the project. The nonparametric tests described in this chapter assume that the
284 data from the M&E or the reference material consist of independent measurements from each
285 distribution. The primary issue associated with the evaluation of scan-only and single in situ
286 measurement survey data is the MDC or MQC as discussed in Section 6.2.1.

287 Asymmetry in the data can be identified using a histogram or a Quantile plot. Information on
288 histograms and Quantile plots is provided in MARSSIM Appendix I and NUREG-1505 Section
289 4.2.2 (NRC 1998a). As discussed in Section 6.2.2.3, data transformations can sometimes be used
290 to minimize the effects of asymmetry.

291 One of the primary advantages to using the nonparametric tests is that they involve fewer
292 assumptions about the data than their parametric counterparts. If parametric tests are used (e.g.,
293 Student's t test) any additional assumptions made in using these tests should be verified (e.g.,
294 testing for normality). These issues are discussed in detail in EPA QA/G-9S (EPA 2006c).

295 One of the more important assumptions made in the survey design is that the number of
296 measurements is sufficient to achieve the DQOs set for the Type I (α) and Type II (β) decision
297 error rates. Verification of the power of the statistical tests ($1-\beta$) may be of particular interest.
298 Methods for assessing power are discussed in Appendix I.9 of MARSSIM. If there is not
299 reasonable assurance the DQOs have been achieved, additional investigations including
300 repeating the survey may be needed. The planning team can develop survey designs cautiously
301 to avoid unnecessary and potentially costly decision errors by:

- 302 • Estimating the potential data variability conservatively,
- 303 • Taking more measurements than suggested by the DQO process, and
- 304 • Estimating the MDCs conservatively.

305 In the absence of other data, each of these estimates could be multiplied by a safety factor of 1.2
306 (i.e., increase the estimate by 20%). Examples of assumptions and possible methods for
307 evaluating and verifying these assumptions are summarized in Table 6.1.

308 Verification of scan-only and in situ survey results focuses on the estimates of the MDC and
309 MQC values used to design the survey. If the assumptions used to estimate these values are
310 incorrect, the survey design may be invalid.

311 The first step in evaluating the MDC and MQC is to review the assumptions used to develop
312 these values. In general, the key assumptions are made in determining the source and detector
313 efficiencies. QA and QC reports should be reviewed to evaluate measurement performance (e.g.,
314 scan speed, source geometry, distance from M&E to the detector, non-uniform response of large
315 area detectors). The description of the M&E from the IA should be compared to the assumptions
316 used to develop the efficiency.

317 In some cases it may be possible to compare the survey results of multiple measurement
318 techniques. For example, if there are multiple radiations associated with the M&E it may be
319 possible to compare gamma measurement results to alpha or beta measurement results to verify
320 the survey results. Direct measurements may provide more quantitative results for areas of
321 elevated activity identified during scan-only surveys.

322

Table 6.1 Issues and Assumptions Underlying the Evaluation Method

Evaluation Method	Issue	Verification Method	Survey Type
Compare single measurements to a limit (see Section 6.3)	Verify the MDC and Measurement Uncertainty	Review the MDC Review QA/QC Reports Review IA and DQOs	Scan-Only In situ
Compare an upper confidence limit for the mean to a limit (see Section 6.4)	Verify the MQC and Measurement Uncertainty	Review the Measurement Uncertainty Review QA/QC Reports Review IA and DQOs	Scan Only In situ
Statistical Tests (see Sections 6.5, 6.6, and 6.7)	Verify the Assumptions of the Statistical Test (e.g., spatial independence, symmetry, data variance, power)	Preliminary Data Review (e.g., posting plot, histogram, summary statistics, power curve)	MARSSIM-Type Survey

323 It may be possible to use an entirely different survey method to provide information to support
324 verification of assumptions used to design a survey. For example, smears or surface scrapings
325 can be used to verify the presence of radionuclides or radioactivity on the surface.³ In situ
326 measurements or sample collection and analysis may be used to verify the results of scan-only
327 survey designs. Care must be taken to ensure comparability of survey methods before evaluating
328 the results to avoid generating conflicting results. For example, consider an in situ survey used
329 to demonstrate the mean activity is less than the action level. A scan-only survey method is used
330 to verify the results and identifies an area of elevated activity. This discrepancy in results
331 warrants additional investigation of the small area of elevated activity. The additional
332 investigation should determine if the activity in this area actually causes the mean activity to
333 exceed the disposition criterion.

³ This smear procedure does not rule out additional volumetric activity.

334 **6.2.5 Draw Conclusions from the Data**

335 The types of measurements performed on M&E are:

- 336 • Scans,
- 337 • In situ or direct measurements at discrete locations, and
- 338 • Samples collected at discrete locations.

339 Specific details for conducting the Sign test and the WRS tests are provided in Sections 6.5 and
340 6.6, respectively. When the data clearly show that the M&E meets or exceeds the disposition
341 criterion, the result is often obvious without performing the formal statistical analysis. This is
342 the expected outcome for Class 2 and Class 3 surveys. Table 6.2 summarizes examples of
343 circumstances leading to specific conclusions based on a simple examination of the data.

344 **6.3 Compare Results to the UBGR**

345 When disposition decisions will be made about individual items, or decisions will be based on
346 individual measurement results, each result (plus or minus a multiple of its combined standard
347 uncertainty) will be compared to the action level (see MARLAP Appendix C.4). In practice, this
348 means that any result that exceeds the critical value (S_C , see Section 5.7.1) when the minimum
349 detectable level (S_D , see Section 5.7.2) equals the UBGR provides evidence that the result
350 exceeds the UBGR.

351 For Scenario A, if all the results are less than the action level, then the mean and the maximum
352 activity must also be below the action level. Thus, the radionuclide concentrations or levels of
353 radioactivity associated with the M&E demonstrate compliance with the disposition criterion.
354 For Scenario B when the action level is not zero or background, all of the results must be below
355 the critical value corresponding to the MDC set equal to the UBGR. If the action level is zero or
356 background, Scenario B must be used and any indication of the presence of radionuclide
357 concentrations or radioactivity above background (i.e., above the discrimination level) would
358 result in rejecting the null hypothesis. For this situation, any measurement result exceeding the
359 critical value corresponding to the required MDC indicates the potential presence of
360 radionuclides or radioactivity above background. This applies to single in situ measurements as
361 well as series of in situ measurements.

Table 6.2 Summary of Evaluation Methods and Statistical Tests

Evaluation Method or Statistical Test	Survey Result	Conclusion
Comparison to a Limit (AL=0) <i>Scenario B only</i> <i>Results may or may not be recorded</i> <i>Scan-only or In situ surveys</i>	All measurements less than the critical value corresponding to the MDC (e.g., does not exceed alarm set point)	M&E meet the disposition criterion
	Any measurement exceeds the critical value corresponding to the MDC	M&E do not meet the disposition criterion
Comparison to a Limit (AL≠0) <i>Scenario A or B</i> <i>Results not recorded</i> <i>Scan-only or In situ surveys</i>	All measurements less than the critical value corresponding to the UBGR	M&E meet the disposition criterion
	Any measurement exceeds the critical value corresponding to the UBGR	M&E do not meet the disposition criterion
Comparison to Upper Confidence Limit <i>Scenario A or B</i> <i>Results must be recorded</i> <i>Scan-only or In situ surveys</i>	Upper confidence limit less than UBGR	M&E meet the disposition criterion
	Upper confidence limit greater than UBGR	M&E do not meet the disposition criterion
Sign Test <i>Radionuclide not in background</i> <i>Nuclide-specific measurements</i> <i>Scenario A or B</i> <i>MARSSIM-type surveys</i>	All measurements less than the action level	M&E meet the disposition criterion
	Mean greater than the action level	M&E do not meet the disposition criterion
	Any measurement greater than the action level and the mean less than the action level	Conduct Sign test (and elevated measurement comparison, if necessary)
Wilcoxon Rank Sum (WRS) Test <i>Radionuclide in background</i> <i>Nuclide non-specific measurements</i> <i>Scenario A or B</i> <i>MARSSIM-type surveys</i>	Difference between maximum survey unit measurement and minimum reference area measurement is less than the UBGR	M&E meet the disposition criterion
	Difference of survey unit mean and reference area mean is greater than the action level	M&E do not meet the disposition criterion

Evaluation Method or Statistical Test	Survey Result	Conclusion
	Difference between any survey unit measurement and any reference area measurement greater than the action level or the difference of survey unit mean and reference area mean is less than the action level	Conduct WRS test (and elevated measurement comparison, if necessary)
Quantile Test <i>Test for non-uniform radioactivity</i> <i>Combine with WRS test</i> <i>Scenario B only</i> <i>MARSSIM-type surveys</i>	Difference between maximum survey unit measurement and minimum reference area measurement is less than the UBGR	M&E meet the disposition criterion
	Difference of survey unit mean and reference area mean is greater than the action level	M&E do not meet the disposition criterion
	Difference between any survey unit measurement and any reference area measurement greater than the action level or the difference of survey unit mean and reference area mean is less than the action level	Conduct Quantile test (and elevated measurement comparison, if necessary)

363 If there is an action level based on small areas of elevated activity or the maximum allowable
364 value, the individual results can be compared directly to the action level. This applies primarily
365 to the evaluation of scanning results for MARSSIM-type surveys (i.e., the EMC), but may be
366 applied to scan-only survey data as well.

367 **6.4 Compare Results Using an Upper Confidence Limit**

368 When disposition decisions are made about the estimated mean of a sampled population, the
369 assessment of the survey results is accomplished by comparing an upper confidence limit for the

370 mean to the UBGR. For scan-only surveys where there are a large number of data points, a
371 simple comparison of the mean activity to the UBGR may be sufficient.⁴

372 If individual scan-only survey results are recorded, a non-parametric confidence interval can be
373 used to evaluate the results of the disposition survey. Similarly, a confidence interval can be
374 used to evaluate a series of in situ measurements with overlapping fields of view. A one-tailed
375 version of Chebyshev's inequality or EPA's ProUCL software can be used to evaluate the
376 probability of exceeding the UBGR (i.e., using an upper confidence limit). The use of an upper
377 confidence limit applies to both Scenario A (where the UBGR equals the action level) and
378 Scenario B when the action level is not zero or background (where the UBGR equals the
379 discrimination limit). Comparison to an upper confidence level should not be used for Scenario
380 B when the action level equals zero or background.⁵

381 If all of the survey results are less than the UBGR, the mean must also be less than the UBGR.
382 In this situation it is not necessary to calculate the upper confidence limit to show that the survey
383 results demonstrate compliance with the disposition criterion.

⁴ The calculation of the upper confidence limit is based partially on the number of measurements. When the number of measurements gets very large, i.e., close to 100% of the M&E have been measured, the estimates for the mean and the standard deviation get close to the actual, but unknown, values. In certain situations (e.g., 100% measurement with a documented measurement method) the planning team may assume that the estimate of the mean based on the survey results is close enough to the actual, but unknown, mean of the population to be compared directly to the UBGR.

⁵ By convention, any result exceeding the critical level is not likely to be zero or background since $1-\alpha$ (i.e., 95% for the MDC) of the background distribution is below the critical level. This means that the null hypothesis stating the radionuclide concentration or level of radioactivity in the M&E is zero or consistent with background should be rejected.

384 **6.4.1 Calculate the Upper Confidence Limit**

385 Chebyshev's inequality calculates the probability that the absolute value of the difference of the
 386 true but unknown mean of the population and a random number from the data set is at least a
 387 specified value. That is, given a specified positive number (n), a mean (μ), and a random number
 388 from the data set (r), then the probability that $|\mu - r|$ is greater than or equal to n is equal to α . In
 389 addition, a one-tailed version of the inequality can be used to calculate an upper confidence limit
 390 (UCL) for a data set that is independent of the data distribution (i.e., there is no requirement to
 391 verify the data are from a normal, lognormal, or any other specified kind of distribution) by
 392 letting the inequality equal the UCL, as described in the following steps.

- 393 1. Calculate the mean (μ) and standard deviation (σ) of the number of results (n) in the data
 394 set.
- 395 2. For Scenario A, retrieve the Type I error rate (α) used to design the survey.
- 396 3. Using Chebyshev's inequality, calculate the maximum UCL using equation 6-1:

$$397 \quad \text{UCL} = \mu + \sqrt{\frac{\sigma^2}{n\alpha} - \frac{\sigma^2}{n}} \quad (6-1)$$

- 398 4. For Scenario B, substitute the Type II error rate (β) used to design the survey for α in
 399 Equation 6-1.
- 400 5. If the maximum UCL is less than the UBGR, the survey demonstrates compliance with
 401 the disposition criterion (i.e., reject the null hypothesis for Scenario A or fail to reject the
 402 null hypothesis for Scenario B).

403 Chebyshev's inequality must be used with caution when there are very few points in the data set.
 404 This is because the population mean and standard deviation in the Chebyshev formula are being
 405 estimated by the sample mean and sample standard deviation. In a small data set from a highly
 406 skewed distribution, the sample mean and sample standard deviation may be underestimated if
 407 the high concentration but low probability portion of the distribution is not captured in the
 408 sample data set. EPA has issued guidance on calculating upper confidence limits for exposure

409 point concentrations (EPA 2002b)⁶. Software for implementing EPA's guidance is available
410 (EPA 2006d).

411 **6.4.2 Upper Confidence Limit Example: Class 1 Concrete Rubble**

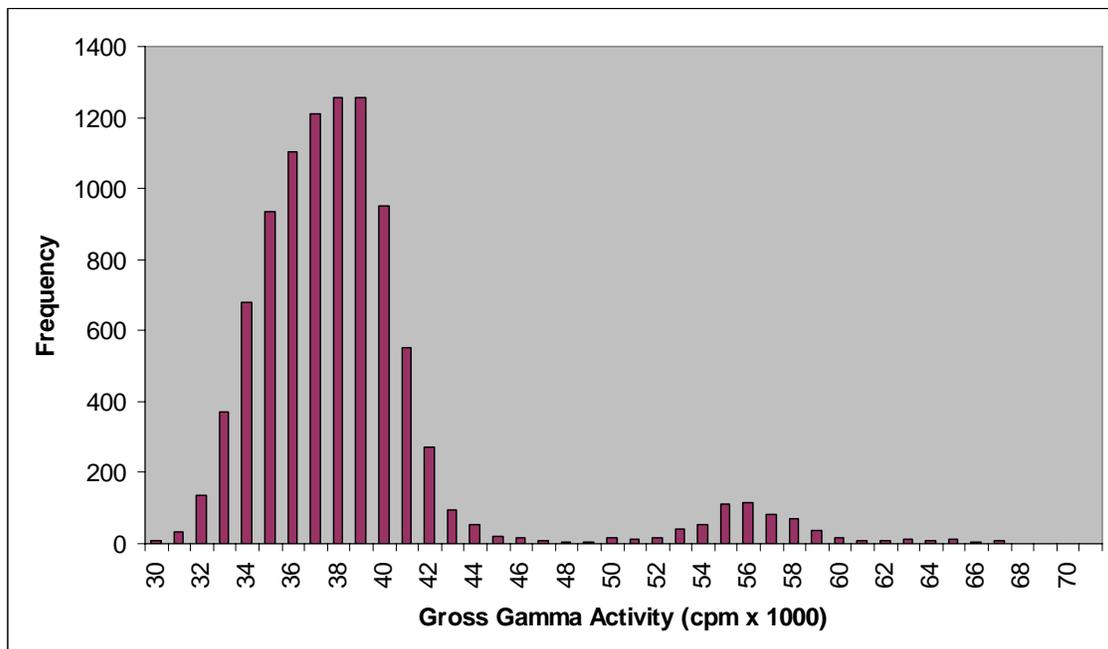
412 This example illustrates the survey design for concrete rubble using 3 in x 3 in NaI(Tl) detectors
413 mounted on a conveyORIZED survey system to measure ¹³⁷Cs. A pile of concrete rubble was
414 loaded on the conveyor and passed beneath the detectors at a pre-determined speed. Each one-
415 second count recorded by a detector corresponds to approximately 9,800 cm³ of concrete rubble
416 (i.e., a 5 cm thick disk with a 50 cm diameter). The following information was used to design
417 the survey:

- 418 • The selected disposition option was clearance, using Scenario A with the null
419 hypothesis that the residual radioactivity exceeds the action level.
- 420 • The IA indicated the concrete was potentially volumetrically contaminated prior to
421 being converted to rubble.
- 422 • The concrete rubble had a maximum particle dimension of less than 0.5 cm.
- 423 • The average background count rate was estimated to be 38,000 cpm based on
424 preliminary surveys of non-impacted concrete, and was used for the LBGR.
- 425 • The action level was set at 20,000 cpm above the average background count rate, so
426 the UBGR was set at 58,000 cpm.
- 427 • The estimated standard deviation of background count rate is 2,500 cpm based on
428 preliminary survey data.
- 429 • The Type I decision error rate was set at 0.10, or 10%.

430 The survey consisted of 9,616 one-second measurements that were recorded using a data logger.
431 The mean count rate for the survey was 39,252 cpm, with a standard deviation of 5,465 cpm.

⁶ In MARSAME, exposure point concentration is used to mean a conservative estimate of the mean radionuclide concentration(s) in or on M&E.

432 The standard deviation of the mean was $5465/\sqrt{9616} = 55.7$. As noted earlier, with such a large
 433 data set, one can expect that the sample mean and standard deviation should be fairly close to
 434 their population values. Note that the estimated coefficient of variation of the mean is
 435 $55.7/39,252 = 0.14\%$. The minimum count rate was 30,080 cpm, and the maximum count rate
 436 was 72,805 cpm. Note that although the mean concentration is well below the action level, there
 437 are data points that exceed the action level. Thus, a test against an UCL for the mean is
 438 warranted. Figure 6.1 shows a frequency plot of the survey results.



439

440 **Figure 6.1 Frequency Plot of Concrete Rubble Data**

441 If the sample size were small, however, the upper part of the bimodal distribution could be
 442 missed and the Chebyshev UCL could be underestimated. In this case, with a sample size of
 443 9,616, the upper confidence level was calculated as described in Section 6.4.1.

444

$$\text{UCL} = 39,252 + \sqrt{\frac{(5,465)^2}{(0.10)(9,616)} + \frac{(5,465)^2}{(9,616)}} = 39,474 \text{ cpm}$$

445 The upper confidence level of 39,474 cpm is much less than the action level of 58,000 cpm. The
446 null hypothesis that the level of radioactivity exceeds the disposition criterion is rejected. The
447 EPA ProUCL software was also applied to these data and the results are shown in Figure 6.2.

448 The software has failed to find a good fit to the data for normal, lognormal or gamma
449 distributions, which is hardly surprising given the bimodal nature of the data. The
450 recommendation is that either a Student's t or a modified Student's t 95% UCL be used. These
451 are both listed as about 39,343. These are lower than the 90% Chebyshev UCL of 39,474 used
452 above, but that would not change the conclusion. A 95% Chebyshev UCL calculated according
453 to Section 6.4.1 would have been 39,574. Note that the 95% Chebyshev UCL calculated by
454 ProUCL, rounded to the nearest count, is slightly different, 39,495, because of the way that the
455 sample mean and standard deviation are estimated before entering them in the Chebyshev
456 formula. The ProUCL User's Manual can be consulted for details. However, with the number
457 of data points at hand, there is little difference among any of the methods for computing an UCL.

458 **6.5 Sign Test**

459 The Sign test is used to compare the measurement results from each survey unit with the
460 applicable disposition criterion. The Sign test can be applied to either Scenario A or Scenario B.
461 The Sign test should only be used if the radionuclide being measured is not present in
462 background. The Sign test may also be used if the radionuclide being measured is present at
463 such a small fraction of the action level as to be considered insignificant. Otherwise, the WRS
464 test described in Section 6.6 should be applied. Additional information on the Sign test can be
465 found in Section 8.3 of MARSSIM and Chapter 5 of NUREG 1505 (NRC 1998a).

UCL Statistics for CPM										
	A	B	C	D	E	F	G	H	I	
1	Data File					Variable:	CPM			
2										
3	Raw Statistics				Normal Distribution Test					
4	Number of Valid Samples			9616	Lilliefors Test Statistic				0.2044466	
5	Number of Unique Samples			6441	Lilliefors 5% Critical Value				0.0090352	
6	Minimum			30080	Data not normal at 5% significance level					
7	Maximum			72805						
8	Mean			39251.847	95% UCL (Assuming Normal Distribution)					
9	Median			38267	Student's-t UCL				39343.497	
10	Standard Deviation			5465.0563						
11	Variance			29866840	Gamma Distribution Test					
12	Coefficient of Variation			0.1392306	A-D Test Statistic				585.96505	
13	Skewness			2.4504964	A-D 5% Critical Value				0.7522512	
14					K-S Test Statistic				0.1788147	
15	Gamma Statistics				K-S 5% Critical Value				0.01814	
16	k hat			61.605609	Data do not follow gamma distribution					
17	k star (bias corrected)			61.586458	at 5% significance level					
18	Theta hat			637.14729						
19	Theta star			637.34542	95% UCLs (Assuming Gamma Distribution)					
20	nu hat			1184799.1	Approximate Gamma UCL				39335.904	
21	nu star			1184430.8	Adjusted Gamma UCL				39335.917	
22	Approx. Chi Square Value (.05)			1181899.7						
23	Adjusted Level of Significance			0.049975	Lognormal Distribution Test					
24	Adjusted Chi Square Value			1181899.4	Lilliefors Test Statistic				0.1656286	
25					Lilliefors 5% Critical Value				0.0090352	
26	Log-transformed Statistics				Data not lognormal at 5% significance level					
27	Minimum of log data			10.311616						
28	Maximum of log data			11.19554	95% UCLs (Assuming Lognormal Distribution)					
29	Mean of log data			10.569616	95% H-UCL				N/A	
30	Standard Deviation of log data			0.1224578	95% Chebyshev (MVUE) UCL				39441.02	
31	Variance of log data			0.0149959	97.5% Chebyshev (MVUE) UCL				39533.758	
32					99% Chebyshev (MVUE) UCL				39715.923	
33										
34					95% Non-parametric UCLs					
35					CLT UCL				39343.516	
36					Adj-CLT UCL (Adjusted for skewness)				39345.004	
37					Mod-t UCL (Adjusted for skewness)				39343.729	
38					Jackknife UCL				39343.497	
39					Standard Bootstrap UCL				39341.993	
40					Bootstrap-t UCL				39342.895	
41	RECOMMENDATION				Hall's Bootstrap UCL					39343.322
42	Data are Non-parametric (0.05)				Percentile Bootstrap UCL					39337.588
43					BCA Bootstrap UCL				39344.539	
44	Use Student's-t UCL				95% Chebyshev (Mean, Sd) UCL					39494.773
45	or Modified-t UCL				97.5% Chebyshev (Mean, Sd) UCL					39599.887
46					99% Chebyshev (Mean, Sd) UCL				39806.364	

Figure 6.2 Output from ProUCL Software for the Sample Data Set

466

467

468 6.5.1 Apply the Sign Test to Scenario A

469 The Sign test is applied to Scenario A by counting the number of measurements from each
470 survey unit that are less than the action level (i.e., UBGR). Each result is subtracted from the
471 action level ($AL - X_i$), and the number of positive values is summed. The result is the test
472 statistic S_+ . Discard any measurement that is exactly equal to the action level and reduce the
473 sample size, N , by the number of such measurements. The value of S_+ is compared to the
474 critical values in A.3. If S_+ is greater than the critical value (k) in the table, the null hypothesis
475 is rejected.

476 6.5.2 Apply the Sign Test to Scenario B

477 The Sign test is applied to Scenario B in a manner similar to that used for Scenario A. However,
478 for Scenario B the action level (i.e., LBGR) is subtracted from each result ($X_i - AL$), and the
479 number of positive values is summed. The result is the test statistic S_+ . Discard any
480 measurement that is exactly equal to the action level and reduce the sample size, N , by the
481 number of such measurements. The value of S_+ is compared to the critical values in Table A.3.
482 If S_+ is greater than the critical value (k) in the table, the null hypothesis is rejected.

483 6.5.3 Sign Test Example: Class 1 Copper Pipes

484 This example illustrates the disposition survey design for copper pipe sections using a gas-flow
485 proportional counter to measure ^{239}Pu . Since the alpha background on the copper material is
486 essentially zero, it was decided the Sign test would be used to determine whether the material
487 meets the disposition criterion. The sample size was determined using the DQO Process and
488 inputs such as the disposition option, action level, expected standard deviation of the
489 measurement results, and the acceptable probability of making Type I and Type II decision
490 errors.

491 The following inputs were used to develop the survey design:

- 492 • The selected disposition option was clearance.
- 493 • The survey was designed using Scenario A, with the null hypothesis that the residual
494 radioactivity exceeds the action level.
- 495 • The IA indicated that the inside surfaces of the pipes potentially came in contact with
496 liquids containing ^{239}Pu , but the outside surfaces were non-impacted.
- 497 • The gross activity action level was 100 dpm/100 cm². When converted to cpm the
498 gross activity action level was 10 cpm (i.e., total efficiency = 0.10 counts per
499 disintegration).
- 500 • The LBGR (i.e., the DL) was set at the expected activity level on the copper pipe
501 sections (i.e., 5 net cpm - the same as the gross mean for an alpha background of
502 zero).
- 503 • The standard deviation for the measurements was estimated at 2 cpm.
- 504 • The relative shift was calculated as $(10-5)/2 = 2.5$.
- 505 • The Type I and Type II decision error rates were both set at 0.05.

506 Table A.2a indicates the number of measurements estimated to be needed for the Sign test, N , is
507 15 ($\alpha=0.05$, $\beta=0.05$, and $\Delta/\sigma=2.5$). Therefore 15 surface activity measurements were randomly
508 collected from the inside surfaces of the copper pipe sections. Survey results are shown in
509 Table 6.3.

510 The surface activity values in Table 6.3 were determined by dividing the measured cpm by the
511 total efficiency (0.10). No probe area correction was necessary. The mean count rate was 5
512 cpm, compared to the estimate of 5 cpm used for the LBGR, and the median was 4 cpm. The
513 standard deviation was 4 cpm, which was higher than the value of 2 used to develop the survey

514 design.⁷ Thus, the power of the test is lower than planned. With the actual value of the relative
 515 shift $(10-5)/4=1.2$, 23 measurements should have been collected.

516 **Table 6.3 Sign Test Example Data**

Surface Concentration (cpm/100 cm ²)	Surface Concentration (dpm/100 cm ²)	< Action Level?
4	40	Yes
3	30	Yes
11	110	No
1	10	Yes
1	10	Yes
4	40	Yes
6	60	Yes
3	30	Yes
9	90	Yes
6	60	Yes
14	140	No
1	10	Yes
4	40	Yes
10	100	No
2	20	Yes
Number of measurements less than the action level (S+) = 12		

517 With the 15 measurements collected, the actual Type II decision error rate was between 0.10 and
 518 0.25 (the closest entries in Table A.2a are for $\alpha=0.05$, $\beta=0.10$, and $\Delta/\sigma=1.2$ with $N=18$, and
 519 $\alpha=0.05$, $\beta=0.25$, and $\Delta/\sigma=1.2$ with $N=12$). Three measurements exceeded the action level. The
 520 portion of the material associated with these measurements merits further investigation.

⁷ Values are reported to one significant figure based on the data in Table 6.3. Interim calculations generally carry extra figures, so rounding to the appropriate number of significant figures only occurs for the final calculation. Rounding results too soon in the calculation may result in unnecessarily deleting individual results (i.e., when the result is exactly equal to the UBGR) resulting in lower statistical power.

521 The value of S^+ , 12, was compared to the appropriate critical value, q , in Table A.3. In this case,
522 for $N=15$ and $\alpha=0.05$, the critical value is 11. Since S^+ exceeds q , reject the null hypothesis that
523 the survey unit exceeds the action level. In this case, the slight loss of power attributable to
524 underestimating the standard deviation did not affect the result. Pending the outcome of the
525 investigation of the three elevated measurements, this survey unit has satisfied the disposition
526 criteria established for clearance.

527 **6.6 Wilcoxon Rank Sum Test**

528 The Wilcoxon Rank Sum (WRS) test is used to compare each material survey unit with an
529 appropriately chosen reference material. Each reference material should be selected on the basis
530 of its similarity to the survey unit material, as discussed in Section 3.9. The WRS test can be
531 applied to either Scenario A or Scenario B. Further information on the WRS test can be found in
532 Section 8.4 of MARSSIM and Chapter 6 of NUREG- 1505 (NRC1998a).

533 **6.6.1 Apply the WRS Test to Scenario A**

534 The WRS test is applied to Scenario A as outlined in the following steps and further illustrated
535 by the example in Section 6.6.2.

- 536 1. Obtain the adjusted reference material measurements, Z_i , by adding the action level to
537 each reference material measurement, X_i . $Z_i = X_i + AL$.
- 538 2. The m adjusted reference sample measurements, Z_i , from the reference material and the n
539 sample measurements, Y_i , from the survey unit are pooled and ranked in order of
540 increasing size from 1 to N , where $N = m+n$.
- 541 3. If several measurements are tied (i.e., have the same value), they are all assigned the
542 mean rank of that group of tied measurements.

- 543 4. If there are t “less than” values, they are all given the mean of the ranks from 1 to t .
 544 Therefore, they are all assigned the rank $t(t+1)/(2t) = (t+1)/2$, which is the mean of the
 545 first t integers. If there is more than one MDC,⁸ all observations below the largest MDC
 546 should be treated as “less than” values. If more than 40% of the data from either the
 547 reference material or the survey unit are reported as less than detectable, the WRS test
 548 *cannot* be used.
- 549 5. The sum of all the ranks, which is the sum of the first N positive integers, is $N(N+1)/2$,
 550 which equals W_r added to W_s . Thus, one needs only to sum the ranks of the either the
 551 adjusted reference measurements (W_r) or the sum of the ranks of the sample
 552 measurements (W_s).
- 553 6. Compare W_r with the critical value (q) given in Table A.4 for the appropriate values of n ,
 554 m , and α . If W_r is greater than the tabulated value for q , reject the hypothesis that the
 555 survey unit exceeds the disposition criterion.

556 **6.6.2 Apply the WRS Test to Scenario B**

557 The WRS test is applied to Scenario B as outlined in the following steps:

- 558 1. Obtain the adjusted survey unit measurements, Z_i , by subtracting the LBGR from each
 559 survey unit measurement, Y_i . $Z_i = Y_i - \text{LBGR}$.
- 560 2. The n adjusted survey unit measurements, Z_i , and the m reference material measurements,
 561 X_i , are pooled and ranked in order of increasing size from 1 to N , where $N = m+n$.
- 562 3. If several measurements are tied (i.e., have the same value), they are all assigned the
 563 mean rank of that group of tied measurements.

⁸ Examples of situations where there could be more than one MDC include using multiple laboratories to perform sample analyses and using different instruments with different backgrounds and different efficiencies to perform measurements.

- 564 4. If there are t “less than” values, they are all given the mean of the ranks from 1 to t .
 565 Therefore, they are all assigned the rank $t(t+1)/(2t) = (t+1)/2$, which is the mean of the
 566 first t integers. If there is more than one MDC, all observations below the largest MDC
 567 should be treated as “less than” values. If more than 40% of the data from either the
 568 reference material or the survey unit are reported as less than detectable, the WRS test
 569 *cannot* be used.
- 570 5. Sum the ranks of the adjusted measurements from the survey unit, W_s . The sum of all the
 571 ranks, which is the sum of the first N positive integers, is $N(N+1)/2$, which equals W_r
 572 added to W_s . Thus, one needs only to sum the ranks of either the adjusted reference
 573 measurements (W_r) or the sum of the ranks of the sample measurements (W_s).
- 574 6. Compare W_s with the critical value (q) given in Table A.4 for the appropriate values of n ,
 575 m , and α . (NOTE: When using this table for Scenario B, the roles of m and n are
 576 reversed. If the Quantile test is being used in addition to the WRS test, then $\alpha/2$ should
 577 be used rather than α .) If W_s is greater than the tabulated value for q , reject the
 578 hypothesis that the difference in the median concentration between the survey unit and
 579 the reference area is less than the LBGR.

580 6.6.3 WRS Test Scenario A Example: Class 2 Metal Ductwork

581 This example illustrates the use of the WRS test for releasing Class 2 metal ductwork. Assume
 582 that a gas-flow proportional detector was used to make gross (non-radionuclide-specific) surface
 583 activity measurements.

584 The DQOs from this survey unit include $\alpha = 0.05$ and $\beta = 0.05$, and the action level converted to
 585 units of gross cpm is 2,300 cpm, which is the UBGR. In this case, the WRS test was used
 586 because the estimated background level (2,100 cpm) was large compared to the action level. The
 587 estimated standard deviation of the measurements, σ , was 375 cpm. The estimated added
 588 activity level was 800 cpm; the LBGR was set at this value, and represents the DL. The relative
 589 shift was calculated as A/σ , which is (action level – LBGR)/ σ , which equals 4.

590 The sample size needed for the WRS test can be found in Table A.2b for these DQOs. The result
 591 is nine measurements in each survey unit and nine in each reference material ($\alpha = 0.05$, and $\beta =$
 592 0.05 , and $\Delta/\sigma = 4$). The ductwork was laid flat onto a prepared grid, and the nine measurements
 593 needed in the survey unit were made using a random-start triangular grid pattern. For the
 594 reference materials, the measurement locations were chosen randomly on a suitable batch of
 595 material. Table 6.4 lists the gross count rate data obtained.

596 **Table 6.4 Scenario A WRS Test Example Data**

Data (cpm)	Area	Adjusted Data	Ranks	Reference Material Ranks
2180	R	4480	15	15
2398	R	4698	16	16
2779	R	5079	18	18
1427	R	3727	10	10
2738	R	5038	17	17
2024	R	4324	13	13
1561	R	3861	11	11
1991	R	4291	12	12
2073	R	4373	14	14
2039	S	2039	3	0
3061	S	3061	8	0
3243	S	3243	9	0
2456	S	2456	7	0
2115	S	2115	4	0
1874	S	1874	2	0
1703	S	1703	1	0
2388	S	2388	6	0
2159	S	2159	5	0
		Sum =	171	126

597 In the “Area” column, the code “R” denotes a reference material measurement and “S” denotes a
598 survey unit measurement. The adjusted data were obtained by adding the action level to the
599 reference material measurements (see Section 6.6.1, Step 1). The ranks of the data range from 1
600 to 18, since there are a total of 9+9 measurements (see Section 6.6.1, Step 2). Note that the sum
601 of all of the ranks is still $18(18+1)/2 = 171$. Checking this value with the formula in Step 5 of
602 Section 6.6.1 is recommended to guard against errors in the rankings.

603 The total of the ranks belonging to the reference material measurements is 126. This is
604 compared with the entry for the critical value of 104 in Table A.4 for $\alpha = 0.05$, with $n = 9$ and
605 $m = 9$. Since the sum of the reference material ranks is greater than the critical value, the null
606 hypothesis (i.e., that the mean survey unit concentration exceeds the action level) is rejected, and
607 the ductwork is released.

608 This conclusion can be reached quickly by noting the difference between the largest survey unit
609 measurement (3,243 cpm) and the smallest reference area measurement (1,427 cpm). This
610 difference ($3,243 - 1,427 = 1,816$ cpm) is less than the action level of 2,300 cpm. Since the
611 largest possible difference is less than the action level, the mean difference must also be less than
612 the action level.

613 **6.6.4 WRS Test Scenario B Example: Class 2 Metal Ductwork**

614 This example illustrates the use of the Scenario B WRS test for releasing Class 2 metal
615 ductwork, using the same data as in Section 6.6.3. The null hypothesis for Scenario B is that
616 there is no detectable radioactivity above background.

617 In this case the action level was set at no radioactivity detectable above the estimated
618 background level (2,100 cpm). The LBGR is equal to the action level, and is set to zero. The
619 regulator specified that the survey be able to detect an average excess of even 1,500 cpm being
620 released. This value is the DL. The UBGR is set equal to the DL (i.e., 1,500 cpm), with $\beta =$
621 0.025. The owner of the ductwork felt that there was very little if any radioactivity above

622 background present, and was willing to set $\alpha = 0.20$. The estimated standard deviation of the
 623 measurements, σ , was 375 cpm. The relative shift is $\Delta/\sigma = (\text{UBGR} - \text{LBGR})/\sigma =$
 624 $(1,500 - 0)/375 = 4$.

625 The sample size needed for the WRS test can be found in Table A.2b. The result is nine
 626 measurements in each survey unit and nine in each reference material $\alpha/2 = 0.10$, and $\beta = 0.025$,
 627 and $\Delta/\sigma = 4$. The data were obtained as in Section 6.6.3. Table 6.4 lists the gross count rate data
 628 obtained. These data were reanalyzed using Scenario B and the results are shown in Table 6.5.

629 **Table 6.5 Scenario B WRS Test Example Data**

Data (cpm)	Area	Adjusted Data	Ranks	Survey Unit Ranks
2180	R	2180	11	0
2398	R	2398	13	0
2779	R	2779	16	0
1427	R	1427	1	0
2738	R	2738	15	0
2024	R	2024	6	0
1561	R	1561	2	0
1991	R	1991	5	0
2073	R	2073	8	0
2039	S	2039	7	7
3061	S	3061	17	17
3243	S	3243	18	18
2456	S	2456	14	14
2115	S	2115	9	9
1874	S	1874	4	4
1703	S	1703	3	3
2388	S	2388	12	12
2159	S	2159	10	10
		Sum =	171	94

630 In the “Area” column, the code “R” denotes a reference material measurement and “S” denotes a
 631 survey unit measurement. The adjusted data would be obtained by subtracting the LBGR from
 632 the survey unit measurements (see Section 6.6.2, Step 1), but since the LBGR is zero, no
 633 adjustment is needed. The ranks of the adjusted data range from 1 to 18, since there are a total of
 634 9+9 measurements (see Section 6.6.2, Step 2). Note that the sum of all of the ranks is still
 635 $18(18+1)/2 = 171$. Checking this value with the formula in Step 5 of Section 6.6.2 is
 636 recommended to guard against errors in the rankings.

637 The total of the ranks belonging to the survey unit measurements is 94. This is compared with
 638 the entry for the critical value of 100 in Table A.4 for $\alpha = 0.10$, with $n = 9$ and $m = 9$. Since the
 639 sum of the reference material ranks is less than the critical value, the null hypothesis (i.e., that
 640 there is no detectable radioactivity above background) is not rejected, and the ductwork may be
 641 released if the Quantile test is passed.

642 **6.7 Quantile Test**

643 The Quantile test was developed to detect differences between the surveyed M&E and the
 644 reference material that consist of a shift to higher values in only a fraction of the surveyed M&E.
 645 The Quantile test is only performed when Scenario B is used, and only if the null hypothesis is
 646 not rejected for the WRS test. Using the Quantile test, in tandem with the WRS test, results in
 647 higher power to identify M&E that do not meet the disposition criterion than either test by itself.

648 Apply the Quantile test as follows:

- 649 1. Calculate α_Q ($\alpha_Q = \alpha/2$).
- 650 2. Obtain the adjusted survey unit measurements, Z_i , by subtracting the LBGR from each
 651 survey unit measurement, Y_i . $Z_i = Y_i - \text{LBGR}$.
- 652 3. The n adjusted survey unit measurements, Z_i , and the m reference material measurements,
 653 X_i , are pooled and ranked in order of increasing size from 1 to N , where $N = m+n$.

- 654 4. If several measurements are tied (i.e., have the same value), they are all assigned the
655 mean rank of that group of tied measurements.
- 656 5. Look up the values for r and q in Table A.5 based on the number of measurements in the
657 survey unit (n), the number of measurements in the reference area (m), and α_Q . The
658 operational decision described in the next step is made using the values for r and q .
- 659 6. If q or more of the r largest measurements in the combined ranked data set are from the
660 survey unit, the null hypothesis is rejected.

661 This form of the Quantile test gives only approximate results, since Table A.5 provides a limited
662 number of combinations of n , m , and α_Q . It is recommended that several combinations of n , m
663 and α_Q be considered when interpreting the results of the Quantile test. Sections 7.2 and 7.3 of
664 NUREG-1505 (NRC 1998a) provide additional guidance on interpreting the results of the
665 Quantile test.

666 As an example, the Quantile test can be applied to the Class 2 Metal Ductwork example of
667 section 6.6.4. Using $n = 9$, $m = 9$, and $\alpha_Q = 0.10$, the nearest entry in Table A.5d has for $r = 3$
668 $q = 3$ with $\alpha_Q = 0.105$ when $n = 10$ and $m = 10$. This means that all three of the highest
669 measurement would have to be from the survey unit in order to reject the null hypothesis. From
670 Table 6.5, one can see that the two largest measurements are from the survey unit, but the third
671 largest is from the reference area. Since the ductwork has passed both the WRS and the Quantile
672 test in the Scenario B example, one would conclude that it could be released from radiological
673 controls.

674 **6.8 Evaluate the Results: The Decision**

675 Once the data and results of the tests are obtained, the specific steps required to make a
676 disposition decision depends on the procedures approved by the regulator. The following
677 considerations are suggested for the interpretation of the test results with respect to the
678 disposition criteria. Note that the tests need not be performed in any particular order.

679 **6.8.1 Interpret Data for Each Survey Type**

680 The interpretation of results from the data evaluation or statistical test is the decision to reject or
681 not to reject the null hypothesis. For some of the survey designs the decision is straightforward,
682 while for other designs the interpretation is more complex. Figures 6.3 and 6.4 summarize the
683 interpretation of results.

684 6.8.1.1 Compare Results to the UBGR

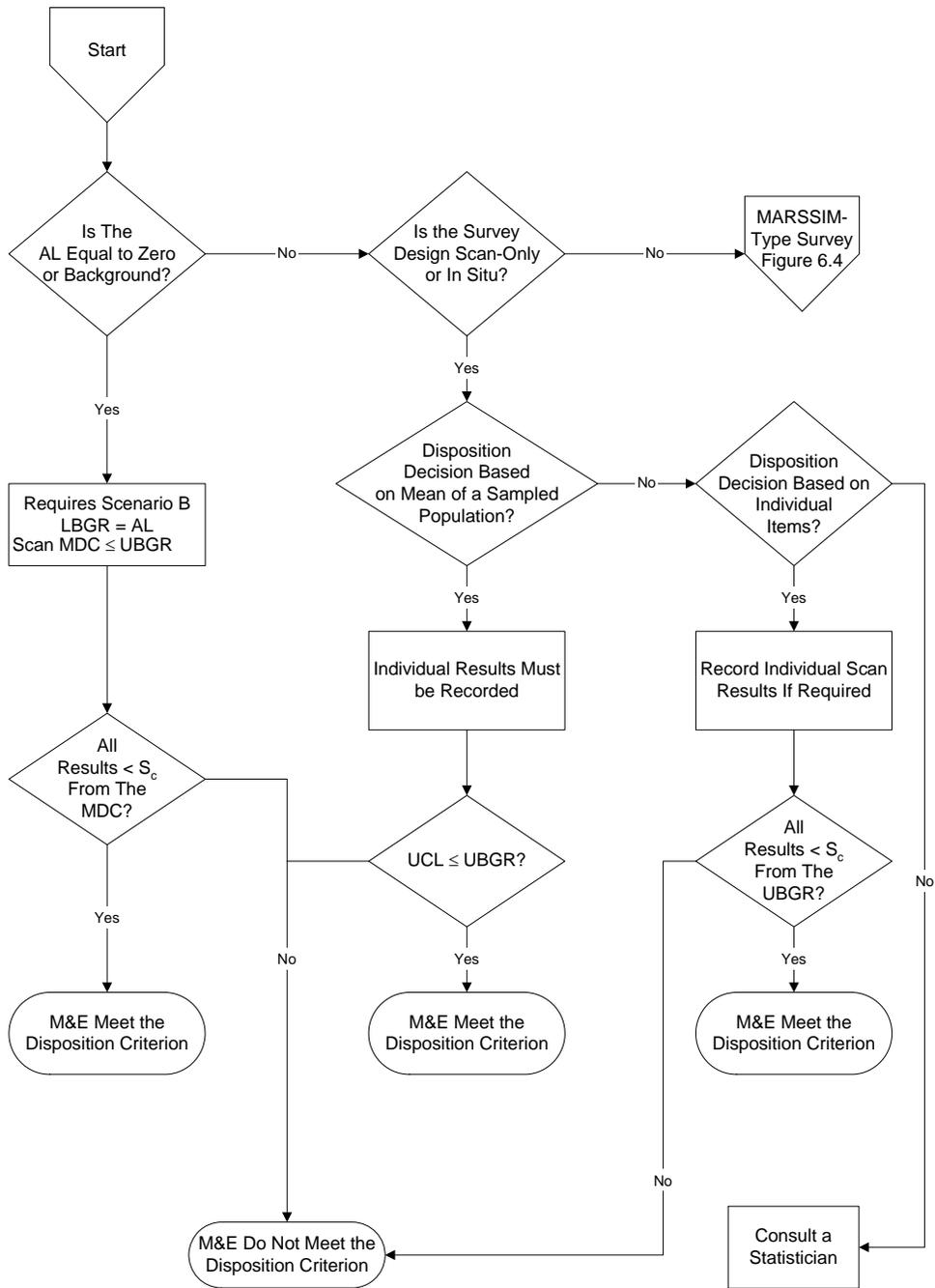
685 The process for interpreting results compared to the UBGR depends on the action level used to
686 develop the survey design.

687 If the action level is zero or background, Scenario B must be used:

- 688 • Compare every measurement result to the critical value corresponding to the required
689 scan MDC.
- 690 • If all results are below the critical value, the M&E demonstrate compliance with the
691 disposition criterion.
- 692 • Any results that exceed the critical value provide evidence of radionuclide
693 concentrations or radioactivity levels exceeding the disposition criteria, so the M&E
694 do not demonstrate compliance with the release criterion.

695 If the action level is not zero or background:

- 696 • Compare every measurement result to the critical value corresponding to the UBGR.
- 697 • If all results are below the critical value, the M&E demonstrate compliance with the
698 disposition criterion.
- 699 • Any results that exceed the critical value provide evidence of radionuclide
700 concentrations or radioactivity levels exceeding the disposition criteria, so the M&E
701 do not demonstrate compliance with the release criterion.



702

703

Figure 6.3 Interpretation of Survey Results for Scan-Only and In Situ Surveys

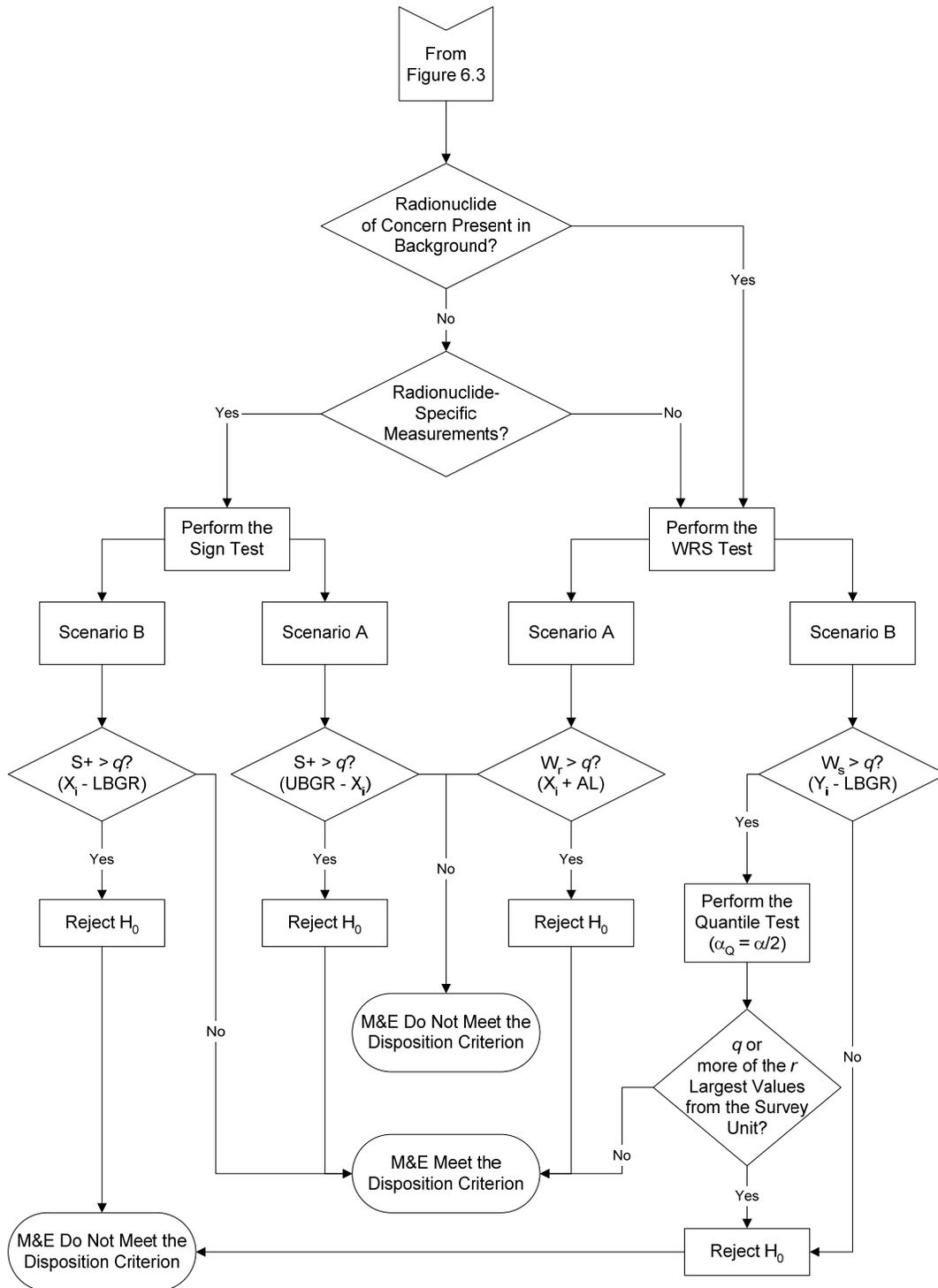


Figure 6.4 Interpretation of Results for MARSSIM-Type Surveys

704

705

706 Scan-only results are usually available as the data are collected. This real-time availability of
707 results allows the surveyor to make decisions as the data are collected. M&E that exceed the
708 action level can be identified and segregated during implementation of the survey. This “clean
709 as you go” approach to surveys is only applicable for Class 1 surveys (i.e., 100% of M&E are
710 measured) where there is high confidence in the quality and accuracy of detection decisions
711 around the UBGR. Extensive documentation of the measurement process, previous applications
712 of the process to the same or similar M&E, and verification of MDCs and MQCs is generally
713 necessary to implement a “clean as you go” survey design.

714 6.8.1.2 Compare Results Using an Upper Confidence Limit

715 When decisions are made based on the mean of a sampled population, the survey results should
716 be evaluated by comparison to an upper confidence limit:

- 717 • Compare every measurement result to the critical value corresponding to the UBGR.
- 718 • If all results are below the critical value, the M&E demonstrate compliance with the
719 disposition criterion.
- 720 • If any results are above the critical value, calculate the upper confidence limit (Section
721 6.4.1).
- 722 • If the upper confidence limit is less than the UBGR, the M&E demonstrate
723 compliance with the disposition criterion.
- 724 • If the upper confidence limit exceeds the UBGR, the M&E do not demonstrate
725 compliance with the disposition criterion.
- 726 • Investigate measurements exceeding the UBGR.
- 727 • Results above the UBGR trigger a reevaluation of classification as Class 2.
- 728 • Results above the MDC trigger a reevaluation of classification as Class 3.

729 6.8.1.3 MARSSIM-Type Surveys

730 The process for evaluating MARSSIM-type survey results is more complicated. This process is
731 explained in more detail in MARSSIM Section 8.5.

- 732 • Calculate the test statistics (see Section 6.5.1, 6.6.1, 6.6.2, and 6.7).
- 733 • Look up the critical value in the appropriate statistical table in Appendix A.
- 734 • Evaluate the results of the statistical test as described in Figures 6.3 and 6.4.
- 735 • Evaluate individual results using the elevated measurement comparison (EMC).
- 736 • M&E must pass the statistical test and the EMC (if applicable) to demonstrate
737 compliance.

738 If the null hypothesis is rejected under Scenario A, there is sufficient evidence to show the
739 median radionuclide concentrations or radiation levels are below the disposition criterion. Under
740 Scenario B, failing to reject the null hypothesis means there is insufficient evidence to overturn
741 the initial assumption the M&E demonstrate compliance with the disposition criterion.

742 If the null hypothesis is rejected under Scenario B, additional investigations are required to
743 determine the final disposition of the M&E (see Section 6.8.2). Failure to reject the null
744 hypothesis under Scenario A also requires additional investigations.

745 **6.8.2 Investigate Causes for Survey Unit Failures**

746 When M&E fail to demonstrate compliance with the disposition criterion, the first step is to
747 review and confirm the data that led to the decision. Once this is done, the DQO Process can be
748 used to evaluate potential problem areas leading to failure. If the level of radioactivity on or in
749 some Class 1 M&E exceeds the UBGR, the simplest solution might be to segregate those items
750 for a different disposition decision (see Section 6.8.1.1 on “clean as you go” surveys).

751 Sometimes activity in excess of background can be removed from the M&E followed by re-
752 evaluation or re-survey. In other cases, a less restrictive disposition option (e.g., disposal as
753 radioactive waste) may be selected. If such a situation were encountered in evaluating Class 2 or

754 Class 3 M&E, the classification would be questioned and the M&E would be reclassified and
755 surveyed as Class 1 M&E. This may also bring other classification decisions into question.

756 As a general rule, it may be useful to anticipate possible modes of failure. These can be
757 formulated as the problem to be solved using the DQO Process. Once the problem has been
758 stated, the decision concerning the failing survey unit can be developed into a decision rule. For
759 example, decide whether to attempt to remove the radioactivity or simply segregate certain types
760 of M&E for low-level waste disposal. Next, determine the additional data, if any, needed to
761 document that a survey unit where pieces with elevated measurements have been removed or
762 areas of added activity removed demonstrates compliance with the disposition criterion.
763 Alternatives to resolving the decision rule should be developed for each type of M&E that may
764 fail the surveys. These alternatives can be evaluated against the DQOs, and a disposition survey
765 design that meets the objectives of the project can be selected.

766 **6.9 Document the Disposition Survey Results**

767 Documentation of survey results is an important part of the disposition survey process. The form
768 of this documentation can vary greatly depending on the survey objectives and regulatory or
769 administrative requirements. Documentation of disposition survey results should be considered
770 during survey design to ensure adequate records are provided during implementation. Generally,
771 survey documentation requirements are provided as part of the documented survey design.

772 Documented items may include:

- 773 • A description of the final disposition, such as disposal in a landfill, return to
774 manufacture for refurbishment, sold as salvage, recycled as ferrous metal, etc.
- 775 • A release statement to the transport carrier and recipient of the material indicating
776 that the M&E described in the bill of lading meet(s) applicable State and Federal
777 regulations.

- 778 • Results of QC measurements made during the conduct of release surveys and
779 confirmation of compliance with facility SOPs and action levels.

780 If the disposition survey is a routine survey documented in an SOP, the documentation
781 requirements for the actual measurement results may be minimal or non-existent. For example,
782 routine surveys performed to clear M&E from a facility may require documentation that the
783 instruments were calibrated and functioning properly and that trained personnel were on duty to
784 perform the surveys. Quality assurance reviews and audits would be performed periodically
785 (typically under a separate SOP) to document that the clearance surveys were being performed
786 properly and that no M&E were cleared without first being surveyed. These records would
787 document that properly trained personnel had adequately surveyed all M&E leaving the facility
788 using properly functioning instruments. Documentation of individual measurement results may
789 not be required or necessary.

790 If the survey is not routine, significantly more documentation may be required. This
791 documentation should provide a complete and unambiguous record of the radiological status of
792 the M&E relative to the selected action levels. In addition, sufficient data and information
793 should be provided to enable an independent evaluation of the survey results, including repeating
794 measurements at some future time. The documentation should comply with all applicable
795 regulatory requirements. Additional information on documentation is provided in Section 2.5,
796 Section 3.6, Section 4.5, MARSSIM Sections 3.8 and 8.6, and MARSSIM Chapter 5.

1 **7 CASE STUDIES**

2 **7.1 Introduction**

3 This chapter presents case studies providing examples of applications of the information in the
4 Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME)
5 supplement to the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).
6 The purpose of these case studies is to illustrate applications of the information in conditions that
7 are frequently encountered and cover a broad range of situations. The general format for each
8 case study mirrors as closely as possible the information presented in MARSAME. References
9 to information, tables, figures, and equations from Chapter 2 through Chapter 6 are provided
10 throughout the case studies.

11 The MARSAME document contains both procedural as well as informative sections. The case
12 studies provide a practical use of the MARSAME process and as such generally apply only the
13 procedural sections. In addition, much of the information in MARSAME is designed to be
14 applied iteratively. In some case studies, the information will be applied in a different sequence
15 than it is presented in MARSAME because of this iterative nature.

16 Section 7.2 provides an example of a survey plan for operations within a radiological control
17 area (RCA) at a nuclear power plant. This survey plan provides the user with a starting point for
18 disposition surveys pertaining to materials and equipment (M&E) used within the RCA, and
19 assists the user in selecting the appropriate standard operating procedure (SOP) to complete the
20 disposition survey for each different variety of M&E used. In real operations one SOP often
21 interlocks with other SOPs. In this example, other hypothetical SOPs and their attachments are
22 only referred to by name. They are not explicitly presented in MARSAME.

23 Section 7.3 provides an example of a disposition survey for a large quantity of bulk material at a
24 mineral processing facility. This represents a special case survey design, establishing gross
25 activity action levels based on normalized effective dose equivalents. These action levels are
26 applied with multiple decision rules using a MARSSIM-type survey design to collect scan
27 survey data as well as systematic and judgmental samples for laboratory analysis.

28 Section 7.4 and Section 7.5 are based on the same mineral processing facility that serves as the
29 basis for Section 7.3. Section 7.4 provides an example of an interdiction survey for rented heavy
30 equipment that is designed to establish a “baseline” estimate of the residual radioactivity
31 associated with a front loader before it is brought into an RCA for the impacted bulk material.
32 This baseline survey establishes zero net activity as the LBGR and applies MARSAME
33 processes to a Scenario B survey design.

34 Section 7.5 demonstrates the clearance of the same rented front loader that was brought on to the
35 site in Section 7.4. Section 7.5 describes a Scenario A clearance survey based on the same
36 surface activity action levels to clear the front loader. Sections that contain redundant
37 information have been presented in Section 7.4 only and have been omitted from Section 7.5.

38 **7.2 Release of M&E and Tools from Radiological Control Areas**

39 **7.2.1 Description**

40 A work crew has just completed performing a maintenance task inside a radiological control area
41 (RCA) at an operating nuclear facility. Disposition decisions need to be made regarding the
42 M&E used within the RCA.

43 **7.2.2 Objectives**

44 The objective is to make an appropriate disposition decision regarding all of the M&E associated
45 with the maintenance work performed in the RCA. This case study provides an example of
46 applying an existing survey design to a repetitive task.

47 **7.2.3 Initial Assessment of M&E**

48 7.2.3.1 Categorize the M&E

49 Tools, parts, and other materials must be categorized as impacted or non-impacted prior to
50 exiting the RCA. The existing information is adequate to categorize the M&E (see Figure 2.1).
51 The M&E have been inside an RCA, so all the M&E are impacted. Additional investigations are
52 necessary before a disposition decision regarding the M&E can be made.

53 7.2.3.2 Design and Implement Preliminary Surveys

54 Following categorization, the M&E are evaluated to determine whether preliminary surveys are
55 necessary to provide information for designing a disposition survey. The existing information is
56 adequate for selecting a disposition option for the M&E (see Figure 2.2). In addition, the M&E
57 appear to meet the requirements of existing SOPs for releasing M&E from an RCA. No
58 preliminary surveys are necessary.

59 7.2.3.3 Select a Disposition Option

60 The selected disposition option depends on the expected future use of the M&E. Tools that will
61 be used in an RCA in the future will be evaluated for reuse in a controlled environment (Option
62 1, Section 2.4). Other M&E (i.e., other tools, parts, and materials) will be evaluated for release
63 without radiological controls (i.e., clearance, Option 2, Section 2.4).

64 7.2.3.4 Document the Results of the IA

65 The documentation requirements for the IA are described in the SOPs. Individual records are not
66 required for each item leaving the RCA. Training records and work schedules show that
67 personnel on duty are properly trained in implementing the SOPs. Quality assurance and quality
68 control (QA/QC) records show that the SOPs are implemented correctly using instruments that
69 are operating properly.

70 **7.2.4 Implement the Survey Design**

71 Since approved SOPs are available for evaluating the M&E, the information on developing a
72 disposition survey design (Chapter 3 and Chapter 4) is not used. This information was used
73 initially to develop the SOPs. Implementation starts with identification of the proper SOP for
74 evaluating specific items leaving the RCA. The M&E are compared to the scope for the SOP to
75 determine whether the SOP is applicable. Then, the M&E are segregated based on which SOP
76 will be applied. The SOP identifies the:

- 77 • Description of M&E to which the SOP applies,
- 78 • Action level,
- 79 • Classification of M&E,
- 80 • Number, type, and location of measurements,
- 81 • Measurement method (including estimates for uncertainty, detectability, and
82 quantifiability), and
- 83 • Documentation requirements for measurement results.

84 7.2.4.1 Select an Appropriate SOP

85 All M&E used within the RCA receive a standardized initial assessment and may be surveyed
86 using an existing SOP. The facility has developed and maintains a collection of SOPs providing
87 disposition survey designs for the majority of M&E associated with the facility. The M&E are
88 compared to the description of applicable M&E in the existing SOPs. If no appropriate SOP is
89 available, radiological control of the M&E is maintained.

90 Each SOP contains the appropriate inputs to the decision and survey design components to
91 reflect the physical and radiological attributes of the appropriate M&E group. Each SOP also

92 contains the action levels, DQOs, MQOs, and QC requirements to validate the quality of
93 measurement data collected using the survey instruments.

94 The process for returning tools to the tool crib is described in SOP #147, *Maintenance of Tools*
95 *in Radiological Control Areas*. Tools are cleaned to remove all visible dirt and placed in plastic
96 bags prior to return to the tool crib.

97 The process for releasing M&E from the RCA depends on the type of M&E being evaluated.
98 The release of hand tools is described in SOP #123, *Clearance of Tools, Materials, and*
99 *Equipment from Radiological Control Areas*. SOP #123 applies to small items such as hand
100 tools that are being removed from radiological control areas. The assumptions used to develop
101 the detection limits (see Attachment A to SOP #123) and action levels describe the types of
102 M&E where this SOP can be applied. The measurements in this SOP assume activity is
103 distributed on the readily accessible surfaces of surveyed items. This SOP does not apply to
104 surveys of personnel or personal affects, porous materials, paper, trash, and electrical instruments
105 (e.g., power tools, computers, PDAs). Items such as briefcases, pens, papers, personal clothing,
106 etc., are exempt from the release survey requirements of this procedure, unless deemed
107 appropriate by the health physics technician. Exempt items will undergo the same exterior
108 surfaces scanning procedure used in performing a whole body frisk when leaving radiological
109 control areas (see SOP #111).

110 The release of trash and waste materials is described in SOP #128, *Clearance of Dry Active*
111 *Waste from Radiological Control Areas*. SOP #128 applies to porous material, paper, and trash
112 being removed from radiological control areas. The assumptions used to develop the detection
113 limits (see Attachment A to SOP #128) and action levels describe the types of M&E where this
114 SOP can be applied. The measurements in this SOP assume uniform activity is distributed
115 volumetrically within surveyed items.

116 Any questions regarding applicability of an SOP to a specific item are directed to the Radiation
117 Safety Officer or duly authorized representative prior to performing a release survey. Items with
118 inaccessible surfaces are disassembled as completely as possible to thoroughly characterize
119 component materials and equipment in order to facilitate proper release surveys. Items with
120 inaccessible surfaces will not be unconditionally released unless evaluated by designated

121 personnel who authorize and document the release. The evaluation procedure encompasses a
122 review of the history of the item under scrutiny, the radiological conditions of the area in which
123 the item had been used or stored, and the release survey performed.

124 7.2.4.2 Segregate the M&E

125 Based on the physical and radiological attributes of the M&E (see Section 2.3), the M&E are
126 segregated based on which SOP will be implemented. For example, tools from the tool crib will
127 be segregated for analysis using SOP #147, *Maintenance of Tools in Radiological Control Areas*,
128 while other tools and parts will be analyzed using SOP #123, *Clearance of Tools, Materials, and*
129 *Equipment from Radiological Control Areas*.

130 7.2.4.3 Perform Measurements and Report the Results

131 Once the M&E are segregated, the measurements described in the SOPs are performed. There is
132 no requirement for documenting individual measurement results. 100% of all M&E leaving the
133 RCA are measured as described in the appropriate SOP.

134 **7.2.5 Assess the Results of the Disposition Survey**

135 Assessment of the disposition survey results is performed while the data are collected. The SOPs
136 include scan-only or in situ designs. Decisions will be made on individual items, so recording
137 individual measurement results is not required (see Figure 6.3). If all of the results are less than
138 the critical value, the M&E demonstrate compliance with the action level. This means that the
139 tools can be returned to the tool crib, or the parts and materials can be cleared for unrestricted
140 use, for example. If any item has a measurement result that exceeds the critical value, additional
141 investigation is required. In most cases tools will be cleaned, while trash or porous items will be
142 evaluated for disposal as low-level radioactive waste.

143 **7.3 Mineral Processing Facility Concrete Rubble**

144 **7.3.1 Description**

145 An abandoned mineral processing facility is being redeveloped for commercial/industrial use.
146 The facility processed mineral ores for various metals for over 30 years and was abandoned more
147 than 10 years ago. The processing equipment and existing stockpiles of ore were transferred to
148 another facility when site renovations began. The receiving facility discovered radioactivity
149 levels in excess of background on exterior portions of processing equipment using hand-held
150 Geiger-Mueller (GM) “pancake” detectors.

151 Prior to discovery of the radioactivity on the processing equipment, the concrete floors had been
152 removed from the processing buildings and stockpiled on-site. Note that if the buildings were
153 still intact, they could be surveyed using a MARRSIM survey. An investigation is performed to
154 trace the source of the radioactivity to the appropriate portion(s) of the mineral processing
155 facility.

156 **7.3.2 Objectives**

157 The objective is to make an appropriate disposition decision regarding the concrete rubble from
158 the impacted portions of the mineral processing facility. It is anticipated that leaks of potentially
159 radioactive processing liquids could have occurred throughout the operating lifetime of the
160 facility. Airborne radioactive concrete dust may have been released during demolition activities,
161 which could have exposed construction personnel and contacted components of the demolition
162 equipment.

163 **7.3.3 Initial Assessment of the M&E**

164 7.3.3.1 Categorize the M&E

165 As part of the IA, it is necessary to determine whether the concrete rubble is impacted or not. A
166 visual inspection of the concrete rubble was performed. Historical records from the facility
167 concerning sources of ore, ore processing techniques, waste disposal practices, industrial
168 accidents, as well as building and equipment repairs, modifications, and upgrades were reviewed.
169 Interviews with key facility personnel were also performed. In addition, research into mineral

170 processing techniques and radionuclide content of raw ores was performed to obtain additional
171 process knowledge.

172 Process knowledge indicated the facility processed ilmenite ore (iron titanium oxide, FeTiO_3)
173 and produced titanium dioxide. A sentinel measurement of a small amount of ilmenite ore
174 remaining at the site was analyzed by alpha spectrometry and found to contain elevated levels of
175 natural uranium and thorium. Additional measurements performed on the radioactive processing
176 equipment determined that natural uranium and thorium were the source of radioactivity on the
177 processing equipment.

178 Site history indicates that the general layout of the process was unchanged over the lifetime of
179 the facility, and it is likely that spills occurred repeatedly in discrete locations. Processing
180 liquids and slurries were considered hazardous because of their low pH; radioactivity was not
181 considered an issue. Limited information regarding site history and operations was obtained
182 through interviews with former employees and review of historical documentation. Former
183 employees stated that spills and leaks of process liquids and slurries occurred periodically in
184 several areas of the processing plant; these represent the only potential source of radioactivity in
185 the plant. Fluid spills were quickly corrected by neutralizing the acid to protect employees and
186 equipment. Spills frequently resulted from seal failure within the various pumps in use at the
187 processing operation.

188 Results from the visual inspection indicated there was a reasonable potential for radioactivity
189 from plant activities to be associated with the concrete rubble. Several chunks of concrete rubble
190 are obviously discolored from plant operations, indicating possible locations of spills. The
191 facility floor consisted of reinforced concrete on a gravel base mat. Portions of the rubble
192 contain possible evidence of staining. The rubble still contains rebar which, for operational
193 reasons, must be segregated and treated as a separate waste stream.

194 The concrete rubble is considered to be impacted due to the discovery of residual radioactivity
195 on exterior portions of the processing equipment, historical records that acidic process fluids may
196 have spilled on the concrete floor, and process knowledge that the acidic process fluids were
197 mixed with raw ore containing elevated levels of naturally-occurring radioactive material

198 (NORM) from the uranium and thorium radioactive decay series. The results of the sentinel
 199 measurement performed on the raw ore support the categorization as impacted.

200 7.3.3.2 Design and Implement Preliminary Surveys

201 Table 7.1 lists the physical attributes of the concrete rubble. No data gaps associated with the
 202 physical attributes were identified.

203 **Table 7.1 Physical Attributes of the Concrete Rubble**

Attribute	Description
Dimensions	<p>Total Mass</p> $400 \text{ ft} \times 100 \text{ ft} \times 1 \text{ ft} \approx 40,000 \text{ ft}^3$ $40,000 \text{ ft}^3 \times 0.0283 \text{ m}^3/\text{ft}^3 \approx 1,132 \text{ m}^3$ The approximate density of crushed concrete is $2.3 \times 10^6 \text{ g/m}^3$ $1,132 \text{ m}^3 \times 2.3 \times 10^6 \text{ g/m}^3 = 2.60 \times 10^9 \text{ g} = 2.60 \times 10^6 \text{ kg}$ Shape The concrete has been broken into chunks less than one meter in the largest dimension. The concrete is stored in three piles, each pile is approximately 1.5 m high, 6 m wide, and 40 m long.
Complexity	Rebar used to reinforce the floor is present in the concrete rubble. The rebar will be segregated and removed, and treated as a separate waste stream.
Accessibility	The concrete rubble may require further reduction in size to ensure measurability.
Inherent Value	The concrete represents inherent value for several potential disposition options. Crushed concrete serves many useful purposes, including recyclable use as roadbed material. This option presents potential cost savings over using virgin materials in place of recycled concrete and a reuse scenario that avoids the relatively high cost for disposal.

204 Table 7.2 lists the known radiological attributes associated with the concrete rubble, as well as
 205 data gaps showing where additional information is required to design a disposition survey. As
 206 presented, the existing information is not adequate to design a disposition survey. Preliminary
 207 surveys were designed and implemented to address the data gaps identified in Table 7.2. The
 208 results of the preliminary surveys were used to modify the conceptual site model by filling some
 209 of the data gaps.

Table 7.2 Radiological Attributes of the Concrete Rubble

Attribute	Description			Data Gaps
Radionuclides	Uranium Series Radionuclides	Principal Emission Particle	Emission Energy (MeV)	The radioactivity is likely to have come in contact with the M&E through spills of process fluids and dumping of solid tailings on the concrete floor. Equilibrium status of the decay series is unknown, although sufficient time has elapsed since site closure for the thorium series to have re-established secular equilibrium.
	²³⁸ U ²³⁴ Th ^{234m} Pa ²³⁴ Pa ²³⁴ U ²³⁰ Th ²²⁶ Ra ²²² Rn ²¹⁸ Po ²¹⁴ Pb ²¹⁴ Bi ²¹⁴ Po ²¹⁰ Pb ²¹⁰ Bi ²¹⁰ Po	Alpha Beta Beta/Gamma Beta Alpha Alpha Alpha/Gamma Alpha Alpha Beta/Gamma Beta/Gamma Alpha Beta Beta Alpha	4.20 0.1886 2.28/1.001 0.224 4.77 4.688 4.78/0.186 5.49 6.00 0.67/0.352 1.54/0.609 7.687 0.016 1.161 5.305	
	Thorium Series Radionuclides	Principal Emission Particle	Emission Energy (MeV)	
	²³² Th ²²⁸ Ra ²²⁸ Ac ²²⁸ Th ²²⁴ Ra ²²⁰ Rn ²¹⁶ Po ²¹² Pb ²¹² Bi ²¹² Po (64%) ²⁰⁸ Tl (36%)	Alpha Beta Beta/Gamma Alpha Alpha Alpha Alpha Beta/Gamma Alpha/Beta Alpha Beta	4.01 0.0389 1.17/0.911 5.42 5.686 6.288 6.78 0.334/0.238 6.05/2.246 8.785 1.80	
Activity	Activity levels range from background (approximately 40 Bq/kg) to 4000 Bq/kg from isolated portions of the concrete rubble where spills occurred.			The expected range of activity is an estimate. Nature and extent of activity needs to be investigated to provide better estimates of average and maximum activity. Better estimates of background are needed.
Distribution	The radioactivity is heterogeneously distributed throughout the mass of concrete rubble.			No data gaps were identified. The current distribution is not a concern since the concrete will be crushed to 2-3 cm size prior to survey.
Location	The concrete rubble is considered a volumetrically impacted mass. The residual radioactivity that is present is a combination of fixed and removable.			The distribution of radioactivity with depth may provide useful information for selecting measurement methods because it can impact the total measurement efficiency.

211 The radionuclides of potential concern are the uranium (^{238}U) and thorium (^{232}Th) natural
212 radioactive decay series. Based on process knowledge, radionuclide concentrations in the raw
213 ore average between 750 and 1,100 Bq/kg for members of the uranium series, and between 200
214 and 400 Bq/kg for members of the thorium series. Following processing, some ^{238}U and ^{232}Th
215 decay products may not have been in equilibrium with the parents. The amount of time since the
216 plant ceased operations (i.e., 10 years) indicates there is a potential for the thorium series
217 radionuclides to have re-established secular equilibrium. Preliminary survey measurements are
218 required to determine the equilibrium status of the uranium and thorium series radionuclides.

219 Limited scanning of concrete rubble was performed using a GM pancake detector. The purpose
220 of the scanning was to determine how the radioactivity associated with the concrete was
221 distributed. The scanning survey also included additional visual inspection of the concrete.

222 Intermittent staining within the concrete rubble and scanning surfaces of concrete chunks
223 demonstrates that the radioactivity was heterogeneously deposited on the processing building
224 floor. Higher levels of radioactivity were found in areas where spills occurred historically (i.e.,
225 discolored concrete). The staining did not appear to have penetrated more than one-quarter inch
226 into the concrete when the floor was intact. Prior to demolition, the presence of cracks and other
227 structural irregularities in the concrete floor provided preferential pathways for activity to
228 penetrate to greater depths. This resulted in some variance in activity with depth of the original
229 concrete floor.

230 Samples were collected from the crushed concrete from the processing mill floor to determine
231 concentrations of residual radioactivity using alpha spectrometry and gamma spectroscopy.
232 Concrete samples were collected from four biased locations, including two areas of elevated
233 gross activity within the concrete rubble with GM readings as high as 250 cpm and visible
234 staining (Samples 1 and 2), and two samples with readings consistent with the average readings
235 observed during scanning (40 to 45 cpm) (Samples 3 and 4). Process knowledge and limited
236 historical site information indicates that radiological materials were never used or stored within
237 the on-site administrative building. Reference Samples 1 and 2 were collected from the concrete
238 floor in this facility to provide information on background activities in non-impacted concrete for
239 the uranium and thorium decay series for the conceptual model. The six samples were sent to a
240 radioanalytical laboratory for analysis, and the results of the analyses are provided in Table 7.3.

241

Table 7.3 Preliminary Survey Analytical Results**242 Alpha Spectrometry Results for Uranium Series Radionuclides (Bq/kg)**

Sample ID	²³⁴ U	CSU ¹	MDC ²	²³⁵ U	CSU ¹	MDC ²	²³⁸ U	CSU ¹	MDC ²
Sample 1	7,000	± 2,100	1,900	340	± 1,900	1,600	7,600	± 2,400	1,900
Sample 2	7,200	± 2,300	1,900	320	± 1,700	1,600	7,000	± 2,100	1,900
Sample 3	21	± 7.4	3.7	0.74	± 1.9	0.74	21	± 7.0	3.7
Sample 4	25	± 8.1	3.7	0.74	± 3.0	0.74	21	± 7.0	3.7
Reference Sample 1	19	± 5.2	3.7	0.37	± 0.74	0.74	20	± 5.6	3.7
Reference Sample 2	13	± 3.7	3.7	0.37	± 0.74	0.74	11	± 3.3	3.7

243 Alpha Spectrometry Results for Thorium Series Radionuclides (Bq/kg)

Sample ID	²³² Th	CSU ¹	MDC ²	²²⁸ Th	CSU ¹	MDC ²
Sample 1	1,400	± 110	110	1,300	± 150	110
Sample 2	1,200	± 130	110	1,500	± 190	110
Sample 3	21	± 1.5	1.1	23	± 1.5	1.1
Sample 4	26	± 1.1	1.1	24	± 1.1	1.1
Reference Sample 1	21	± 1.1	1.1	22	± 1.1	1.1
Reference Sample 2	23	± 1.1	1.1	23	± 1.1	1.1

244 Gamma Spectroscopy Results for Uranium Series Radionuclides (Bq/kg)

Sample ID	²¹⁴ Bi	CSU ¹	MDC ²	²¹⁴ Pb	CSU ¹	MDC ²	²²⁶ Ra	CSU ¹	MDC ²
Sample 1	93	± 920	1,400	530	± 780	1,300	47	± 1,100	1,500
Sample 2	740	± 1,000	1,300	1,000	± 870	1,200	192	± 1,200	1,400
Sample 3	21	± 1.1	3.6	21	± 1.1	6.3	64	± 9.6	16
Sample 4	22	± 1.1	4.1	23	± 1.1	7.0	68	± 8.5	19
Reference Sample 1	17	± 1.1	3.1	17	± 1.1	7.0	36	± 6.3	18
Reference Sample 2	20	± 1.1	3.4	20	± 1.1	5.6	52	± 7.1	17

245

246 **Gamma Spectroscopy Results for Thorium Series Radionuclides (Bq/kg)**

Sample ID	²²⁸ Ac	CSU ¹	MDC ²
Sample 1	1,600	± 180	52
Sample 2	1,400	± 130	41
Sample 3	14	± 2.6	4.4
Sample 4	21	± 3.1	6.3
Reference Sample 1	15	± 3.3	5.9
Reference Sample 2	16	± 3.4	3.4

247 ¹ CSU is the combined standard uncertainty of the measurement result reported by the analytical laboratory.

248 ² MDC is the minimum detectable concentration reported by the analytical laboratory.

249 **7.3.3.3 Select a Disposition Option**

250 The preferred disposition of the concrete rubble is clearance. It is expected that the concrete will
 251 be reused as roadbed or disposed of in a municipal landfill. If the activity levels exceed the
 252 project action levels, then the concrete may need to be disposed of as discrete naturally-occurring
 253 or accelerator-produced (NARM) waste. If the activity is below the alternate action levels, the
 254 concrete may either be reused or disposed of as diffuse NARM waste.

255 **7.3.3.4 Document the Results of the IA**

256 The results of the IA were documented in a letter report. The purpose of the letter report was to
 257 document the categorization decision and all supporting information. The letter report was
 258 reviewed and finalized by the facility owner. Detailed results of the IA will be included in the
 259 final documentation of the survey design.

260 **7.3.4 Identify Inputs to the Decision**

261 Following completion of the IA, additional information was needed to develop the disposition
 262 survey design.

263 7.3.4.1 Finalize the List of Radionuclides to be Measured

264 The list of radionuclides of concern was finalized based on the preliminary survey results.
265 Uranium-238, ^{234}U , and ^{226}Ra are the radionuclides of concern for the uranium natural decay
266 series. The alpha spectrometry results indicate that ^{238}U and ^{234}U are in equilibrium (i.e., have
267 equal concentrations). Since alpha spectrometry for uranium isotopes provides results for both
268 ^{238}U and ^{234}U , both isotopes (and their decay products with half-lives less than six months) will
269 be kept as radionuclides of concern. There is no indication of enrichment or depletion of uranium
270 as a result of site activities based on the uranium alpha spectrometry results listed in Table 7.3.

271 Radium-226 decay products, including ^{210}Pb , are assumed to be out of secular equilibrium with
272 the other uranium series radionuclides (e.g., ^{238}U and ^{234}U) because process knowledge shows
273 the chemical processing at the plant would separate uranium from radium. Bismuth-214 and
274 ^{214}Pb can be used as beta or gamma emission surrogates for ^{226}Ra , because the decay products of
275 ^{226}Ra should be in secular equilibrium with one another. However, a twenty-one day ingrowth
276 period may be required to confirm this assumption. The planning team determined an ingrowth
277 study was not required for this project following discussions with the regulators.

278 Thorium-232 is the radionuclide of concern for the thorium natural decay series. Based on the
279 alpha spectrometry and gamma spectroscopy results shown in Table 7.3, all members of the
280 thorium natural decay series are in secular equilibrium. Actinium-228 emits gamma rays that are
281 easy to quantify using gamma spectroscopy, and can be used as a surrogate for the members of
282 the thorium series.

283 7.3.4.2 Select an Action Level

284 An action level of 0.01 mSv/y was selected based on discussions with the stakeholders. Using
285 information provided in NUREG-1640 (NRC 2003), the action levels were converted into
286 concentration units based on clearance as the disposition option. Incorporating the concrete
287 rubble into roadbed material would provide the highest potential doses following clearance. The
288 mean values from NUREG-1640 (NRC 2003), Table I 1.13 (Normalized effective dose
289 equivalents from all pathways: Driving on road [$\mu\text{Sv/y per Bq/g}$]) were selected as the basis for
290 the action levels.

Radionuclide of concern	²³⁸ U	²³⁴ U	²³² Th	²²⁶ Ra
Mass-based EDE mean values ($\mu\text{Sv/y}$ per Bq/g)	0.26	8.2×10^{-4}	30	22

291 The action levels from Table I1.13, NUREG-1640 (NRC 2003) are expressed in units of $\mu\text{Sv/y}$
 292 per Bq/g, but the preliminary survey measurement results are in Bq/kg. To make a direct
 293 comparison, the action levels were converted to units of Bq/kg. The action levels were
 294 converted to concentrations by inverting the action levels and multiplying by the selected dose
 295 limit (i.e., the inverted action levels in units of Bq/g per $\mu\text{Sv/y}$ are multiplied by 0.01 mSv/y,
 296 1,000 g/kg, and 1,000 $\mu\text{Sv/mSv}$ providing action levels in Bq/kg). Table 7.4 lists the action
 297 levels in concentration units of Bq/kg.

298 **Table 7.4 Radionuclide-Specific Action Levels**

Radionuclide	Mass-Based EDE Mean Values (Bq/g per $\mu\text{Sv/y}$)	Action Level (Bq/kg)
²³⁸ U	$\frac{1 \text{ Bq/g}}{0.26 \mu\text{Sv/y}} \times 0.01 \text{ mSv/y} \times 1 \times 10^6 = 38,000$	38,000
²³⁴ U	$\frac{1 \text{ Bq/g}}{8.2 \times 10^{-4} \mu\text{Sv/y}} \times 0.01 \text{ mSv/y} \times 1 \times 10^6 = 12,000,000$	12,000,000
²³² Th	$\frac{1 \text{ Bq/g}}{3.0 \times 10^1 \mu\text{Sv/y}} \times 0.01 \text{ mSv/y} \times 1 \times 10^6 = 330$	330
²²⁶ Ra	$\frac{1 \text{ Bq/g}}{2.2 \times 10^1 \mu\text{Sv/y}} \times 0.01 \text{ mSv/y} \times 1 \times 10^6 = 450$	450

299 The unity rule (Equation 7-1) was used to account for the individual radionuclide action levels.
 300 The unity rule is satisfied when the summed analyses of each radionuclide against its respective
 301 action level yields a value less than one:

302 The Unity Rule = $\frac{C_1}{AL_1} + \frac{C_2}{AL_2} + \dots + \frac{C_n}{AL_n} \leq 1$ (7-1)

303 Where:

304 C = Concentration of each individual radionuclide (1, 2, ... n)

305 AL = Action level value for each individual radionuclide (1, 2, ... n)

306 Equation 7-1 was used to calculate the sum of fractions for each of the preliminary survey
307 results:

308 The Unity Rule =
$$\frac{C_{^{238}\text{U}}}{AL_{^{238}\text{U}}} + \frac{C_{^{234}\text{U}}}{AL_{^{234}\text{U}}} + \frac{C_{^{232}\text{Th}}}{AL_{^{232}\text{Th}}} + \frac{C_{^{226}\text{Ra}}}{AL_{^{226}\text{Ra}}} \leq 1$$

309 Sample 1 =
$$\frac{7,600 \text{ Bq/kg}}{38,000 \text{ Bq/kg}} + \frac{7,000 \text{ Bq/kg}}{12,000,000 \text{ Bq/kg}} + \frac{1,400 \text{ Bq/kg}}{330 \text{ Bq/kg}} + \frac{47 \text{ Bq/kg}}{450 \text{ Bq/kg}} = 4.5$$

310 Sample 2 =
$$\frac{6,900 \text{ Bq/kg}}{38,000 \text{ Bq/kg}} + \frac{7,200 \text{ Bq/g}}{12,000,000 \text{ Bq/kg}} + \frac{1,230 \text{ Bq/kg}}{330 \text{ Bq/kg}} + \frac{192 \text{ Bq/kg}}{450 \text{ Bq/g}} = 4.2$$

311 Sample 3 =
$$\frac{21 \text{ Bq/kg}}{38,000 \text{ Bq/kg}} + \frac{21 \text{ Bq/kg}}{12,000,000 \text{ Bq/kg}} + \frac{21 \text{ Bq/kg}}{330 \text{ Bq/kg}} + \frac{64 \text{ Bq/kg}}{450 \text{ Bq/g}} = 0.21$$

312 Sample 4 =
$$\frac{21 \text{ Bq/kg}}{38,000 \text{ Bq/kg}} + \frac{25 \text{ Bq/kg}}{12,000,000 \text{ Bq/kg}} + \frac{26 \text{ Bq/kg}}{330 \text{ Bq/kg}} + \frac{68 \text{ Bq/kg}}{450 \text{ Bq/g}} = 0.23$$

313 The results of the calculations for Samples 1 and 2 exceed a sum of fractions of 1.0, and indicate
314 the presence of small volumes of concrete with elevated activity. Note that the reported MDCs
315 for gamma spectroscopy for ^{226}Ra in Samples 1 and 2 would not meet the MQOs for clearance
316 (i.e., the MDC exceeds the action level). However, the radionuclide concentrations in these two
317 samples clearly exceed the action level. Therefore, the quality of these results is acceptable to
318 support the disposition survey design.

319 The results of the calculations for Samples 3 and 4 indicate that, on average, the concrete rubble
320 is expected to have radionuclide concentrations below the action levels. Therefore, the average
321 activity in the concrete rubble is expected to be below the action level. Large blocks containing
322 elevated levels of radioactivity may be visually identified via staining, verified with a GM
323 detector, and segregated prior to removal of the rebar.

324 7.3.4.3 Identify the Parameter of Interest

325 Since the disposition option is stated in terms of dose, the parameter of interest is the mean
326 radionuclide concentration. The target population is all of the possible measurement results that
327 could be obtained within a survey unit. This means the target population will be defined by the
328 survey unit boundaries (Section 7.3.4.4) and the selected measurement method (Section 7.3.4.5).

329 7.3.4.4 Survey Unit Boundaries

330 Survey unit boundaries are based primarily on the modeling assumptions used to develop the
331 action levels. The volume of concrete used to model exposures for building a road is 83 cubic
332 meters (NUREG-1640 (NRC 2003) Volume 2, Appendix B, Tables B-8 and B-11). Each survey
333 unit will consist of approximately 80 cubic meters of crushed concrete (approximately 25 meters
334 \times 22 meters \times 0.15 meters).

335 The volume of concrete poured to create the floor of the processing mill was approximately
336 1,100 cubic meters. Crushing the concrete and removing the rebar is expected to result in
337 approximately a 25% increase in volume due to air gaps, for a total volume of 1,400 cubic
338 meters of crushed concrete. Using these calculations, there will therefore be a total of 18 survey
339 units plus one reference area.

340 The concrete rubble can be spread into a relatively uniform layer approximately 15 centimeters
341 thick and scanned. This adapts an approach used in MARSSIM to survey the top 15 centimeters
342 of surface soil as a two-dimensional object.

343 7.3.4.5 Inputs for Selection of Measurement Methods

344 The selected measurement method will be required, at a minimum, to detect radionuclide
345 concentrations at or below the action levels in Table 7.4. The survey planners considered each of
346 the three possible measurement techniques (see Section 5.9.1).

347 Scan-only techniques have the ability to detect surface activity at concentrations below the action
348 levels, as shown in Appendix F. In situ measurement techniques are also expected to have the
349 ability to measure radionuclide concentrations at the action levels. However, uncertainties
350 associated with the efficiency for both techniques will be large. In order to reduce these
351 uncertainties to a level where the radionuclide concentrations are measurable, the concrete would

352 need to be pulverized and mixed rather than just crushed to 2-3 cm size. Since the cost of
353 processing the concrete this way would be a major cost associated with the disposition survey, a
354 MARSSIM-type survey design was selected for the disposition survey.

355 Concrete samples will be analyzed in a laboratory using alpha spectrometry for uranium isotopes
356 (i.e., ^{234}U and ^{238}U) as well as gamma spectroscopy for other radionuclides of concern (i.e., ^{214}Bi ,
357 ^{214}Pb , and ^{228}Ac). Sample sizes must be sufficient to allow quantification of radionuclide
358 concentrations at the action levels. By convention, the MQC for each radionuclide of concern is
359 selected so the measurement method uncertainty at concentrations equal to the action levels in
360 Table 7.4 is 10%. Alternatively, the samples can be sealed in an airtight container for twenty-
361 one days to allow secular equilibrium to be reestablished.

362 Due to the rough, irregular shape of the concrete rubble, alpha radiation is easily attenuated and
363 is difficult to measure. Beta and gamma measurements typically provide a more accurate
364 assessment of thorium and uranium activity on most building surfaces because surface conditions
365 cause significantly less attenuation of beta and gamma particles than alpha particles. For this
366 reason, scanning will be performed using instruments that detect beta or gamma radiation.
367 Surface scans, using a 12.7-centimeter by 0.16-centimeter field instrument for detection of low-
368 energy radiation (FIDLER) sodium iodide (NaI[Tl]) scintillation probe, are used to scan for
369 gamma emissions. The approximate detection sensitivity of the FIDLER is 300 Bq/kg for
370 natural uranium and 20 Bq/kg for natural thorium (see Appendix F) when activity is present at
371 the surface. The FIDLER has a large probe and can detect gammas from a greater height above
372 the crushed concrete than alpha or beta detection equipment, making it a more practical choice
373 for surveying large volumes of material. The selection of the FIDLER over more conventional
374 NaI(Tl) detectors (e.g., a three-inch by three-inch gamma scintillation detector) is primarily
375 based on the FIDLER's ability to detect low-energy gamma radiation, which comprises the
376 majority of the gamma radiation from the radionuclides of concern.

377 7.3.4.6 Modify the Action Levels to Account for Multiple Radionuclides

378 Radionuclide-specific action levels need to be combined into a single gross gamma action level
379 for evaluating the FIDLER scan measurements. The information in Section 3.3.3.1 requires an
380 estimate of the relative fraction of the total activity contributed by each radionuclide. A

381 consistent relationship between ^{238}U and ^{232}Th concentrations is not expected based on the IA,
 382 since different ore bodies could contain different ratios of these radionuclides. Rather than
 383 develop a preliminary survey attempting to develop this relationship, a conservative approach
 384 was adopted for this project.

385 Assuming the entire radioactivity detected by the FIDLER results from the presence of the most
 386 restrictive radionuclide will provide the most conservative gross gamma action level. The ratios
 387 of exposure rate to radionuclide concentration ($\mu\text{R/h}$ per Bq/kg) and instrument response to
 388 exposure rate (cpm per $\mu\text{R/h}$) were developed in Appendix F during development of the scan
 389 MDC for both ^{238}U and ^{232}Th . These ratios can be used to calculate the count rate above
 390 background associated with a radionuclide activity equal to the action level as shown in
 391 Equation 7-2.

$$392 \quad GG_{AL} = AL \times \left(\frac{\mu\text{R/h}}{\text{Bq/kg}} \right) \times \left(\frac{\text{cpm}}{\mu\text{R/h}} \right) \quad (7-2)$$

393 Where:

394 GG_{AL} = Gross gamma action level (cpm)

395 AL = Action level value for each individual radionuclide (Bq/kg)

396 Equation 7-2 was used to calculate a gross gamma count rate above background for the FIDLER
 397 assuming each radionuclide of concern was present at a concentration equal to the action level.
 398 The gross gamma count rates were divided by two to account for uncertainty associated with the
 399 detector efficiency calculation (see Appendix F) and added to the background count rate from
 400 Appendix F. The result is a gross gamma action level for the FIDLER to identify locations with
 401 unexpectedly high gamma activity that could result in doses near the action level of 0.01 mSv/y.
 402 The results of the calculations are shown in Table 7.5. The ^{232}Th gross gamma action level of
 403 30,000 cpm is more conservative than the ^{238}U gross gamma action level of 140,000 cpm, so
 404 30,000 cpm was selected as the gross gamma action level.

405 FIDLER readings that exceed the ^{232}Th gross gamma action level indicate locations where
 406 radionuclide concentrations could result in doses exceeding 0.01 mSv/y if all of the activity
 407 results from ^{232}Th .

408

Table 7.5 Calculation of the Gross Gamma Action Level

Action Level (Bq/kg)	μR/h per Bq/kg (from Appendix F)	cpm per μR/h (from Appendix F)	Gross Gamma Count Rate (cpm)	Adjusted Gross Gamma Count Rate (cpm)	Background Count Rate (cpm)	Gross Gamma Action Level (cpm)
²³⁸ U 38,000	1.413E-04	45,593	244,807	122,404	12,870	140,000
²³² Th 330	2.619E-02	3,923	33,905	16,953	12,870	30,000

409 Since ²³²Th has decay products in secular equilibrium that can be used to estimate the ²³²Th
 410 activity, gamma spectroscopy can be used to quantify ²³²Th concentrations. FIDLER readings
 411 that exceed 140,000 cpm identify locations where radionuclide concentrations could result in
 412 doses exceeding 0.01 mSv/y if all of the activity results from ²³⁸U. Alpha spectrometry is
 413 required to quantify ²³⁸U concentrations.

414 7.3.4.7 Identify Alternative Actions

415 The alternative actions identify the results of decisions based on the measurement results. If the
 416 radionuclide concentrations do not result in a dose that exceeds the action level, the material is
 417 cleared. If the dose exceeds the action level, materials exceeding the action level will be
 418 segregated and investigated for disposal as NARM waste.

419 7.3.4.8 Decision Rules

420 MARSSIM-type surveys are designed to evaluate the average radionuclide concentration in a
 421 survey unit using samples or direct measurements, as well as small areas of elevated activity
 422 using scans. Small areas of elevated activity receive additional investigation. Since there are

423 multiple action levels and multiple decisions to be made, there are multiple decision rules for the
424 disposition survey. The first two decision rules address how small areas of elevated activity are
425 identified by scans and what investigations will be performed. The third decision rule evaluates
426 the results of the investigations of small areas of elevated activity. The fourth decision rule
427 evaluates the average activity in each survey unit.

- 428 1. If any FIDLER scanning measurement result exceeds the gross gamma action level of
429 30,000 cpm (see Section 7.3.5.4), a biased sample will be collected for laboratory
430 analysis by gamma spectroscopy, otherwise no biased samples will be collected.
- 431 2. If any FIDLER scanning measurement exceeds 140,000 cpm, the biased sample collected
432 for gamma spectroscopy analysis will also be analyzed by alpha spectrometry for
433 uranium and thorium isotopes, otherwise the concrete will be held awaiting the results of
434 the gamma spectrometry analysis.
- 435 3. If the results from a biased sample result in a sum of fractions for ^{238}U , ^{234}U , ^{226}Ra , and
436 ^{232}Th exceeding 1.0, the concrete will be segregated and investigated for disposal as
437 NARM waste. Otherwise, the survey unit will be evaluated based on the WRS test results
438 for the samples taken over a systematic grid.
- 439 4. If the mean sum of fractions in a survey unit exceeds 1.0, the concrete will be segregated
440 and investigated for disposal as NARM waste. Otherwise, the WRS test will be
441 performed to support the final disposition decision for that survey unit.

442 7.3.4.9 Reference Materials

443 Concrete from the administrative building contains non-impacted materials, as established by the
444 process knowledge discussed in Section 7.3.3.1. The reference material measurements will be
445 performed on the floor in the administrative building. The geometry of the floor is similar
446 enough to the concrete rubble (after crushing to 2-3 cm size and arrangement into a 15 cm thick
447 layer) that modifications to the building are not required.

448 7.3.5 Survey Design

449 The concrete rubble from the mineral processing facility is surveyed for clearance using a
450 MARSSIM-type disposition survey. The survey includes scanning to identify small areas of
451 elevated activity combined with collection and analysis of samples to evaluate the average
452 activity in the concrete rubble.

453 Scenario A will be used to design the survey, since decisions will be made based on average
454 radionuclide concentrations and radioactivity levels in each survey unit. The null hypothesis is
455 that the radionuclide concentrations in the concrete rubble will result in a dose that exceeds
456 0.01 mSv/y. There are two decisions for MARSSIM-type surveys. The first decision is based on
457 the average radionuclide concentrations in the survey unit, and the second decision is based on
458 the scanning survey results and subsequent biased sample results from flagged locations. The
459 same null hypothesis applies to both decisions.

460 A Type I decision error would occur if the decision maker decided the activity levels in the
461 concrete rubble were below the action level when they actually exceeded the action level. The
462 consequences of making this decision error could result in increased doses to members of the
463 public and failing to identify small areas of elevated radionuclide concentrations. The
464 stakeholders agreed to a Type I decision error rate of 5% based on the consequences of making
465 this decision error. This Type I error rate applies to both the scanning portion of the survey
466 design as well as sampling on a systematic grid.

467 A Type II decision error would occur if the decision maker decided the activity levels in the
468 concrete rubble exceeded the action level when they were actually below the action level. The
469 consequences of making this decision error could result in increased disposal costs. The
470 stakeholders agreed to a Type II decision error rate of 10% based on the consequences of making
471 this decision error for sampling. However, during scanning the consequences of making this
472 decision error are simply collecting additional data, so a Type II decision error rate of 60% is
473 selected for the scanning surveys (i.e., deciding to stop and count longer when no radioactivity is
474 present).

475 7.3.5.1 Classification

476 All of the concrete rubble from the floor of the processing facility has the potential to exceed one
477 or more of the action levels. The concrete rubble is classified as Class 1 M&E.

478 7.3.5.2 Scanning Survey Design

479 The concrete must be crushed prior to performing the scanning survey to reduce the size of
480 individual particles to less than 2-3 cm in diameter. This provides a uniform matrix of material
481 ensuring a representative sample can be collected, and also allows the rebar to be removed. The
482 crushed concrete is distributed in a layer approximately 15 cm thick, and surveyed using a
483 FIDLER at a height of 10 cm above the surface. The scan speed is 0.25 meter per second, which
484 is consistent with the scan MDC calculations (see Appendix F). One hundred percent of the
485 concrete rubble is scanned with readings in excess of 30,000 cpm flagged for additional
486 investigation. The additional investigations include collection and analysis of samples using
487 gamma spectrometry to quantify activity levels for the radionuclides of concern. Samples
488 collected from locations with readings in excess of 140,000 cpm are also analyzed for uranium
489 and thorium isotopes by alpha spectrometry.

490 7.3.5.3 Sample Collection Survey Design

491 The concrete rubble is divided into survey units and a statistically based number of samples are
492 collected from each survey unit. Since multiple radionuclides are present, the unity rule is used
493 to evaluate the sample results. Since the radionuclides are present in background, the Wilcoxon
494 Rank Sum (WRS) test is used to evaluate the survey results.

495 The upper bound of the gray region (UBGR) is set equal to the action level, which is a sum of
496 fractions of 1.0 above background. The lower bound of the gray region (LBGR) is set equal to
497 the expected sum of fractions based on results from the preliminary survey. The expected
498 average activity in the concrete rubble is close to background, even though isolated areas have
499 results more than four times the action level. An LBGR value of 0.15 is selected, which is
500 consistent with results reported in Table 7.3 for the two randomly selected samples (i.e., Samples
501 3 and 4). Since the values are not corrected for background, this value is considered
502 conservative. The shift (UBGR - LBGR) is 0.85.

503 The variability in the activity levels for the concrete rubble is not well defined. To be
504 conservative, the variability in the results should be large for results near the LBGR. A value of
505 0.15 was selected for the variability. This value is equal to the LBGR, and represents 100%
506 variability in results that are at or near background. The relative shift equals 5.6 (0.85 divided by
507 0.15 and rounded down). Since relative shifts greater than 4.0 do not result in significantly
508 smaller numbers of samples, a relative shift of 4.0 was used to determine the number of samples
509 and also help to ensure adequate statistical power.

510 Table A.2b (Appendix A) lists the number of samples required for each survey unit and reference
511 area for use with the WRS test. Seven samples are required for each survey unit and reference
512 area using a relative shift of 4.0, Type I decision error rate of five percent, and Type II decision
513 error rate of 10 percent. The radionuclide or radioactivity concentrations derived from the dose-
514 based action level are based on an average radionuclide concentration or level of radioactivity
515 over the entire survey unit. No adjustments need to be made to the number of measurements to
516 account for the scan MDC, since the scan MDC is less than the action level for both ^{238}U and
517 ^{232}Th .

518 Seven samples of approximately 1,000 grams of concrete rubble are collected from each survey
519 unit. This mass corresponds to a cylinder with a diameter of approximately 6 cm (2.5 inches) to
520 a depth of 15 cm (6 inches). This disposition survey design will be applied to all of the concrete
521 rubble, including the concrete segregated based on visual inspection and elevated scanning
522 results with a GM detector during the preliminary surveys (see Section 7.3.4.2).

523 7.3.5.4 Develop an Operational Decision Rule

524 The action level is stated in terms of incremental dose above background. In a MARSSIM
525 survey, there are requirements for both sample measurements and scanning results. Samples will
526 be collected from non-impacted concrete to represent background radionuclide concentrations.
527 The WRS test will be used to evaluate the survey results. If the test statistic for the WRS test is
528 less than or equal to 65 ($n = m = 7, \alpha = 0.05$), decide that the dose from that survey unit exceeds
529 0.01 mSv/y and the concrete will not be cleared.

530 For the scanning results, if any FIDLER measurement exceeds 30,000 cpm, collect a biased
531 concrete sample at the location of the elevated measurement for analysis by gamma
532 spectroscopy. If any FIDLER measurement exceeds 140,000 cpm, analyze the biased concrete
533 sample by alpha spectrometry as well. If the sum of fractions for any biased sample exceeds 1.0,
534 decide that the dose from that survey unit exceeds 0.01 mSv/y and the concrete will not be
535 cleared.

536 7.3.5.5 Document the Survey Design

537 The final survey design was documented in a detailed work plan. The work plan provided the
538 results of the IA, as well as all of the assumptions used to develop the survey design. The DQOs
539 and MQOs for the survey design were also included.

540 The draft work plan was submitted to the stakeholders for review. Comments were received, and
541 responses to comments developed and approved. The approved responses to comments were
542 incorporated into a final work plan documenting the disposition survey design.

543 **7.3.6 Implement the Disposition Survey Design**

544 7.3.6.1 Protection of Health and Safety

545 A job safety analysis (JSA) was performed based on the tasks defined in the work plan
546 documenting the disposition survey design. Table 7.6 shows the results of the JSA. Potential
547 health and safety hazards identified by the JSA are addressed in a site-specific health and safety
548 plan. No hazards associated with the concrete rubble will notably affect how the disposition
549 survey is implemented.

550 7.3.6.2 Segregation

551 Concrete rubble with visible stains and pitting on the floor surface is segregated as having higher
552 activity concentrations. Stained and unstained concrete were grouped into separate survey units.
553 Following segregation, the concrete was crushed to 2-3 cm diameter pieces and the rebar was
554 removed.

Table 7.6 Job Safety Analysis for Surveying Concrete Rubble

Sequence of Basic Job Steps	Potential Hazards	Recommended Action or Procedure
1. Dividing rubble into manageable survey units	Use of front end loader by untrained personnel	Ensure equipment operators are adequately trained
	Personnel in area could be struck by heavy equipment	Area workers must maintain eye contact with equipment operators
		Reflective vests will be worn to improve visibility
	Exposure to silica	Use of a real-time dust monitor will document dust levels. Respiratory protection will be used if dust levels exceed established action levels (dependent on silica content of concrete)
	Lower back strain from lifting	Proper lifting techniques will be used
Loads will be sized so as not to create unreasonable weights for manual lifting		
Exposure to radiological contamination	PPE including booties, Tyveks, and gloves will be used	
2. Establish exclusion zone for survey area	None anticipated	
3. Use hand-held survey instruments to perform survey measurements on the crushed concrete	Unstable footing may result in slips, trips, or falls	Spread out rubble in a way to minimize tripping hazards by creating clear rows between rows of concrete
4. Physical handling of larger pieces of concrete debris to expose underside for gamma surveying	Rough surfaces may cut and scrape skin on hands	Wear a set of work gloves to protect hands when handling concrete pieces
5. Entering Exclusion Zone (EZ) to perform survey	Tripping	Maintain good housekeeping in survey area
	Exposure to radiological contamination	PPE including booties, Tyveks, and gloves will be used
	Spread of radiological contamination outside EZ	Establish step-off area outside of EZ
6. Moving contaminated or clean material to appropriate disposal containers	Use of front end loader by untrained personnel	Ensure equipment operators are adequately trained
	Lower back strain from lifting	Proper lifting techniques will be used. Loads will be sized so as not to create unreasonable weights for manual lifting
	Exposure to radiological contamination	PPE including booties, Tyveks, and gloves will be used
	Exposure to silica	Use of a real-time dust monitor will document dust levels. Respiratory protection will be used if dust levels exceed established action levels (dependent on silica content of concrete)

556 7.3.6.3 Handling

557 The concrete rubble must be crushed to a uniform size of less than one inch to implement the
 558 disposition survey design and meet the MQOs. The crushing process will generate dust
 559 potentially containing radioactive material. Controls to limit dust generation were implemented
 560 during concrete crushing activities. Equipment involved in handling the concrete during
 561 crushing activities (e.g., front loader, crusher, rebar separator, conveyor belts, dump trucks) is
 562 categorized as impacted and will require a disposition survey before the equipment can be
 563 released. Surveys of the front loader used for these operations are discussed in Section 7.4 and
 564 Section 7.5.

565 7.3.6.4 Uncertainty in the Scan MDC

566 The two most important MQOs for this survey design are the scan MDC for the FIDLER
 567 measurements and the required measurement method uncertainty, u_{MR} , for the measurements on
 568 the systematic grid. The former will be addressed in this section, and the latter in the next.
 569 Several of the equations used in this section are discussed further in Appendices F and G.

570 As noted in Section 5.7.3, the MDC itself has an uncertainty which can be estimated using the
 571 methods of Section 5.6 and Appendix G.2.

572 From Equation F-10,

$$573 \text{ Scan MDC} = y = C \frac{\text{MDER}}{R_T}.$$

574 Substituting for MDER from Equation F-9,

$$575 \text{ MDER} = \frac{\text{MDCR}_{\text{surveyor}}}{W_T}, \text{ then}$$

$$576 y = C \frac{\left(\frac{\text{MDCR}_{\text{surveyor}}}{W_T} \right)}{R_T}.$$

577 Inserting Equation F-8 for $MDCR_{surveyor} = s_{i, surveyor} \times (60/i)$

578 and Equation F-7 for $s_{i, surveyor} = \frac{d' \sqrt{b_i}}{\sqrt{p}}$, we get

$$579 \quad y = C \frac{\left(\frac{s_{i, surveyor} (60/i)}{W_T} \right)}{R_T} = C \frac{\left(\frac{\left(\frac{d' \sqrt{b_i}}{\sqrt{p}} \right) (60/i)}{W_T} \right)}{R_T} = \frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \quad (7-3)$$

580 Where:

- 581 b_i = the average number of counts in the background interval (214.5 counts)
 582 was chosen as a constant value in Appendix F. Here b_i will be assumed to
 583 have a triangular distribution of half-width of 30%, so the mean value of b_i
 584 will be rounded to 215 and $u(i) = 64/\sqrt{6} = 26$.
- 585 i = the observation interval length (one second) was chosen as a constant
 586 value in Appendix F. Here i will be assumed to have a triangular
 587 distribution of half-width 0.5, so the mean value of $i = 1.0$ and
 588 $u(i) = 0.5/\sqrt{6} = 0.2$.
- 589 p = efficiency of a less than ideal surveyor, range of 0.5 to 0.75 from
 590 NUREG-1507 (NRC 1998b); a value 0.5 was chosen as a conservative
 591 value in Appendix F. Here p will be assumed to have a rectangular
 592 distribution of half-width 0.125, so the mean value of $p = 0.625$ and
 593 $u(p) = 0.125/\sqrt{3} = 0.072$.
- 594 d' = detectability index from Table 6.1 of NUREG-1507 (NRC 1998b); a
 595 value of 1.38 was selected, which represents a true positive detection rate
 596 of 95% and a false positive detection rate of 60%.
- 597 $s_{i, surveyor}$ = minimum detectable number of net source counts in the observation
 598 interval by a less than ideal surveyor.
- 599 $MDCR_{surveyor}$ = minimum detectable count rate by a less than ideal surveyor (cpm).
- 600 $MDER$ = minimum detectable exposure rate for the "ith" source term, by a less
 601 than ideal surveyor, ($\mu R/h$).
- 602 W_T = total weighted instrument sensitivity (cpm per $\mu R/h$)
 603 $W_T = 44,923$ for natural uranium from Table F.3 and
 604 $W_T = 3,881$ for natural thorium from Table F.4.
- 605 R_T = total exposure rate with buildup ($\mu R/h$)
 606 $R_T = 1.413 \times 10^{-4}$ for natural uranium from Table F.3 and
 607 $R_T = 2.619 \times 10^{-2}$ for natural thorium from Table F.4.
- 608 C = concentration of source term (set at 1 Bq/kg in Section F.5).

609 Scan MDC $\equiv y =$ minimum detectable concentration by scanning (Bq/kg), where the
 610 symbol y has been introduced for the Scan MDC for simplicity of notation
 611 in the following, y_U for natural uranium and y_{Th} for natural thorium.

612 The uncertainties for W_T and R_T will be discussed further below.

613 Inserting the values above into the equation for y we obtain:

$$614 \quad y_U = \frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} = \frac{60(1)(1.38)\sqrt{215}}{(1)(44,923)(1.413 \times 10^{-4})\sqrt{0.625}} = 242 \text{ Bq/kg and}$$

$$615 \quad y_{Th} = \frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} = \frac{60(1)(1.38)\sqrt{215}}{(1)(3,881)(2.619 \times 10^{-2})\sqrt{0.625}} = 15 \text{ Bq/kg}$$

616 Since we are assuming there are no correlations among the input variables, the combined
 617 standard uncertainty of y can be calculated using the following equation from Section 5.6.1:

$$618 \quad u_c^2(y) = \sum_{i=1}^N \left(\frac{\partial y}{\partial x_i} \right)^2 u^2(x_i) = \sum_{i=1}^N c_i^2 u^2(x_i).$$

619 The concentration of the source term, C , and the detectability index, d' , are chosen constants, so

$$620 \quad u_c^2(y) = \left(\frac{\partial y}{\partial b_i} \right)^2 u^2(b_i) + \left(\frac{\partial y}{\partial i} \right)^2 u^2(i) + \left(\frac{\partial y}{\partial p} \right)^2 u^2(p) + \left(\frac{\partial y}{\partial R_T} \right)^2 u^2(R_T) + \left(\frac{\partial y}{\partial W_T} \right)^2 u^2(W_T)$$

621 The sensitivity coefficients, c_i^2 , are calculated as follows:

$$622 \quad \left(\frac{\partial y}{\partial b_i} \right) = \frac{\partial \left(\frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \right)}{\partial b_i} = \left(\frac{1}{2} \right) \frac{60Cd'}{iW_T R_T \sqrt{p} \sqrt{b_i}} = \left(\frac{1}{2} \right) \frac{y}{b_i}$$

$$623 \quad \left(\frac{\partial y}{\partial p} \right) = \frac{\partial \left(\frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \right)}{\partial p} = \left(-\frac{1}{2} \right) \frac{60Cd' \sqrt{b_i}}{iW_T R_T p^{3/2}} = \left(-\frac{1}{2} \right) \frac{y}{p}$$

$$624 \quad \left(\frac{\partial y}{\partial i} \right) = \frac{\partial \left(\frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \right)}{\partial i} = -\frac{60Cd' \sqrt{b_i}}{i^2 W_T R_T \sqrt{p}} = -\frac{y}{i}$$

$$625 \quad \left(\frac{\partial y}{\partial R_T} \right) = \frac{\partial \left(\frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \right)}{\partial R_T} = -\frac{60Cd' \sqrt{b_i}}{iW_T R_T^2 \sqrt{p}} = -\frac{y}{R_T}$$

$$626 \quad \left(\frac{\partial y}{\partial W_T} \right) = \frac{\partial \left(\frac{60Cd' \sqrt{b_i}}{iW_T R_T \sqrt{p}} \right)}{\partial W_T} = -\frac{60Cd' \sqrt{b_i}}{iW_T^2 R_T \sqrt{p}} = -\frac{y}{W_T}$$

627 Therefore,

$$\begin{aligned}
 u_c^2(y) &= \left(\frac{y}{2b_i} \right)^2 u^2(b_i) + \left(\frac{-y}{i} \right)^2 u^2(i) + \left(\frac{-y}{2p} \right)^2 u^2(p) + \left(\frac{-y}{R_T} \right)^2 u^2(R_T) + \left(\frac{-y}{W_T} \right)^2 u^2(W_T) \\
 628 \quad &= y^2 \left[\left(\frac{u(b_i)}{2b_i} \right)^2 + \left(\frac{u(i)}{i} \right)^2 + \left(\frac{u(p)}{2p} \right)^2 + \left(\frac{u(R_T)}{R_T} \right)^2 + \left(\frac{u(W_T)}{W_T} \right)^2 \right] \quad (7-4) \\
 &= y^2 \left[\left(\frac{26}{2(215)} \right)^2 + \left(\frac{0.2}{1} \right)^2 + \left(\frac{0.072}{2(0.625)} \right)^2 + \left(\frac{u(R_T)}{R_T} \right)^2 + \left(\frac{u(W_T)}{W_T} \right)^2 \right].
 \end{aligned}$$

629 The most notable sources of uncertainty associated with W_T and R_T are the modeling assumptions
 630 for the source-to-detector separation distance during scanning and the depth distribution of the
 631 radioactivity in the crushed concrete. To calculate uncertainties, the same basic modeling
 632 assumptions as those for the MDC calculations were applied, though with variations to both the
 633 source-to-detector separation distance during scanning and the distribution of the radioactivity in
 634 the crushed concrete. While the MDC calculation in Appendix F assumes a source-to-detector
 635 distance of 10 cm and that the activity is uniformly-distributed within a cylindrical volume of
 636 crushed concrete 15 cm thick with a radius of 28 cm, several other calculations were made using
 637 source-to-detector separation distances during scanning of 8, 10, and 12 cm, and by varying the
 638 distribution of the radioactivity in the crushed concrete from uniform to uniformly-distributed
 639 within both the top and bottom 7.5 cm of the cylindrical volume of crushed concrete, to assess
 640 the potential variability in the MDC. In each calculation the total activity was the same, only the

641 distribution with depth was changed. The extreme cases were for a source-to-detector distance
 642 of 8 cm with the activity uniformly distributed within the top 7.5 cm of the concrete versus a
 643 source-to-detector distance of 12 cm with the activity uniformly distributed within the bottom 7.5
 644 cm of the concrete. While more extreme conditions might be imagined, the foregoing were
 645 considered to represent reasonable bounds on the source-to-detector distance and the activity
 646 distribution with depth. The other assumptions used in the calculations were the same as used in
 647 Appendix F. Therefore, there are three values each to describe the distribution of the possible
 648 values of W_T and R_T : The estimated mean value calculated for a uniform distribution of
 649 radioactivity in the 15 cm of concrete surveyed at 10 cm above; an estimated lower bound
 650 calculated for a uniform distribution of radioactivity in the bottom 7.5 cm of concrete surveyed at
 651 12 cm above; and an estimated upper bound calculated for a uniform distribution of radioactivity
 652 in the top 7.5 cm of concrete surveyed at 8 cm above.

653 The values for W_T and R_T at the extremes considered were not equally distant from the mean, i.e.,
 654 their distribution was not symmetric. However the GUM suggests that in the absence of more
 655 information the simplest approximation is a symmetric rectangular distribution of the same total
 656 width. With this approximation, $u(W_T) = 6673$ and $u(R_T) = 4.638 \times 10^{-5}$ for natural uranium and
 657 $u(W_T) = 539$ and $u(R_T) = 7.315 \times 10^{-3}$ for natural thorium.

658 Using this information in Equation 7-4 we find:

$$\begin{aligned}
 u_c^2(y_U) &= y_U^2 \left[\left(\frac{26}{2(215)} \right)^2 + \left(\frac{0.2}{1} \right)^2 + \left(\frac{0.072}{2(0.625)} \right)^2 + \left(\frac{u(R_T)}{R_T} \right)^2 + \left(\frac{u(W_T)}{W_T} \right)^2 \right] \\
 659 \quad &= (238)^2 \left[\left(\frac{26}{2(215)} \right)^2 + \left(\frac{0.2}{1} \right)^2 + \left(\frac{0.072}{2(0.625)} \right)^2 + \left(\frac{4.638 \times 10^{-5}}{1.413 \times 10^{-4}} \right)^2 + \left(\frac{6673}{44,923} \right)^2 \right] \\
 &= 10,013 \text{ (Bq/kg)}^2.
 \end{aligned}$$

660 So, with rounding,

661 $u_c(y_U) = 100$ Bq/kg. Therefore the FIDLER Scan MDC is $y_U = 242$ Bq/kg with an expanded
 662 uncertainty of 200 Bq/kg using a coverage factor of 2 and an estimated coverage probability of
 663 95%. The upper bound of the Scan MDC using this interval is 442 Bq/kg.

664 Similarly,

$$\begin{aligned}
 u_c^2(y_{Th}) &= y_{Th}^2 \left[\left(\frac{26}{2(215)} \right)^2 + \left(\frac{0.2}{1} \right)^2 + \left(\frac{0.072}{2(0.625)} \right)^2 + \left(\frac{u(R_T)}{R_T} \right)^2 + \left(\frac{u(W_T)}{W_T} \right)^2 \right] \\
 665 \quad &= (15)^2 \left[\left(\frac{26}{2(215)} \right)^2 + \left(\frac{0.2}{1} \right)^2 + \left(\frac{0.072}{2(0.625)} \right)^2 + \left(\frac{7.315 \times 10^{-3}}{2.619 \times 10^{-2}} \right)^2 + \left(\frac{539}{3,881} \right)^2 \right] \\
 &= 32 \text{ (Bq/kg)}^2.
 \end{aligned}$$

666 So, with rounding,

667 $u_c(y_{Th}) = 6 \text{ Bq/kg}$. Therefore the FIDLER Scan MDC is $y_{Th} = 15 \text{ Bq/kg}$ with an expanded
 668 uncertainty of 12 Bq/kg using a coverage factor of 2 and an estimated coverage probability of
 669 95%. The upper bound of the Scan MDC using this interval is 27 Bq/kg .

670 The scan MDCs of approximately 438 Bq/kg for uranium and 27 Bq/kg for thorium are both less
 671 than their respective NUREG-1640-based activity action levels of $38,000$ and 330 Bq/kg ,
 672 respectively.

673 7.3.6.5 Measurement Quantifiability

674 MARSAME recommends the requirement $u_{MR} \leq \Delta / 10$ by default when decisions are being
 675 made about the mean of a sampled population.

676 For this case study, the Unity Rule, $\frac{C_{238\text{U}}}{AL_{238\text{U}}} + \frac{C_{234\text{U}}}{AL_{234\text{U}}} + \frac{C_{232\text{Th}}}{AL_{232\text{Th}}} + \frac{C_{226\text{Ra}}}{AL_{226\text{Ra}}} \leq 1$, will be used to

677 compare the sum of the ratios of the radionuclide concentrations to their respective action levels.

678 In Section 7.3.5.3 the LBGR was chosen to be 0.15 , so $u_{MR} \leq \Delta / 10 = (\text{UBGR} - \text{LBGR})/10$
 679 $= (1.0 - 0.15)/10 = 0.085$. Therefore the requirement on the relative uncertainty of the sum of
 680 fractions at the action level is slightly more stringent than simply requiring that the MQC be less
 681 than the action level. We require that

$$682 \quad u_c \left(\frac{C_{238\text{U}}}{AL_{238\text{U}}} + \frac{C_{234\text{U}}}{AL_{234\text{U}}} + \frac{C_{232\text{Th}}}{AL_{232\text{Th}}} + \frac{C_{226\text{Ra}}}{AL_{226\text{Ra}}} \right) \leq 0.085 \text{ when } \left(\frac{C_{238\text{U}}}{AL_{238\text{U}}} + \frac{C_{234\text{U}}}{AL_{234\text{U}}} + \frac{C_{232\text{Th}}}{AL_{232\text{Th}}} + \frac{C_{226\text{Ra}}}{AL_{226\text{Ra}}} \right) = 1.0.$$

683

683 Clearly, if each of the four terms in the sum is constrained to a fourth of its limit, the unity rule
684 will be satisfied.

685 If the concentrations of the radionuclides of concern are independent, then the requirement on u_c
686 can be expressed as:

$$687 \quad u_c^2 \left(\frac{C_{238\text{U}}}{0.25AL_{238\text{U}}} + \frac{C_{234\text{U}}}{0.25AL_{234\text{U}}} + \frac{C_{232\text{Th}}}{0.25AL_{232\text{Th}}} + \frac{C_{226\text{Ra}}}{0.25AL_{226\text{Ra}}} \right) \\ = \left(\frac{u(C_{238\text{U}})}{0.25AL_{238\text{U}}} \right)^2 + \left(\frac{u(C_{234\text{U}})}{0.25AL_{234\text{U}}} \right)^2 + \left(\frac{u(C_{232\text{Th}})}{0.25AL_{232\text{Th}}} \right)^2 + \left(\frac{u(C_{226\text{Ra}})}{0.25AL_{226\text{Ra}}} \right)^2 \leq (0.085)^2.$$

688 If the required relative measurement method uncertainty is the same for each radionuclide, then

$$689 \quad \left(\frac{u(C_{238\text{U}})}{0.25AL_{238\text{U}}} \right)^2 = \left(\frac{u(C_{234\text{U}})}{0.25AL_{234\text{U}}} \right)^2 = \left(\frac{u(C_{232\text{Th}})}{0.25AL_{232\text{Th}}} \right)^2 = \left(\frac{u(C_{226\text{Ra}})}{0.25AL_{226\text{Ra}}} \right)^2 \leq (0.085)^2 / 4 = (0.0425)^2.$$

690 **Table 7.7 Radionuclide-Specific Required Relative Measurement Method Uncertainties**

Radionuclide	Modified Action Level (Bq/kg)	Required Relative Measurement Method Uncertainty, ϕ_{MR}
^{238}U	$38,000 / 4 = 9500$	4.25%
^{234}U	$12,000,000 / 4 = 3,000,000$	4.25%
^{232}Th	$330 / 4 = 82.5$	4.25%
^{226}Ra	$450 / 4 = 112.5$	4.25%

691 7.3.6.6 Survey Data

692 As the concrete is removed from the crusher, it is placed in a wooden frame (measuring 8 meters
693 by 10 meters by 15 cm) on a concrete pad. The wooden frame's volume (12 cubic meters)
694 corresponds to the volume associated with each sample from the survey design (i.e., 83 cubic
695 meters divided by seven samples). Therefore, seven batches of concrete equal one survey unit.
696 One sample is collected from the center of the concrete rubble residing in the wooden form for
697 each batch of crushed concrete. One hundred percent of the surface is surveyed to identify

698 locations with count rates greater than 30,000 cpm to investigate for areas of elevated activity
699 and establish biased sampling points. A sample is collected at each location exceeding 30,000
700 cpm.

701 If no scan results exceed 30,000 cpm, the concrete is removed from the form and placed in the
702 non-impacted concrete staging area awaiting laboratory analysis of the samples. If the scan
703 survey identifies areas exceeding 30,000 cpm, the concrete is transferred to a holding container
704 to control access to the concrete until the laboratory analyses are completed. A total of 126
705 batches of concrete are scanned (7 batches for each of the 18 survey units). Seventeen batches of
706 concrete are segregated as potentially containing elevated levels of radioactivity based on the
707 scan survey results, and one additional sample is collected from each batch as part of the
708 investigation. No areas exceeding 100,000 cpm are identified during implementation of the
709 disposition survey.

710 Five additional samples are collected from random locations on the floor of the administrative
711 building to provide a total of seven reference area samples. The results of the two samples
712 collected from the administrative building during the preliminary surveys are reviewed and
713 determined to be of adequate quality for the disposition survey.

714 All of the concrete samples collected during implementation of the disposition survey are sent to
715 a laboratory for analysis by gamma spectrometry and alpha spectrometry for uranium isotopes.
716 Thorium-232 is quantified based on the ^{228}Ac gamma spectrometry results. Radium-226 is
717 quantified based on the ^{214}Bi gamma spectrometry results. A total of 150 samples are analyzed,
718 including seven samples from the reference area. The 17 biased sample locations identified by
719 the scan survey were analyzed by gamma spectroscopy.

720 Performance checks of the FIDLER were made at the beginning and end of collection activities
721 for each survey unit. These performance checks included a blank measurement in an area away
722 from potential sources of radioactivity and a source check. Control charts were constructed to
723 monitor the performance of the FIDLER throughout the survey. One FIDLER was dropped
724 while performing a scan survey and the window was damaged. The instrument was removed
725 from service and all scan measurements were repeated using a replacement FIDLER for that

726 survey unit. No quality related problems were identified during the performance of the scan
727 surveys.

728 The offsite laboratory provided the results of the laboratory analyses. The quality control
729 measurements specified in the work plan were performed. All of the QC results were within the
730 limits specified in the work plan. No quality related issues were identified during the
731 performance of the sampling surveys.

732 **7.3.7 Assess the Results of the Disposition Survey**

733 7.3.7.1 Data Quality Assessment

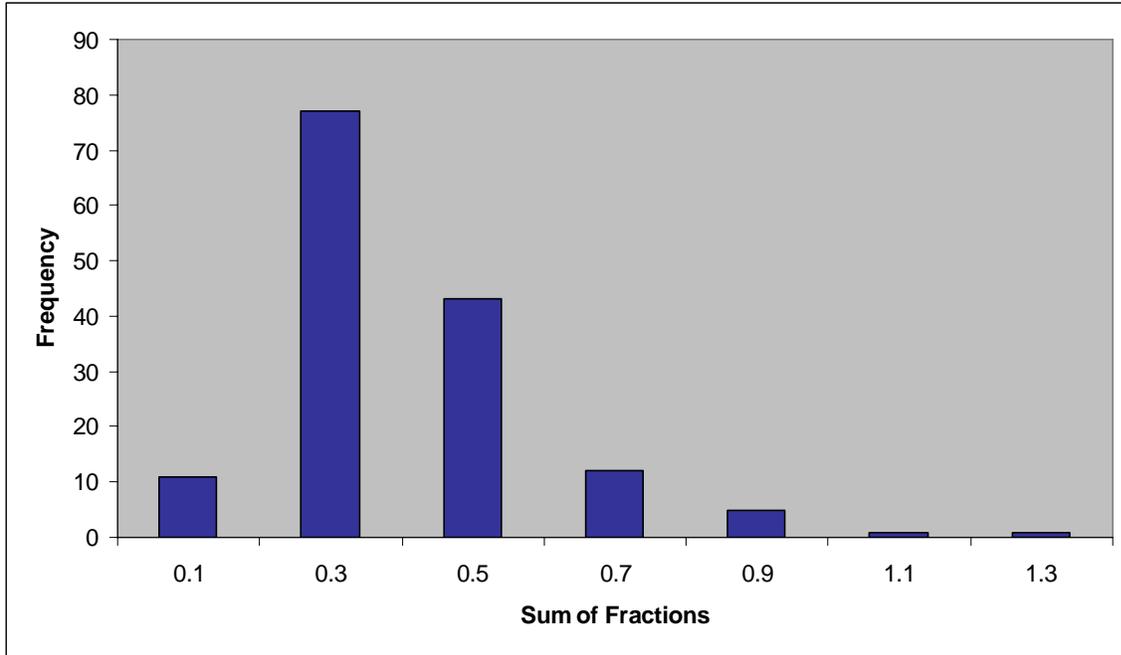
734 The disposition survey design for the concrete rubble is verified as having been executed very
735 closely to the survey design, with the appropriate number of measurements collected for each of
736 the survey units.

737 The quality control sample results from the laboratory are reviewed and the data are deemed
738 acceptable. An exploratory data analysis of the entire data set is performed to gain an
739 understanding of the structure of the data.

740 The sum of fractions for each sample is calculated using the results for ^{238}U , ^{234}U , ^{232}Th (^{228}Ac),
741 and ^{226}Ra (^{214}Bi) and the radionuclide specific action levels. Only two samples result in sums of
742 fractions greater than 1.0 without correcting for background. Both of these samples came from
743 batches that were segregated prior to crushing based on visual evidence of staining within the
744 concrete rubble; these were also the two locations with the highest scan survey results. A
745 frequency plot (Figure 7.1) and normal cumulative frequency plot (Figure 7.2) were constructed
746 to provide visual representations of the data.

747 7.3.7.2 Wilcoxon Rank Sum Test

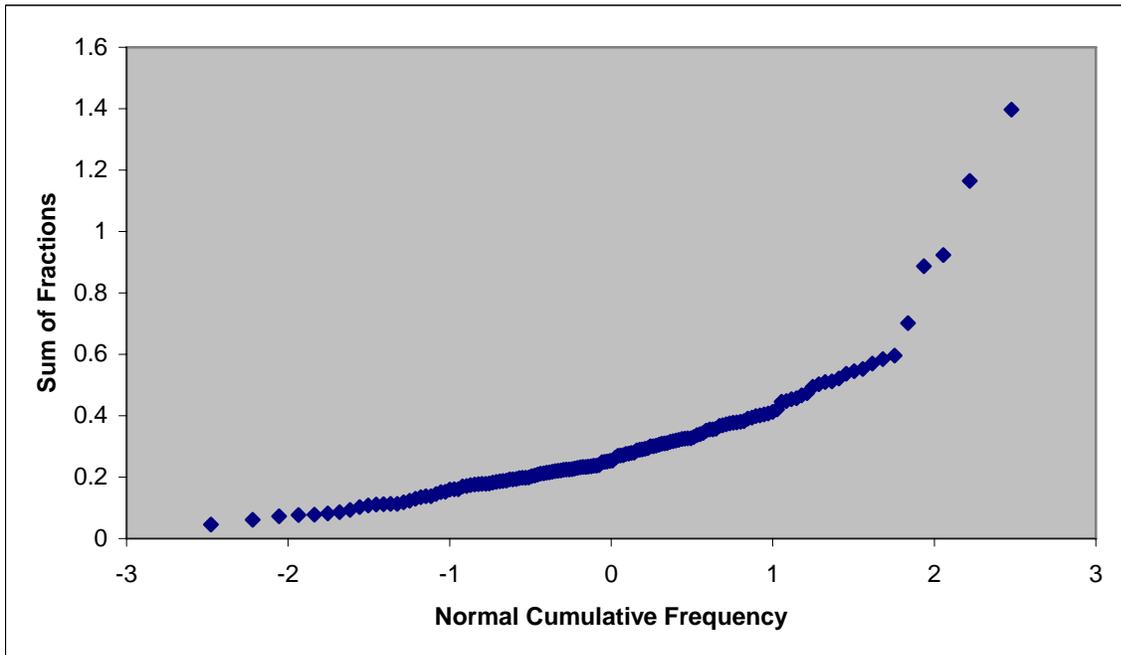
748 The Wilcoxon Rank Sum test was used to compare the reference area data to the survey unit
749 data. In each case the test statistic exceeded the critical value of 65, so the null hypothesis was
750 rejected for all seventeen survey units. It was concluded that the average activity in the crushed
751 concrete exceeds background by less than a sum of fractions of 1.0.



752

753

Figure 7.1 Frequency Plot of Case Study Data



754

755

Figure 7.2 Cumulative Frequency Plot of Case Study Data

756 7.3.8 The Decision

757 In every survey unit, including those with stained concrete, the test statistic for the WRS test
758 exceeded the critical value in Table A.4 in Appendix A. The null hypothesis that the mean sum
759 of fractions in the survey unit exceeds 1.0 is rejected. Even though the standard deviation of the
760 survey unit results (0.287) exceeded the variability used to design the survey (i.e., 0.15), it did
761 not significantly impact the ability to make a decision about the concrete rubble. Based on the
762 results of the disposition survey, the crushed concrete can be cleared.

763 **7.4 Mineral Processing Facility Rented Equipment Baseline Survey**

764 **7.4.1 Description**

765 Heavy equipment is required to move the piles of concrete rubble at the mineral processing
766 facility discussed in Section 7.3. A front loader is rented to assist with the work. The
767 radiological history of the rented front loader is unknown.

768 **7.4.2 Objectives**

769 The objective is to apply interdiction controls to prevent the introduction of offsite radioactive
770 materials to the mineral processing facility. In addition, surveying the front loader before it
771 enters the site may provide reference area data for use in clearing the front loader at the end of
772 the project (see Section 7.5). The scope of this case study is limited to a rented front loader
773 being brought to the site for on-site transport of impacted concrete rubble.

774 **7.4.3 Initial Assessment of the M&E**

775 7.4.3.1 Categorize the M&E

776 The material to be assessed is a rented front loader (Figure 7.3). A review of the existing
777 information shows it is not adequate to categorize the front loader (see Figure 2.1). A visual
778 inspection of the front loader as it is delivered to the site shows the equipment has been used, but
779 there are no notable quantities of soil. No detailed historical records pertaining to the usage
780 history of the front loader are available for review, other than that available from the rental
781 company pertaining to the types of sites where heavy equipment is rented and used. Natural
782 radionuclides are present in or commingled with soil, sediment, rubble, debris, and water. Heavy
783 equipment is in direct contact with natural uranium and thorium during operations. Since there is
784 a possibility the M&E may contain radionuclide concentrations or radioactivity exceeding the
785 background at the mineral processing facility, the front loader is categorized as impacted.



786

787

Figure 7.3 Front Loader

788 7.4.3.2 Preliminary Surveys

789 The information available after categorizing the front loader is not adequate to select a
790 disposition option (see Figure 2.2). The data gaps for the front loader are associated with
791 describing the physical and radiological attributes of the front loader. The scoping survey design
792 includes scanning external and easily measurable areas of the front loader that have the highest
793 potential to contact radioactive materials.

794 A description of the physical attributes of the front loader is listed in Table 7.8 (per Table 2.1).
795 The front loader is a large, complicated piece of machinery. It incorporates four wheels that are
796 50 centimeters (cm) (1 feet [ft], 8 inches [in]) wide and 150 cm (5 ft) tall, a wheelbase of 345 cm
797 (11 ft, 4 in), an additional section of 246 cm (8 ft, 1 in) behind the rear wheels for the engine
798 housing, and a height of 363 cm (11 ft, 9 in) to the top of the operator cab. The front loader uses
799 a 320 cm-wide (10 ft, 6 in), 4.7 cubic meters-(m³) capacity bucket (six cubic yards [yd³]). The
800 overall length with the bucket is 914 cm (30 ft, 0 in).

801

Table 7.8 Physical Attributes Used to Describe the Front Loader

Attribute	Description
Dimensions	<p><u>Size</u> - Total Mass $\approx 25,490$ kg (56,196 lbs)</p> <p><u>Shape</u> - Total Surface Area ≈ 180 m²</p>
Complexity	<p>The front loader is composed of multiple materials. Most external components are painted steel. However, the tires are rubber, the cab is comprised of large sections of glass, hydraulic fluid hoses are composed of high-pressure silicon, and the joints are coated with grease.</p> <p>Disassembly would ideally be avoided for the considerable time and expense it adds to performing disposition surveys on the equipment.</p> <p>Options for surveying interior surfaces include surveying of the engine air filters and interior surfaces of the exhaust plumbing to determine whether radioactive materials have spread into the engine.</p>
Accessibility	<p>The inside corners of the bucket and portions of each tire and wheel are difficult to measure using conventional hand-held measurements, even with a relatively small hand-held GM detector probe. The large height of the front loader, the underside of the front loader, and the varying orientation of surfaces associated with the equipment represent a scenario that makes accessibility difficult.</p> <p>There are only a few porous surfaces that allow permeation of radioactivity, such as the grease used on external hinges and joints.</p> <p>Air inlets, grease used on external hinges and joints, and air vents in the external panels represent areas where radioactivity could penetrate to difficult-to-measure areas.</p>
Inherent Value	<p>The front loader can be decontaminated, reused, or recycled. The costs associated with either replacing impacted portions of the front loader, or disposing of the front loader and replacing it, are very high. As long as only exterior surfaces of the front loader become impacted, the cost of decontamination to allow unrestricted release and reuse elsewhere will probably not be substantial.</p>

802 The surface area was estimated by dividing the front loader into components with regular
803 geometric shapes and rounding to the nearest square meter. For example, the tires were modeled
804 as cylinders and the cab was modeled as a box. The bucket has a surface area of 13.5 m², which
805 is applied to the inside and outside surfaces for a total of 27 m². The exterior surfaces of the
806 body have a surface area of approximately 76 m². The tires have a surface area of 24 m², and the
807 inside of the cab is estimated at 16 m². Since the surfaces are not actually regular geometric

808 shapes, a contingency factor of 25% (35 m²) was used to account for irregular surfaces, hoses,
809 etc. This contingency factor was based on professional judgment and approved through
810 discussions with the regulators. The rounded total surface area is 180 m².

811 The front loader is composed of multiple materials. Most external components are painted steel.
812 However, the tires are rubber, the cab is comprised of large sections of glass, hydraulic fluid
813 hoses are composed of high-pressure silicon, and the joints are coated with grease. The front
814 loader is deemed accessible, as the areas most likely to contain radioactivity are all accessible
815 (though some portions of the front loader are more accessible than others) for conducting
816 measurements with hand-held instruments. Internal areas of the front loader are inaccessible
817 without disassembly.

818 The radiological attributes of the front loader are listed in Table 7.9 (per Table 2.2).
819 Radionuclides of potential concern include any radionuclides that may be present. Members of
820 the uranium and thorium radioactive decay series are used as a preliminary list of radionuclides
821 since these are the radionuclides of concern for the site (Appendix C lists types of sites where
822 uranium and thorium series radionuclides may be present). These are the radionuclides that are
823 known to be present at the mineral processing facility. Radioactivity associated with the front
824 loader is anticipated to be present at near-background concentrations. Materials may have built
825 up in specific locations on the front loader (e.g., joints with external grease, tires, corners of the
826 bucket) resulting in small areas of elevated radioactivity. The distribution of radioactive material
827 is expected to be concentrated on the underside and lower edges of the front loader. Horizontal
828 surfaces also present areas for the potential deposition of airborne radioactivity (angled and
829 vertical surfaces also present areas for the potential deposition of airborne radioactivity but
830 deposition of radioactivity is less likely in these areas due to surface orientation).

831 Given the unknown use history of the front loader, professional judgment and process knowledge
832 are used to develop a likely scenario for the potential distribution of radioactivity. Radioactivity
833 associated with the front loader is expected to be surficial only. Since the radioactivity is
834 expected to be associated with materials from the site, the radioactivity is also expected to be
835 removable. Process knowledge does not provide a likely scenario for activation or other method
836 for volumetrically-impacting the front loader.

837

Table 7.9 Radiological Attributes Used to Describe the Front Loader

Attribute	Description
Radionuclides	Radionuclides of potential concern are any radionuclides that can be identified. The uranium and thorium series radionuclides are used as a preliminary list, since these are the radionuclides of concern for the mineral processing facility.
Activity	Radionuclide concentrations are expected to be close to background or zero.
Distribution	Radioactivity is expected to be associated with materials that have come in contact with the front loader. These materials will likely build up in specific locations resulting in small areas of elevated activity that can be visually identified.
Location	Radioactivity associated with the front loader is expected to be surficial and removable.

838 7.4.3.3 Implement Preliminary Surveys

839 A Geiger-Mueller (GM) meter is used to collect initial scanning survey data to help address data
840 gaps on the bucket and tires (i.e., external and easily measurable areas of the front loader that
841 have the highest potential for residual radioactivity). The maximum reading from the bucket was
842 80 counts per minute (cpm), and the maximum reading from the tires was 65 cpm. A collimated
843 in situ gamma spectrum made of the front loader showed no gamma lines other than those
844 associated with natural uranium, potassium, and thorium. Although one might expect some trace
845 amounts of ^{137}Cs from atmospheric fallout, there was not enough to show up in the spectrum.

846 A non-impacted section of steel I-beam approximately one foot long (which resembles the
847 majority of the surfaces of the front loader) is used as a reference material to establish the GM's
848 background count rate. Scanning measurements are collected from flat surfaces, edges, and
849 inside corners of the I-beam; count rates of 30 to 35 cpm are observed. Daily quality control
850 checks were performed to ensure the instruments were operating properly.

851 7.4.3.4 Select a Disposition Option

852 The disposition options for the front loader are to accept it for use at the mineral processing
853 facility following an interdiction survey, or to return it to the rental company.

854 7.4.3.5 Document the Results of the Initial Assessment

855 The results of the IA were documented in a letter report to the project manager. The decision to
856 categorize the front loader as impacted was included in the report, along with the descriptions of
857 the physical and radiological attributes of the front loader. The letter report described the
858 scoping survey and listed the results of the measurements.

859 **7.4.4 Identify Inputs to the Decision**

860 Following completion of the IA, additional information needed to develop the disposition survey
861 design is collected.

862 7.4.4.1 Select Radionuclides or Radiations of Concern

863 The initial assessment indicates that natural uranium and natural thorium are the radionuclides
864 of potential concern.

865 7.4.4.2 Identify Action Levels

866 The action level selected for the interdiction survey is no detectable surface radioactivity above
867 background. Since there are multiple radionuclides to be evaluated during the interdiction
868 survey, additional discussion of action levels may be necessary.

869 7.4.4.3 Identify the Parameter of Interest

870 The parameter of interest for an interdiction survey with an action level of no detectable activity
871 is the level of radioactivity reported for each measurement. Any measurement that detects the
872 presence of radioactivity indicates the action level has been exceeded.

873 7.4.4.4 Identify Alternative Actions

874 The alternative actions are determined by the disposition option. If the front loader is refused
875 access to the site, it will be returned to the rental company. If the front loader is granted access
876 to the site, it will be used to transport concrete rubble.

877 7.4.4.5 Develop a Decision Rule

878 The decision rule incorporates the action level, parameter of interest, and alternative actions into
879 an “if...then” statement.

880 If the results of any measurement identify surface radioactivity in excess of background, then the
881 front loader will be refused access to the site. If no surface radioactivity in excess of background
882 is detected, then the front loader will be granted access to the site.

883 7.4.4.6 Identify Survey Units

884 A survey unit is defined as the quantity of M&E for which a separate disposition decision will be
885 made. The front loader is the survey unit. The decision rule will be applied by comparing
886 individual measurement results to the critical value for detection. All measurements must be
887 below the critical value (i.e., no surface radioactivity in excess of background detected) in order
888 to accept the front loader.

889 7.4.4.7 Inputs for Selection of Measurement Methods

890 The selection of a measurement method depends on the list of radionuclides or radiations of
891 concern and will affect the survey unit boundaries. Establishing performance characteristics for
892 the measurement method (i.e., measurement quality objectives [MQOs]) will help ensure the
893 measurement results are adequate to support the disposition decision.

894 Detection Capability

895 Since the action level is stated in terms of detection capability, the detection capability is critical
896 in selecting an acceptable measurement method. The detection capability is defined as the
897 minimum detectable concentration (MDC). The survey design will need to specify how hard to
898 look (i.e., select an appropriate discrimination limit) before the MQO for detection capability can
899 be established. The MDC for the selected measurement method must be less than or equal to the
900 discrimination limit.

901 Measurement Method Uncertainty

902 The measurement method uncertainty is also important in selecting a measurement method. The
903 MQO for detection capability will determine the acceptability of a measurement method, but it

904 will also include information on the measurement method uncertainty. The measurement
905 method uncertainty at background concentrations is used to calculate the MDC, as well as the
906 critical value for the detection decision.

907 Range

908 The selected measurement method must be able to detect radionuclide concentrations or
909 radioactivity at the discrimination limit. However, the measurement method must also be able to
910 operate and quantify radionuclide concentrations or radioactivity at levels equal to those
911 identified in the M&E at the site.

912 Specificity

913 The requirement for specificity will be tied to the list of radionuclides and radiations of concern.
914 If radionuclide specific measurements are required, the measurement method must be able to
915 identify radioactivity associated with specific radionuclides. If radionuclide specific
916 measurements are not required, methods that measure gross activity may be acceptable.

917 Ruggedness

918 Ruggedness is not expected to be a major concern for selecting a measurement method. Since
919 only surficial radioactivity is expected, in situ measurements of front loader surfaces will be used
920 to collect data for comparison to the action levels. The selected measurement method must be
921 able to perform these surface measurements in the field where the front loader is located. The
922 environmental conditions will depend on the site location (e.g. northeast vs. southwest) and the
923 time of the year (e.g., winter vs. summer).

924 7.4.4.8 Reference Materials

925 The majority of the surfaces on the front loader are metal (e.g., steel), although there are several
926 rubber surfaces as well (e.g., tires, hoses). The small steel I-beam used to estimate background
927 during the preliminary surveys will be used as the reference materials for the disposition survey.
928 There is no inherent radioactivity from the uranium or thorium decay series expected in steel or
929 rubber, so the selection of the reference material is not expected to result in any bias during
930 interpretation of the results.

931 **7.4.5 Survey Design**

932 7.4.5.1 Select a Null Hypothesis

933 The hypotheses being tested are:

934 *Null Hypothesis:* The front loader contains no detectable radionuclide concentrations or
935 radioactivity above background levels (i.e., indistinguishable from background).

936 *Alternative Hypothesis:* The front loader contains detectable radionuclide concentrations or
937 radioactivity above background levels.

938 MARSAME processes require the use of Scenario B when the action level is zero, which is the
939 case for indistinguishable from background.

940 7.4.5.2 Set the Discrimination Limit

941 The discrimination limit is the radionuclide concentration or level of radioactivity that can be
942 reliably distinguished from the action level by performing measurements. Under Scenario B, the
943 discrimination limit determines how hard the surveyor needs to look to determine there is no
944 detectable radioactivity.

945 Acceptable surface activity levels derived from the relevant regulatory agency were selected as
946 the discrimination limits for radionuclides of potential concern. Table 7.10 lists the potential
947 discrimination limits based on the preliminary list of radionuclides of concern.

948 **Table 7.10 Potential Discrimination Limits**

Radionuclide of Potential Concern	Natural U	Natural Th
Average (dpm/100 cm ²)	5,000	1,000
Maximum (dpm/100 cm ²)	15,000	3,000

949 Based on the preliminary selection of radionuclides of potential concern, the discrimination
950 limits for natural thorium represent the limiting case.

951 7.4.5.3 Limits on Decision Errors

952 If while scanning, an area is perceived to exceed background, a one-minute direct measurement
953 will be performed at that location to verify the scan results. If the results of the one-minute count
954 exceed background the front loader may not be acceptable for use on the site. Thus, there are
955 two decisions being made for scanning surveys. The first occurs when the surveyor decides to
956 stop and flag a location to take a direct measurement. The second is when a decision is made on
957 whether the direct measurement exceeds background.

958 A Type I decision error occurs when the null hypothesis is rejected when it is true. For this
959 survey, a Type I decision error would be refusing to allow the front loader onto the site even
960 though there is no radioactivity present that exceeds background. The consequences of this
961 decision error may include unnecessarily returning the front loader and taking additional time to
962 locate a replacement, or possibly deciding to decontaminate the front loader prior to use on the
963 site. For this reason a Type I decision error rate of 1% is specified for the direct measurements.
964 However, during scanning the consequences of making this decision error are simply collecting
965 additional data, so a Type I decision error rate of 60% is selected for the scanning surveys (i.e.,
966 deciding to stop and count longer when no radioactivity is present).

967 A Type II decision error occurs when the null hypothesis is not rejected when it is false. For this
968 survey, a Type II decision error would be allowing the front loader to be used on the site when
969 there is radioactivity above background. The consequences of a Type II decision error may
970 include introducing additional radionuclides on to the site and slightly increased exposures to
971 workers. It may also make it difficult to clear front loader and return it to the rental company
972 when the work is complete. For this reason a Type II decision error rate of 1% is specified for
973 the direct measurements and a Type II decision error rate of 5% is selected for the scanning.

974 7.4.5.4 Select a Measurement Technique

975 At this point in the survey design process, the planning team decides to evaluate each of the three
976 measurement techniques to determine what might be feasible for surveying the front loader.
977 Selection of a measurement technique will help determine the final survey design and decide
978 between the multiple options currently available for the survey.

979 A scan-only survey approach requires that the measurement method be capable of detecting
980 radioactivity at the discrimination limit. Any results exceeding the critical value would provide
981 evidence of radioactivity levels exceeding background. There would be no need to record
982 individual measurement results, since every result would be compared to the critical value. The
983 calculation of the total efficiency is expected to be a major source of measurement method
984 uncertainty. Additional measurements or assumptions are required to select a source term as the
985 basis for the efficiency calculations. Scanning can be performed for alpha, beta, gamma, or
986 some combination of the types of radiation. The amount of the front loader requiring scanning
987 (i.e. 10 to 100%) would be determined by the classification. It is unknown if any scan-only
988 measurement methods are available that meet the MQOs.

989 In situ survey approaches also require that the measurement method be capable of detecting
990 radioactivity at the discrimination limit. In situ techniques allow identification of specific
991 radionuclides, if necessary. The major source of measurement method uncertainty will likely be
992 the model used to calculate the efficiency. Additional measurements or assumptions are required
993 to select a source term as the basis for the efficiency calculations. The amount of the front loader
994 requiring measurement (i.e., 10 to 100%) would be determined by the classification. The final
995 number of measurements will be linked to the field of view of the detector. For example, a
996 detector with a 1-m² field of view would require more than 180 measurements to measure 100%
997 of the external surfaces of the front loader. An instrument such as the GM probe used during the
998 scoping survey with a field of view of less than 100 cm² would require thousands of
999 measurements to measure the minimum 10% of the front loader.

1000 A MARSSIM-type approach would use a combination of direct measurements or samples with
1001 scanning to support a disposition decision. Sampling could damage the front loader, so direct
1002 measurements would be preferred. Locating measurements on the surface of the front loader
1003 will be problematic. Similar to scan-only and in situ designs, the scanning and direct
1004 measurements should be capable of detecting radioactivity at the discrimination limit. The
1005 MARSSIM-type survey design would require the most resources to implement.

1006 Based on the evaluation of measurement techniques, a scan-only survey design is the preferred
1007 approach. Assumptions about the radionuclides of concern will need to be established and the
1008 availability of scan-only measurement methods needs to be verified.

1009 7.4.5.5 Finalize Selection of Radiations to be Measured

1010 Scan-only measurement methods are available for alpha, beta, and gamma radiations. The
1011 higher background associated with scanning for gamma radiation makes it unlikely that the
1012 measurement method could detect radioactivity at the discrimination limit. Alpha particles are
1013 attenuated more than beta particles, increasing the uncertainty caused by variations in source to
1014 detector distance. Scan-only measurement methods for beta radiation should provide the
1015 optimum survey design. However, the lower detection limits associated with alpha
1016 measurements may be required to meet the detection capability MQO. Any radioactivity in
1017 excess of background is assumed to result from natural thorium, which is the limiting
1018 radionuclide.

1019 7.4.5.6 Develop an Operational Decision Rule

1020 A scan-only survey will be performed for beta (and possibly alpha) radiation. Any result that
1021 exceeds the critical value associated with the MDC set at the discrimination limit will result in
1022 rejection of the null hypothesis, and the front loader will not be allowed on the site. Additional
1023 constraints on data collection activities include that the front loader be clean and dry when the
1024 measurements are performed.

1025 7.4.5.7 Classify the M&E

1026 The expected levels of radioactivity are background (see table 7.9). No radioactivity in excess of
1027 background is expected, so the front loader is classified as Class 3.

1028 7.4.5.8 Select a Measurement Method

1029 The planning team decided to verify the availability of an acceptable measurement method prior
1030 to finalizing the survey design. The GM pancake probe used to perform the scoping survey is
1031 evaluated first. The expected range of radioactivity based on the reference material and
1032 preliminary survey data is approximately 35 cpm (i.e., background) to 80 cpm.

1033 Based on the scanning survey data collected using the GM detector during the preliminary
1034 surveys, the anticipated Scan MDC of the GM pancake may not be capable of detecting
1035 radioactivity at the discrimination limit of 1000 dpm/100 cm² (see Table 7.10).

1036 An alpha-beta gas proportional detector utilizing a larger detector probe area will help achieve a
 1037 lower scan MDC. The maximum reading for measurements from the bucket is 250 cpm; and the
 1038 maximum reading from the tires was 220 cpm. Measurements collected from flat surfaces,
 1039 edges, and inside corners of the reference material I-beam provide count rates between 180 and
 1040 190 cpm. The maximum background count rate is converted to scan MDC using NUREG 1761
 1041 (NRC 2002) equations 4-3 and 4-4.

$$1042 \quad s_i = d' \sqrt{b_i} = 1.38 \times \sqrt{8.3} = 4.0 \text{ counts}$$

$$1043 \quad \text{MDCR} = s_i \times (60 / i) = 4.0 \times (60 / 2) = 120 \text{ cpm}$$

$$1044 \quad \text{Scan MDC} = \frac{\text{MDCR}}{\sqrt{p} \varepsilon_i \varepsilon_s} = \frac{120}{\sqrt{0.5} \times 1.29} = 132 \text{ dpm/100 cm}^2$$

1045 Where:

1046 b_i = the average number of background counts in the observation interval 2(250/60)
 1047 = 8.3 counts)

1048 i = the interval length (2 s) based on a scan speed of 5 cm/s

1049 p = efficiency of a less than ideal surveyor, range of 0.5 to 0.75 from NUREG-
 1050 1507 (NRC 1998b); a value 0.5 was chosen as a conservative value

1051 d' = detectability index from Table 6.1 of NUREG-1507 (NRC 1998b); a value of
 1052 1.38 was selected, which represents a true positive detection rate of 95% and a
 1053 false positive detection rate of 60%

1054 s_i = minimum detectable number of net source counts in the observation interval
 1055 (counts)

1056 MDCR = minimum detectable count rate (cpm)

1057 $\varepsilon_i \varepsilon_s$ = weighted total alpha-beta efficiency for natural thorium in equilibrium with its
 1058 progeny on the surveyed media (1.29, see Table 7.11)

1059 The scan MDC for activity is now below 1,000 dpm/ 100 cm² and is good enough to detect
 1060 radioactivity at the ²³²Th discrimination limit. However, the large size of the proportional
 1061 counter may make it necessary to take some additional biased direct measurements with the GM
 1062 probe in tight curves or hard to reach locations.

1063 **Table 7.11: Detector Efficiency for the Mineral Processing Facility (^{232}Th in Complete**
 1064 **Equilibrium with its Progeny) using a Gas Proportional Detector**

Radionuclide	Average Energy (keV)	Fraction	Instrument Efficiency	Surface Efficiency	Weighted Efficiency
^{232}Th	alpha	1	0.40	0.25	0.1
^{228}Ra	7.2 keV beta	1	0	0	0
^{228}Ac	377 keV beta	1	0.54	0.50	0.27
^{228}Th	alpha	1	0.40	0.25	0.1
^{224}Ra	alpha	1	0.40	0.25	0.1
^{220}Rn	alpha	1	0.40	0.25	0.1
^{216}Po	alpha	1	0.40	0.25	0.1
^{212}Pb	102 keV beta	1	0.40	0.25	0.1
^{212}Bi	770 keV beta	0.64	0.66	0.50	0.211
^{212}Bi	alpha	0.36	0.40	0.25	0.036
^{212}Po	alpha	0.64	0.40	0.25	0.064
^{208}Tl	557 keV beta	0.36	0.58	0.50	0.104
Total					efficiency =
					1.29

1065 From NUREG 1761 (NRC 2002) Table 4.3

1066 7.4.5.9 Optimize the Disposition Survey Design

1067 A scan-only interdiction survey will be performed of the exterior surfaces of the front loader.

1068 Since the front loader is Class 3, approximately 10% of the external surface area will be

1069 surveyed. Professional judgment will be used to select the locations for the scans in the locations

1070 with the highest potential for radioactivity (i.e., the bucket, tires, and floor of the cab).

1071 Approximately 50% of each of these areas will be surveyed, for a total of approximately 18 m²

1072 (7 m² of the bucket, 10 m² of the tires, and 1 m² of the cab floor). Experienced technicians

1073 capable of detecting radioactivity in excess of background more than 60% of the time will be

1074 used to perform the surveys. The scan speed will be 5 cm per second, so the scan should take

1075 approximately one man-hour to complete. The scans will be performed using a 100 cm² active

1076 probe area alpha-beta gas-proportional detector.

1077 If while scanning, an area is perceived to exceed background, a one-minute direct measurement
1078 will be performed at that location to verify the scan results. If the results of the one-minute count
1079 exceed the critical value calculated in 7.4.6.5, the radioactivity at that location exceeds
1080 background. The results of all one-minute verification counts will be recorded on a log sheet.
1081 The location of any one-minute count that exceeds the critical value will be clearly marked.

1082 Quality control (QC) measurements will be performed prior to the start of the survey and at the
1083 completion of the survey. These QC measurements will demonstrate that the instruments were
1084 working properly while the survey was being performed. In addition, approximately 5% of the
1085 survey will be repeated using a different surveyor to confirm the results of the initial survey.

1086 7.4.5.10 Disposition Survey Design Documentation

1087 The interdiction survey design was documented in a letter report to the project manager. The
1088 results of the IA were also included in this letter report.

1089 **7.4.6 Implementation of Disposition Surveys**

1090 7.4.6.1 Ensure Protection of Health and Safety

1091 Protection of health and safety was performed as part of the survey implementation, but is not
1092 included in this case study (see Section 7.3.6.1 for an example Job Safety Analysis.)

1093 7.4.6.2 Consider Issues for Handling M&E

1094 Since only a portion of the front loader needs to be accessed to implement the survey design, the
1095 front loader does not need to be moved to provide access to additional areas during the survey
1096 (e.g., bottom of tires, underside of bucket). Areas included in the survey do not need to be
1097 marked, outside of the small area that will be re-surveyed as part of the QC checks and locations
1098 of direct measurements exceeding the critical value. The front loader will not be parked adjacent
1099 to areas known to contain radionuclide concentrations or radioactivity in excess of background
1100 (e.g., piles of concrete rubble) while the survey is performed.

1101 7.4.6.3 Segregate the M&E

1102 No segregation of the front loader is required to implement the survey design.

1103 7.4.6.4 Measurement Detection Capability

1104 Section 7.4.4.7 established the MQO for the measurement detection capability. The scan MDC
1105 must be less than or equal to the discrimination limit.

1106 7.4.6.5 Calculation of the Critical Value and the MDC

1107 Both Type I and Type II errors are equally undesirable in the direct measurements made during a
1108 scan. The consequence of incorrectly alleging that the front loader is contaminated (Type I
1109 error) may raise unnecessary regulatory concerns. On the other hand, accepting a front loader
1110 that has radioactivity detectable above facility background (Type II error) may make it difficult
1111 to clear when the work is finished. Thus it is desirable to initially set $\alpha = \beta = 0.01$. The critical
1112 value for one minute static counts may be calculated from the equation in line 1 of Table 5.1:

$$1113 \quad S_C = z_{1-\alpha} \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)} = 2.326 \sqrt{2 \times 250} = 2.326 \sqrt{500} = 52 \text{ net counts,}$$

1114 Where:

1115 S_C is the critical value

1116 N_B is the mean background count (250 counts)

1117 t_S is the count time for the test source (one minute)

1118 t_B is the count time for the background (one minute)

1119 $z_{1-\alpha}$ is the $(1 - \alpha)$ -quantile of the standard normal distribution (2.326 when $\alpha = 0.01$).

1120 The minimum detectable net count can be calculated from the equation in line 1 of Table 5.2:

$$1121 \quad S_D = S_C + \frac{z_{1-\beta}^2}{2} + z_{1-\beta} \sqrt{\frac{z_{1-\beta}^2}{4} + S_C + N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}$$

$$= 52 + \frac{2.326^2}{2} + 2.326 \sqrt{\frac{2.326^2}{4} + 52 + 250(2)} = 109 \text{ net counts,}$$

1122 Where:

1123 $z_{1-\beta}$ is the $(1 - \beta)$ -quantile of the standard normal distribution (2.326 when $\beta=0.01$)

1124 S_D is the minimum detectable value of the net instrument signal (discrimination limit, 7 cpm)

1125 The direct measurement MDC can be calculated from equation 4-1 in NUREG 1761 (NRC
1126 2002):

$$1127 \text{ MDC} = \frac{\text{detection limit}}{\text{total efficiency} \times \text{sample size}} = \frac{S_D}{\varepsilon_i \varepsilon_s \times \frac{\text{Probe Area}}{100}} = \frac{(109)}{(1.29) \times \frac{100}{100}} = \frac{109}{1.29} = 84.5 \text{ dpm/100 cm}^2$$

1128 of natural thorium.

1129 7.4.6.6 Uncertainty of the Direct Measurement MDC

$$1130 \text{ MDC} = \frac{S_D}{(\varepsilon_i \varepsilon_s) \times \frac{\text{Probe Area}}{100}}$$

1131 Assuming a negligible uncertainty in the probe area, the combined standard uncertainty of the
1132 MDC is (see equation G-14):

$$1133 u_c^2(\text{MDC}) = \left(\frac{\partial \text{MDC}}{\partial S_D} \right)^2 u^2(S_D) + \left(\frac{\partial \text{MDC}}{\partial \varepsilon_i \varepsilon_s} \right)^2 u^2(\varepsilon_i \varepsilon_s).$$

1134 Note that $\varepsilon_i \varepsilon_s$ is treated as a single input variable because it is the weighted total alpha-beta
1135 efficiency for natural thorium in equilibrium with its progeny on the surveyed media.

1136 Because the MDC is of the form of a ratio of products, Equation G-15 may be used:

$$1137 u_c^2(\text{MDC}) = \text{MDC}^2 \left(\frac{u^2(S_D)}{S_D^2} + \frac{u^2(\varepsilon_i \varepsilon_s)}{\varepsilon_i^2 \varepsilon_s^2} \right).$$

$$\begin{aligned}
S_D &= S_C + \frac{z_{1-\beta}^2}{2} + z_{1-\beta} \sqrt{\frac{z_{1-\beta}^2}{4} + S_C + N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)} \\
&= S_C + \frac{2.326^2}{2} + 2.326 \sqrt{\frac{2.326^2}{4} + S_C + N_B (2)} \\
1138 \quad &= z_{1-\alpha} \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right) + \frac{2.326^2}{2} + 2.326 \sqrt{\frac{2.326^2}{4} + \left(z_{1-\alpha} \sqrt{N_B \frac{t_S}{t_B} \left(1 + \frac{t_S}{t_B}\right)}\right) + 2N_B} \\
&= 2.326 \sqrt{N_B (2)} + \frac{2.326^2}{2} + 2.326 \sqrt{\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B}
\end{aligned}$$

1139 Where the formula for S_C and the values of the constants have been inserted. The uncertainty in
 1140 the time is assumed negligible, so these have also been treated as constants. Thus, the
 1141 uncertainty in S_D will be due entirely to the uncertainty in the background count:

$$1142 \quad u^2(S_D) = \left(\frac{\partial S_D}{\partial N_B}\right)^2 u^2(N_B)$$

1143 The sensitivity coefficient for S_D at $N_B = 250$ is

$$\begin{aligned}
\left(\frac{\partial S_D}{\partial N_B}\right) &= \left(\frac{\partial \left(2.326 \sqrt{N_B (2)} + \frac{2.326^2}{2} + 2.326 \sqrt{\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B} \right)}{\partial N_B} \right) \\
1144 \quad &= \left(\frac{\partial \left(2.326 \sqrt{N_B (2)} \right)}{\partial N_B} \right) + \frac{\partial \left(\frac{2.326^2}{2} \right)}{\partial N_B} + \frac{\partial \left(2.326 \sqrt{\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B} \right)}{\partial N_B} \\
&= \left(\frac{(2.326 \sqrt{2})}{2 \sqrt{N_B}} \right) + 0 + 2.326 \left[\frac{\partial \left(\sqrt{\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B} \right)}{\partial \left(\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B \right)} \right] \left[\frac{\partial \left(\frac{2.326^2}{4} + \left(2.326 \sqrt{N_B (2)}\right) + 2N_B \right)}{\partial N_B} \right]
\end{aligned}$$

1145

$$\begin{aligned}
&= \left(\frac{1.6447}{\sqrt{N_B}} \right) + 2.326 \left[\frac{\partial \left(\sqrt{0.5815 + 3.289\sqrt{N_B} + 2N_B} \right)}{\partial \left(0.5815 + 3.289\sqrt{N_B} + 2N_B \right)} \right] \left[\frac{\partial \left(0.5815 + 3.289\sqrt{N_B} + 2N_B \right)}{\partial N_B} \right] \\
1146 \quad &= \frac{1.6447}{\sqrt{N_B}} + \frac{1.163 \left(\frac{1.6447}{\sqrt{N_B}} + 2 \right)}{\sqrt{\left(0.5815 + 3.289\sqrt{N_B} + 2N_B \right)}} \\
&= 0.104 + \frac{2.447}{23.5} = 0.208
\end{aligned}$$

1147 Suppose the spatial variability in N_B can be described by a triangular distribution with mean 250
 1148 with a half-width of 50, then,

$$1149 \quad u(N_B) = 50 / \sqrt{6} = 20.4.$$

$$1150 \quad \text{Then } u(S_D) = \left(\frac{\partial S_D}{\partial N_B} \right) u(N_B) = (0.208)(20.4) = 4.2.$$

1151 A complete analysis of the uncertainty in, $\varepsilon_i \varepsilon_s$, the weighted total alpha-beta efficiency for
 1152 natural thorium in equilibrium with its progeny on the surveyed media would involve a
 1153 propagation of uncertainty through all if the input quantities in Table 7.11. A simpler estimate
 1154 may be made by assuming that if all instrument efficiencies could be in error by as much as 10%
 1155 and all the surface efficiencies could be in error by as much as 30%, both in the same direction,
 1156 then the uncertainty in $\varepsilon_i \varepsilon_s$ might be roughly estimated with a triangular distribution with a half-
 1157 width of 0.5. A triangular distribution is used because values near the mean are considered to be
 1158 more likely than those at the extremes. Then, $u(\varepsilon_i \varepsilon_s) = 0.5 / \sqrt{6} = 0.20$.

1159 Putting this information together into the equation for the combined total variance of the MDC,
 1160 given earlier in this section, we have:

$$\begin{aligned}
 u_c^2(\text{MDC}) &= \text{MDC}^2 \left(\frac{u^2(S_D)}{S_D^2} + \frac{u^2(\varepsilon_i \varepsilon_s)}{\varepsilon_i^2 \varepsilon_s^2} \right) \\
 1161 \quad &= 84.5^2 \left(\frac{4.2^2}{109^2} + \frac{0.20^2}{1.29^2} \right) \\
 &= 7,140(0.000148 + .024) \\
 &= 172.4
 \end{aligned}$$

1162 So the estimated combined standard uncertainty in the MDC is $u_c(\text{MDC}) = 13.1$.

1163 7.4.6.7 Quality Control

1164 The required QC measurements are performed as described in the survey design.

1165 7.4.6.8 Survey Data

1166 Data from the survey of the front loader is collected consistent with the survey design and
 1167 provides a complete record of the data collected. Thirty-seven locations were flagged during the
 1168 survey for investigations using direct measurements. None of the direct measurement results
 1169 exceeded the critical value.

1170 **7.4.7 Assess the Results of the Disposition Survey**

1171 7.4.7.1 Data Quality Assessment

1172 The surveying procedure utilized for the front loader was verified as having been executed very
 1173 closely to the survey design, with the appropriate survey coverage. The results of the QC
 1174 measurements demonstrated that the instruments were working properly and a different surveyor
 1175 could duplicate the results of the survey. Control charts used to check the performance of the
 1176 survey instruments did not identify any potential problems with the instruments.

1177 7.4.7.2 Preliminary Data Review

1178 The preliminary data review for this baseline survey does not yield identifying patterns,
 1179 relationships, or potential anomalies. The locations of the additional investigations appear to be
 1180 randomly located based on visual inspection of the front loader.

1181 7.4.7.3 Statistical Tests

1182 The statistical test selected for this in situ survey is direct comparison to the critical level. If all
1183 the results are below the critical level associated with the discrimination limit, there is no
1184 detectable radioactivity above background. All of the scanning results that exceeded the critical
1185 value were subjected to additional investigation. All of the results of the additional
1186 investigations were below the critical value.

1187 **7.4.8 The Decision**

1188 Based on the results of the baseline survey, the front loader is determined to have no detectable
1189 radioactivity above background and is therefore allowed to enter the site.

1190 **7.5 Mineral Processing Facility Rented Equipment Disposition Survey**

1191 **7.5.1 Description**

1192 The radiological surveys at the mineral processing facility described in Section 7.3 have been
1193 completed. The front loader that was brought on site to assist with handling the concrete rubble
1194 (see Section 7.4) is no longer being used. The front loader must be cleared before it can be
1195 returned to the rental company.

1196 **7.5.2 Objectives**

1197 The objective is to demonstrate the front loader can be cleared. The scope of this case study is
1198 limited to the rented front loader used for the on-site transport of impacted concrete rubble.

1199 An interdiction survey was performed to demonstrate there was no detectable radioactivity
1200 associated with the front loader when it entered the site. This case study provides a comparison
1201 between interdiction and clearance surveys performed on the same piece of equipment.

1202 **7.5.3 Initial Assessment of the M&E**

1203 7.5.3.1 Categorize the M&E

1204 The existing information is adequate to categorize the front loader. The front loader was used to
1205 transport concrete rubble containing radionuclides with concentrations exceeding background.
1206 The front loader is impacted. Following use, the front loader was steam cleaned to remove loose
1207 dirt and grease (together with any associated radioactivity) for acceptance by the rental company.

1208 7.5.3.2 Design and Implement Preliminary Surveys

1209 The description of the physical attributes associated with the front loader has not changed (see
1210 Table 7.7). The uranium series and thorium series radionuclides listed in Table 7.2 are the
1211 radionuclides of potential concern for the front loader. The existing information is adequate to
1212 select a disposition option, and there are no data gaps.

1213 7.5.3.3 Select a Disposition Option

1214 The preferred disposition option for the front loader is clearance. The existing interdiction
1215 survey design used to allow the front loader access to the site will be evaluated for applicability
1216 as a clearance survey (see Section 7.5.4.2).

1217 7.5.3.4 Document the Results of the Initial Assessment

1218 The decision to categorize the front loader as impacted will be documented with the results of the
1219 survey. The planning team determined that no other documentation is necessary.

1220 7.5.4 Inputs to the Decision

1221 7.5.4.1 Action Levels

1222 The action level selected for the interdiction survey was no detectable surface radioactivity
1223 above background. The action levels in this case are the limits shown in Table 7.10. The limiting
1224 value is 1000 dpm/100 cm² for natural thorium.

1225 7.5.4.2 Evaluate an Existing Survey Design

1226 Since the same front loader is being surveyed, the measurement methods are still adequate. The
1227 scan MDC of 132 dpm/100 cm² for natural thorium is well below the action level. There were no
1228 problems identified during the interdiction survey that would prevent using the measurement
1229 methods for a clearance survey. The population parameter of interest and the survey unit
1230 boundaries are linked to the measurement method (see Sections 7.4.4.3 and 7.4.4.6).

1231 The alternative actions are different for the clearance survey. If the front loader is cleared, it will
1232 be returned to the rental company. If the front loader is not cleared, it will remain on site. This
1233 results in a change to the decision rule. If the results of any measurement identify surface
1234 radioactivity in excess of background, the front loader will remain on site and radiological
1235 controls will remain in place. If no surface radioactivity in excess of 1,000 dpm/100 cm² over
1236 background is detected, the front loader will be cleared and returned to the rental company.

1237 **7.5.5 Survey Design**

1238 7.5.5.1 Select the Null Hypothesis

1239 The hypotheses being tested are:

1240 *Null Hypothesis:* The front loader contains detectable radionuclide concentrations or
1241 radioactivity in excess of 1,000 dpm/100 cm² above background levels

1242 *Alternative Hypothesis:* The front loader contains radionuclide concentrations or radioactivity
1243 less than 1,000 dpm/100 cm² above background levels.

1244 Since the action level is not zero, Scenario A is being used.

1245 7.5.5.2 Set the Discrimination Limit

1246 The discrimination limit is the radionuclide concentration or level of radioactivity that can be
1247 reliably distinguished from the action level by performing measurements. Under Scenario A, the
1248 discrimination limit should represent a prudently conservative estimate of any amount of natural
1249 thorium that may be present on the front loader in excess of background.

1250 7.5.5.3 Specify Limits on Decision Errors

1251 A Type I decision error occurs when the null hypothesis is rejected when it is true. For this
1252 survey, a Type I decision error would be clearing the front loader when there is radioactivity
1253 detectable more than 1,000 dpm/100 cm² above background. The consequences of a Type I
1254 decision error may include releasing radionuclides from the site and increased exposures to
1255 members of the public.

1256 A Type II decision error occurs when the null hypothesis is not rejected when it is false. For this
1257 survey, a Type II decision error would be refusing to clear the front loader even though the
1258 radioactivity present exceeds background by less than 1,000 dpm/100 cm². The consequences of
1259 this decision error may include unnecessarily remediating the front loader, incurring additional
1260 costs for extra rental time, or even purchasing the front loader and disposing of it as low-level
1261 radioactive waste.

1262 The existing survey design minimizes the potential for Type II decision errors by performing
1263 additional direct measurements when scanning results are perceived to exceed background and
1264 also by having experienced technicians perform the survey.

1265 7.5.5.4 Classify the M&E

1266 The potential for radioactivity exceeding background has increased since the front loader is
1267 known to have contacted concrete rubble containing radionuclides at concentrations that exceed
1268 background. This increased potential for radioactivity exceeding background results in a higher
1269 classification for portions of the front loader for the clearance survey. The inside of the bucket is
1270 now classified as Class 1. The remaining external surfaces are considered Class 3 so
1271 professional judgment can still be used to determine where surveys will be performed.

1272 7.5.5.5 Optimize the Existing Survey Design

1273 The front loader will be scanned with an alpha-beta gas proportional detector. Experienced
1274 technicians will perform the surveys. If while scanning, an area is perceived to exceed
1275 background, a one-minute direct measurement will be performed at that location to verify the
1276 scan results. If the results of the one-minute count exceed $1,000 \text{ dpm}/100 \text{ cm}^2$ above background
1277 the front loader will require further remediation before it can be released. The results of all one-
1278 minute verification counts will be recorded on a log sheet. The location of any one-minute count
1279 that exceeds the critical value will be clearly marked.

1280 Based on the classification of the inside of the bucket as Class 1, 100% of the inside of the
1281 bucket will be surveyed. In addition, 25% of the outside surface of the bucket will be surveyed,
1282 concentrating on the bottom where the bucket frequently came in contact with the concrete
1283 rubble. Similar to the interdiction survey, 50% of the tires and the floor of the cab will be
1284 surveyed. In addition, 10% of the bottom and 5% the top (i.e., horizontal surfaces) will be
1285 included in the clearance survey. Areas to be scanned will be biased to locations where residual
1286 dirt or grease is visible. The increased surface area to be scanned is expected to increase the scan
1287 time to approximately three man-hours. Based on professional judgment, four times as many
1288 investigations are expected for the clearance survey, or approximately 150 one-minute direct
1289 measurements. The additional investigations are expected to require an additional three man-
1290 hours.

1291 Implementation of this survey design will likely identify locations with radioactivity levels
1292 exceeding 1,000 dpm/100 cm² above background. To minimize these occurrences, the front
1293 loader will be steam cleaned and dried prior to implementing the survey design. Locations on
1294 the bucket (which is a Class 1 survey unit) where the additional direct measurement exceeds the
1295 action level will be delineated using scanning techniques, scrubbed clean to remove any surface
1296 radioactivity, and re-surveyed (i.e., clean-as-you-go).

1297 7.5.5.6 Disposition Survey Design Documentation

1298 The modified survey design was documented in a letter report to the project manager. The letter
1299 report included the results of the categorization decision (see Section 7.5.3.1).

1300 **7.5.6 Implementation of Disposition Surveys**

1301 The front loader was positioned on a concrete pad during steam cleaning operations. The water
1302 was collected and containerized for survey prior to release. The bucket was lifted off the ground
1303 and supported with wooden beams to provide access to the bottom of the bucket.

1304 The survey was implemented as described in the survey design. The beta background in the area
1305 underneath the bucket was higher than expected (i.e., 350 cpm instead of the 250 cpm used to
1306 design the survey). The bucket was lifted higher off the ground (i.e., 1.5 meters instead of 15 cm)
1307 and the scan survey was repeated with a lower background.

1308 The survey results were documented in a letter report to the project manager.

1309 **7.5.7 Assess the Results of the Disposition Survey**

1310 7.5.7.1 Data Quality Assessment

1311 The surveying procedure utilized for the front loader was verified as having been executed very
1312 closely to the survey design. The surveys included the appropriate scan coverage and number of
1313 additional investigations. The preliminary data review for this baseline survey does not yield
1314 identifying patterns, relationships, or potential anomalies. Control charts documenting the
1315 results of quantitative QC checks and performance checks indicate the DQOs have been
1316 achieved for this clearance survey.

1317 7.5.7.2 Statistical Tests

1318 The statistical test selected for this in situ survey is direct comparison to the action level of 1,000
1319 dpm/100 cm² above background. If all of the measurement results are below the action level, the
1320 average natural thorium above background cannot exceed 1,000 dpm/100 cm² above
1321 background.

1322 At 83 locations the scan MDC of 132 dpm/100 cm² above background appeared to be exceeded.
1323 However, none of the one-minute follow up counts at those locations exceeded 500 dpm/100 cm²
1324 above background.

1325 **7.5.8 The Decision**

1326 Based on the results of the disposition survey, the front loader is determined to have no
1327 radioactivity above the action level and so can be cleared.