MARSSIM Overview II

MARSSIM Technical Seminar Series

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Lecture Topics

- DCGLs for Multiple Radionuclides
- MARSSIM Final Status Survey Instruments
- MDC Concepts
- Statistics…just enough to whet your appetite

Key Steps of FSS Design (by P. Frame)

1) Classify site areas; identify survey units and reference areas
2) Determine the DCGLs
3) Determine whether Scenario A or B will be used; specify statistical tests for survey design (Sign test or WRS test)
4) Determine whether unity rule will be used for multiple radionuclides (also gross DCGLs for surface activity)
5) Choose equipment and measurement protocols
6) Determine scan and measurement MDCs
7) Determine survey investigation levels
8) Set acceptable probability of Type I and II errors
9) Determine number of statistical samples
10) Create reference grid and sample locations

Application of DCGLs for Multiple Radionuclides

Introduction

- Pathway Scenarios
- DCGLs
- Application of DCGLs
  - Unity Rule (for soil)
  - Gross Activity DCGLs (for building surfaces)
  - Use of Surrogate Measurements (for soil)

Decommissioning Criteria

- Regulatory Agencies Establish Radiation Dose Standards for Release
  - For example, 25 mrem/y to average member of "critical group" – i.e. group of individuals reasonably expected to receive greatest exposure

Pathway Scenarios

- Various pathways and scenarios are used to translate dose standard to residual radioactivity levels (measurable quantities)
  - Residential scenario
  - Building occupancy scenario
  - Building renovation scenario
  - Drinking water scenario
  - Reference: NUREG/CR-5512, vol. 1

Derived Concentration Guideline Levels (DCGLs)

- DCGLs refer to average levels of residual radioactivity above background levels
- Provided for surface activity (dpm/100 cm^2) and soil contamination (pCi/g)
- DCGLs will be obtained from regulatory guidance based on default parameters (Appendix C of NUREG-1727); or from site-specific pathway modeling (using RESRAD or DandD codes)

DCGLs (cont.)

- DCGLs are provided for uniform contamination and for hot spots
  - $DCGL_W$ is the uniform residual radioactivity concentration level that corresponds to release criterion
  - $DCGL_{EMC}$ is the concentration level for a specific areal size that corresponds to the release criterion; value becomes larger as areal size is reduced

DCGLs (cont.)

- The $DCGL_{EMC}$ is determined by
  - $DCGL_{EMC} = (DCGL_W)*(\text{Area Factor})$
- The area factor represents the magnitude that the concentration in a specified area can exceed $DCGL_W$, while maintaining compliance with release criterion
- MARSSIM Tables 5.6 and 5.7 provide illustrative examples of area factors; RESRAD can be used to generate area factors

Application of DCGLs

- Prerequisites for application of DCGLs
  - Identity of site contaminants
  - Relative ratios among the contaminants, for multiple contaminants
  - Isotopic ratios and state of equilibrium for decay chains (U, Th)
- Generally requires alpha and gamma spectroscopy of representative samples

Application of DCGLs (cont.)

- Multiple Contaminants
  - Unity Rule (for soil)
  - Gross Activity DCGLs (for building surfaces)
  - Use of Surrogate Measurements (for soil)
- For some survey units, surrogates and the unity rule are used at the same time

Application of DCGLs (cont.)

- Gross activity DCGL (for surface activity)
  - Assumes that contaminant ratios are known and consistent (justify with HSA and characterization data)

$$Gross\ Activity\ DCGL = \frac{1}{f_1/DCGL_1 + f_2/DCGL_2 + \ldots + f_n/DCGL_n}$$

Application of DCGLs (cont.)

- Example: Gross activity DCGL for C-14 and Co-60 surface contamination
  - $DCGL_{C\text{-}14}$ = 180,000 dpm/100 cm^2 ; $DCGL_{Co\text{-}60}$ = 7,000 dpm/100 cm^2
  - Assume fixed contaminant ratio:

    25% C-14 and 75% Co-60

Application of DCGLs (cont.)

- Example: Gross activity DCGL (cont.)

$$Gross\ \ DCGL = \frac{1}{0.25/180{,}000 + 0.75/7{,}000} = 9{,}200\ dpm/100\ cm^2$$

  - Efficiency should be weighted consistent with contaminant mix (e.g. 0.25 $\varepsilon_{C\text{-}14}$ + 0.75 $\varepsilon_{Co\text{-}60}$)
  - Survey data compared (using nonparametric statistics) to gross activity DCGL

Application of DCGLs (cont.)

- Use of Surrogate Measurements
  - Possible to measure just one contaminant and infer the concentration of others; e.g., measuring Co-60 in soil to assess level of Ni-63
  - A sufficient number of measurements are needed to establish a consistent ratio (DQOs)
    - estimate ratio **conservatively** if variability large
    - remediation may change contaminant ratios

Application of DCGLs (cont.)

- Use of Surrogate Measurements (cont.)
  - Need to modify the DCGL of the measured radionuclide (Co-60) to account for the presence of the inferred radionuclide
  - Assume C_{Ni} / C_{Co} is "fixed" ratio, then

$$DCGL_{Mod,\,Co} = DCGL_{Co} * [\frac{DCGL_{Ni}}{((C_{Ni} / C_{Co}) * DCGL_{Co}) + DCGL_{Ni}}]$$

Application of DCGLs (cont.)

- Use of Surrogate Measurements (cont.)
  - Example: Survey unit contaminated with both Co-60 and Ni-63; Co-60 will be surrogate
  - $DCGL_{Co}$ = 18 pCi/g; $DCGL_{Ni}$ = 500 pCi/g
  - "Fixed" ratio of C_{Ni} / C_{Co} is 7
  - Modified DCGL for Co-60 is 14.4 pCi/g
  - This modified DCGL is used in statistical tests—both in planning and data reduction

MARSSIM FSS Instrumentation

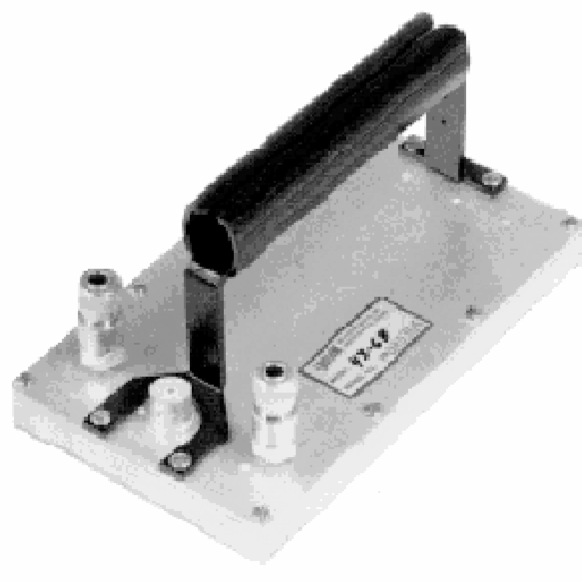
- Field survey instruments used to perform scanning in buildings and land areas, and to make surface activity measurements
- Laboratory instruments to determine radionuclide concentrations in soil – depending on radionuclides includes gamma spec, alpha spec and wet chemistry

Survey Instrumentation

- Field survey instruments described in MARSSIM Appendix H:
  - Gas proportional
    - Alpha-only (using voltage setting)
    - Beta-only (using Mylar thickness)
    - Alpha plus Beta
  - GM (measures primarily beta)
  - ZnS (alpha measurements)
  - Dual phosphor (alpha and beta, cross talk)

Gas Flow Proportional Counters

- Can distinguish alphas and bet
- P-10 gas needed
- connected or disconnected
- large windows
- very thin window
- problems with gas

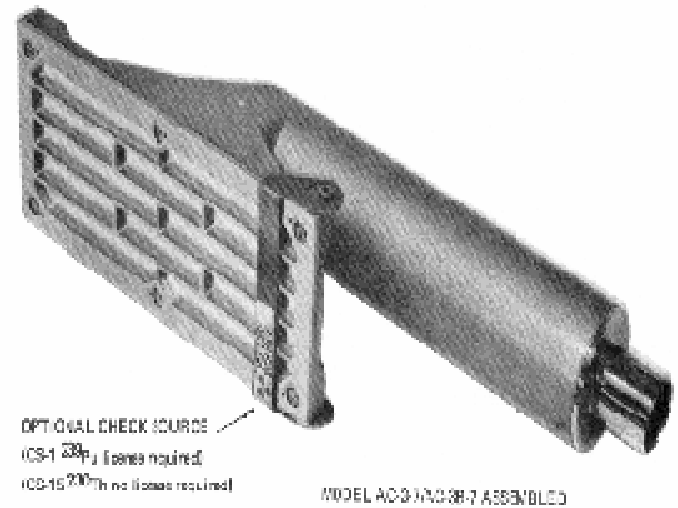


Combined Alpha –Beta Scintillators

- can distinguish alphas and betas
- no gas supply required
- large window areas
- beta efficiency can be relatively poor
- light leaks

Alpha Scintillators - ZnS

- only responds to alphas
- no gas supply
- large window areas
- light leaks

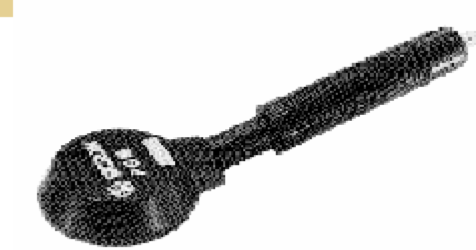


Windowless Gas Flow Proportional Counter

- for H-3
- needs continuous source of gas
- fixed measurements not scans
- flat surfaces
- interference from dust and static charges—very “finicky”

Pancake GM

- responds to alphas, betas and gammas
- small window
- shielded versions available
- rugged



Selection of Instrumentation

- Selection based on contaminants, their associated radiations, media surveyed and MDCs (sensitivity)
- MARSSIM Guidance: MDCs less than 10% of the $DCGL_W$ are preferable—while MDCs up to 50% of the $DCGL_W$ are acceptable (this does **not** apply to scan MDCs)

NaI Gamma Scintillators

- most sensitive gamma detector
- easily measures background
- cpm or µR/h
- limited size, heavy, fragile

Plastic Scintillators

- easily measures background (µR/h or µrem/h)
- lighter and more rugged than NaI
- energy independent

Low Energy Gamma Detectors

- thin (1 mm) NaI crystals
- primarily used for I-125
- light leaks

FIDLER

- large area thin NaI crystal
- primarily used for Am-241
- window settings critical
- heavy – more suited to fixed measurements than scanning

Minimum Detectable Concentration

- MDC is the smallest activity level that can be detected with specific confidence (usually 95%) for a given instrument and measurement procedure.
- MDCs should be less than 50% of DCGL (from MARSSIM)
- MDC concepts are derived from hypothesis testing:

H_0: No net activity is present in the sample

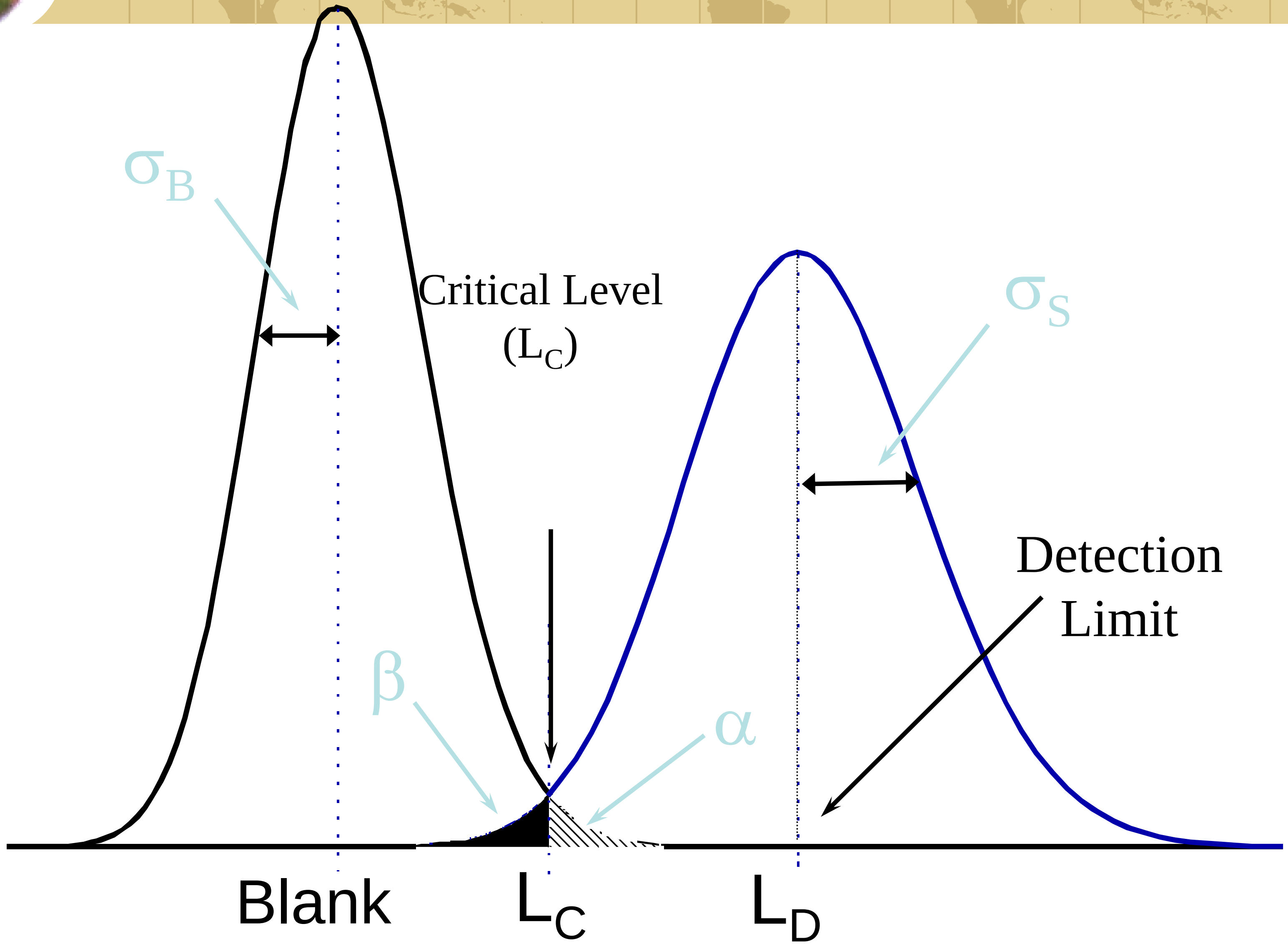
MDC Concepts

- Critical level (L_C): the net count at or above which a decision is made that activity is present in a sample

- A Type I error is made when the net count in a blank sample exceeds the L_C

MDC Concepts (cont.)

- Detection limit (L_D): the smallest number of net counts that will be detected with a probability (β) of non-detection (Type II error), while accepting a Type I error of incorrectly deciding that activity is present in a sample (false positive).



σB
Critical Level
(LC)
σS
Detection
Limit
β
α
Blank
LC
LD

STATIC MDC EXPRESSION

- For equal count times of background and sample

$$MDC = \frac{3 + 4.65\sqrt{C_B}}{KT} \qquad (in\ dpm/100\ cm^2)$$

where:

C_B = Background count in time T, and

K = Proportionality constant that embodies instrument efficiency, surface efficiency, and probe area corrections

STATIC MDC EXPRESSION (cont.)

- For cases when background and sample counted for different time intervals:

$$MDC = \frac{3 + 3.29\sqrt{R_B T_{S+B}(1 + T_{S+B}/T_B)}}{K T_{S+B}}$$

- where:

R_B	=	Background counting rate
T_{S+B}	=	Sample count time
T_B	=	Background count time

SCAN MDCs

- Considered human factors involved with scanning
- Signal detection theory - Did signal arise from “Background Alone” or “Background Plus Source”?
- Evaluated scan sensitivity for ideal observer through computer simulation tests, and performed field tests to evaluate model

HUMAN FACTORS DURING SCANNING

- Bias toward "false alarms" where surveyor expects contamination–bias toward "misses" when not expected (Class 1 vs. Class 3)
- During extended periods of scanning
  - Vigilance decrement - less likely to find contamination if it does exist
  - Probe is usually moved more quickly
- Reference: NUREG/CR-6364

HUMAN FACTORS DURING SCANNING (cont.)

- Surveyor influenced by relative costs of "misses" and "false alarms"
- Two stages of scanning:
  - continuous monitoring - brief "look" at potential sources
  - stationary sampling (holding probe stationary)
- Cost of deciding a signal is present:
  - For continuous monitoring, time holding probe at location
  - For stationary sampling, cost is taking direct measurements or soil samples

Ideal Poisson Observer

- Makes decision on presence/absence of contamination based on number of counts in an interval, i - based on scan rate
- Not subject to human factors, makes optimal use of available information
- Provides theoretical upper bound on scan MDC

ESTIMATION OF SCAN MDC

- The minimum detectable count rate (MDCR) in the observation interval is determined:

$$MDCR = \frac{d'\sqrt{b_i}}{i\sqrt{p}}$$

- where:

  b_i = Background counts in observation interval

  d′ = Detectability index, based on acceptable correct detection rate and false positives

  p = Surveyor efficiency relative to ideal observer (based on experimentation)

Statistics

- Two broad categories of statistics
  - Descriptive statistics
  - Inferential statistics

Descriptive Statistics

- Data Collection
- Summarizing Data
- Interpreting Data
- Drawing Conclusions from Data

Inferential Statistics

- Sampling Distributions
- Central Limit Theorem
- Confidence Interval Testing
- Hypothesis Testing

Big picture

Use a random sample to learn something about a larger population.

Random Sample
(Unofficial Definition)

- Every unit in the population has an equal probability of being included in the sample

Gold Nugget #1

- A random sample should represent the population well, so sample statistics from a random sample should provide reasonable estimates of population parameters

Gold Nugget #2

- All sample statistics have some error in estimating population parameters

Gold Nugget #3

- If repeated samples are taken from a population and the same statistic (e.g. mean) is calculated from each sample, the statistics will vary, that is, they will have a distribution

Gold Nugget #4

- A larger sample provides more information than a smaller sample so a statistic from a large sample should have less error than a statistic from a small sample

4 Gold Nuggets

- Random sampling is necessary
- Statistics have error
- Statistics have distributions
- Larger sample size (n) is better - less error

Sampling Distributions

- Different samples produce different results
- Value of a statistic, like mean or proportion, depends on the particular sample obtained
- Some values may be more likely than others
- The probability distribution of a statistic ("**sampling distribution**") indicates the likelihood of getting certain values

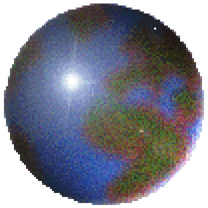
Mean and Standard Deviation of $\overline{X}$

mean = $\mu_{\overline{x}} = \mu$

and

standard deviation = $\sigma_{\overline{x}} = \dfrac{\sigma}{\sqrt{n}}$

Distribution of $\overline{X}$ *when sampling from a normal distribution*



has a <u>normal distribution</u> with

mean = $\overline{X}$

and $\mu_{\overline{x}} = \mu$

standard deviation =

$$\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{n}}$$

Central Limit Theorem

If the sample size (n) is large enough, $\overline{X}$ has a normal distribution with

mean = $\mu_{\bar{x}} = \mu$

and

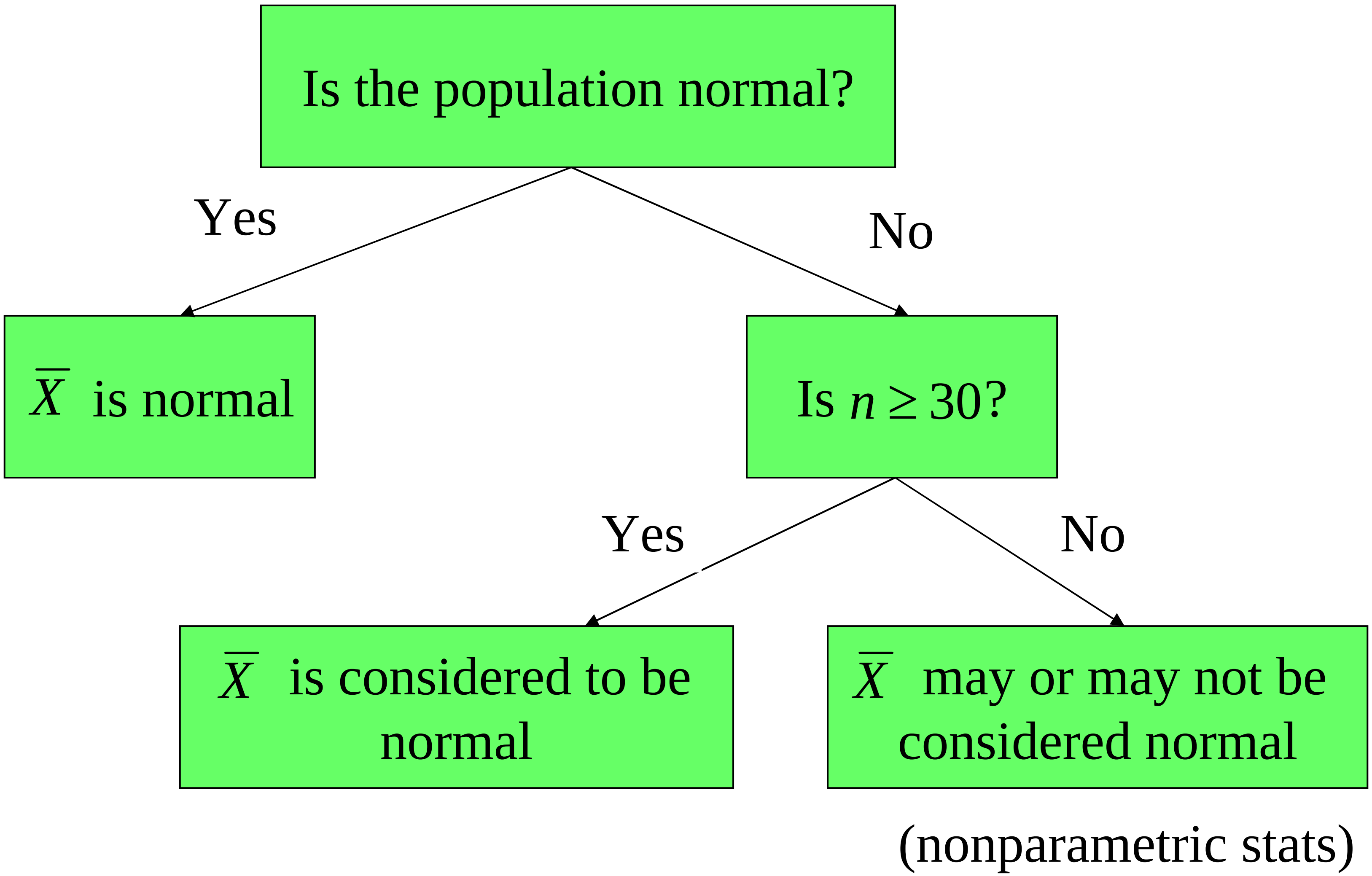
standard deviation = $\sigma_{\bar{x}} = \dfrac{\sigma}{\sqrt{n}}$

regardless of the population distribution

What is Large Enough?

$$n \geq 30$$

Does $\bar{X}$ have a normal distribution?



Two ways to learn about a population

- Confidence intervals
- Hypothesis testing

Confidence Intervals

- Allow us to use sample data to **estimate** a population value, like the true mean or the true proportion.

- *Example:* What is the mean surface activity level in the Class 2 survey unit?

Confidence Interval Testing

- A range of reasonable guesses at a population value, a mean for instance
- Confidence level = chance that range of guesses captures the the population value
- Most common confidence level is 95%

As long as you have a "large" sample….

A confidence interval for a population mean is:

$$\bar{x} \pm Z\left(\frac{s}{\sqrt{n}}\right)$$

where the average, standard deviation, and n depend on the sample, and Z depends on the confidence level.

Confidence Levels for a Normal Distribution

Interval	Confidence Level
$\mu \pm 0.674\ \sigma$	0.50
$\mu \pm 1.00\ \sigma$	0.68
$\mu \pm 1.65\ \sigma$	0.90
$\mu \pm 1.96\ \sigma$	0.95
$\mu \pm 2.58\ \sigma$	0.99
$\mu \pm 3.00\ \sigma$	0.997

Example

Random **sample** of 59 soil samples had an average of 273.20 pCi/g. Sample standard deviation was 94.40 pCi/g.

$$273.20 \pm 1.96\left(\frac{94.4}{\sqrt{59}}\right) = 273.20 \pm 24.09$$

We can be 95% confident that the average soil concentration in **all** soil samples was between 249.11 and 297.29 pCi/g.

What happens if you can only take a “small” sample?

- Random sample of **15 smears** had an average of 6.4 dpm alpha with standard deviation of 1 dpm alpha.
- What is the average alpha dpm from **all smears**?

*If you have a "**small**" **sample**...*

Replace the Z value with a **t value** to get:

$$\bar{x} \pm t\left(\frac{s}{\sqrt{n}}\right)$$

where "**t**" comes from **Student's t distribution**, and depends on the sample size through the **degrees of freedom "n-1". (Must assume normal distribution is being sampled)**

OK, back to our example!

Sample of **15 smears** had an average of 6.4 dpm alpha with standard deviation of 1 dpm alpha.

Need t with n-1 = 15-1 = 14 d.f.

For 95% confidence, $t_{14} = 2.145$

$$\bar{x} \pm t\left(\frac{s}{\sqrt{n}}\right) = 6.4 \pm 2.145\left(\frac{1}{\sqrt{15}}\right) = 6.4 \pm 0.55$$

That is...

We can be 95% confident that average dpm alpha on the smears is between 5.85 and 6.95

Remember: This assumes that the smear activity is normally distributed.

What happens to CI as sample gets larger?

$$\bar{x} \pm Z\left(\frac{s}{\sqrt{n}}\right)$$

$$\bar{x} \pm t\left(\frac{s}{\sqrt{n}}\right)$$

For large samples:

Z and t values become almost identical, so CIs are almost identical.

One not-so-small problem!

- It is only OK to use the t interval for small samples if your original measurements are normally distributed.
- We'll learn how to check for normality later in this presentation.

Strategy for deciding how to analyze

- If you have a large sample of, say, 60 or more measurements, then don't worry about normality, and use the t-interval.
- If you have a small sample and your data are normally distributed, then use the t-interval.
- If you have a small sample and your data are not normally distributed, then do not use the t-interval: **** Welcome to nonparametric statistics! ****

Hypothesis Testing

General Idea of Hypothesis Testing

- Used to make an assertion concerning one or more populations (e.g., residual radioactivity in survey unit > release level)
- Collect evidence (data) - random samples
- Based on the available evidence, decide whether or not the initial assumption (hypothesis) is reasonable