OAK RIDGE INSTITUTE
FOR SCIENCE AND EDUCATION

Shaping the Future of Science

Estimating Scan Minimum Detectable Activity for a Discrete Radioactive Particle

Nick Altic, CHP

Health Physicist

NRC DRP Public Workshop – November 3, 2022

Overview

- Background
- Method
  - Detector position
  - Detector efficiency as a function of position
  - Detector response as a function of position
  - Total integrated detector response
- Results
- MicroShield® Re-evaluation
- MCNP® vs MicroShield®
- Conclusions

Background

- Scan MDC plays an integral role in planning final status surveys
- NUREG 1507, *Minimum Detectable Concentrations with Typical Radiation Survey for Instruments for Various Contaminants and Field Conditions, Rev. 1* provides calculation techniques to estimate Scan MDCs for building surfaces and open land areas
- Calculation techniques presented in NUREG 1507 are for volumetric contamination

Background

- Traditional scan MDC calculation assumes detector efficiency is constant at all points across the assumed contamination volume
- The above assumption may be tolerable for volumetric contamination, but more of an issue for DRPs
- The above bullet highlights the motivation for this work; an alternate approach is needed

Method

Summary of calculation method:

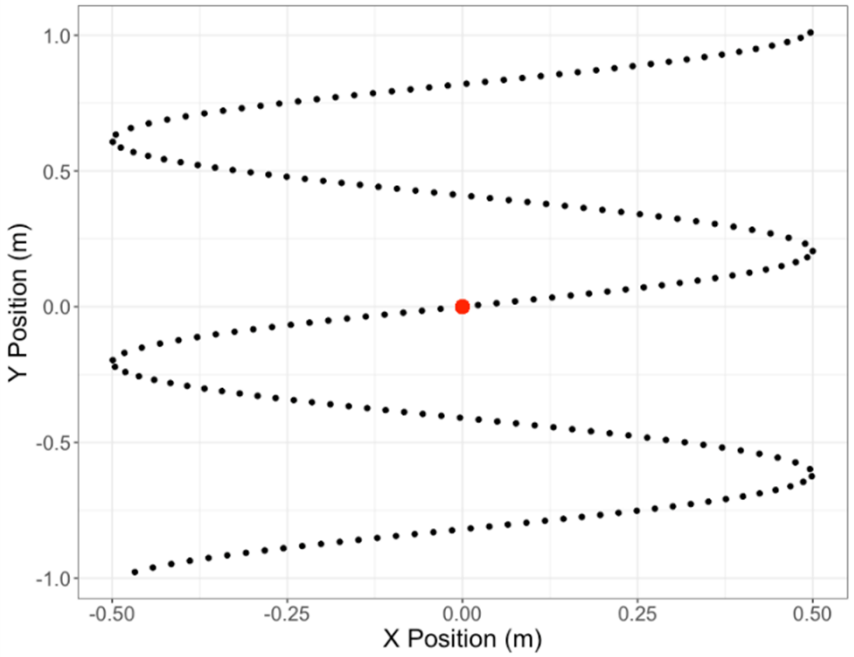
1. Estimate detector location along surveyor transect
2. Calculate detector efficiency at each detector location along surveyor transect
3. Calculate detector response at each detector location along surveyor transect
4. Integrate detector response over a period that corresponds to an audible ‘blip’ in instrument output
5. Calculate scan MDA

Method – cont.

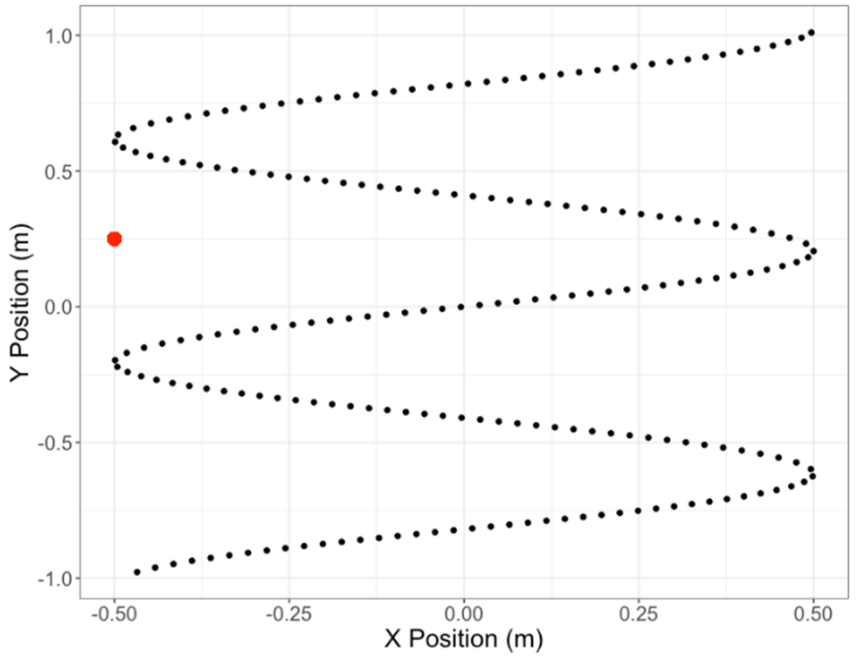
- Conditions evaluated:
  - Radionuclides: Co-60, Cs-137, Th-232, and Am-241
  - Surveyor speed: 0.25 m/s, 0.5 m/s, and 1.0 m/s
  - Ground-to-detector distance: 7.5 cm and 10 cm
  - DRP depth in soil: surface, 7.5 cm, and 15 cm.
    - Depths of 30 cm evaluated for Co-60 and Cs-137 at a ground-to-detector distance of 7.5 cm
  - DRP position: detector passes directly over DRP (optimistic scenario) and detector does not pass over DRP (pessimistic scenario)
    - Above is 'best-case' and 'worst-case' scenarios – actual scan MDA would follow some distribution depending on DRP location and depth

1. Detector Location

Optimistic

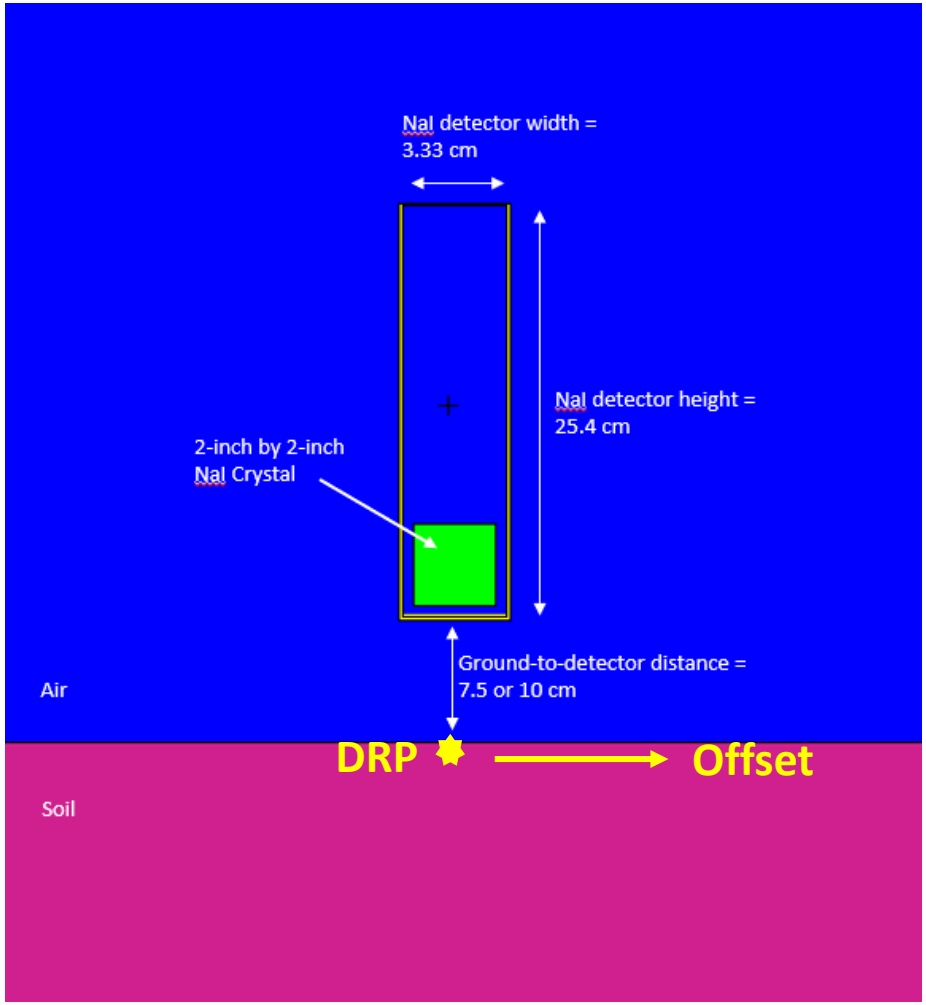


Pessimistic



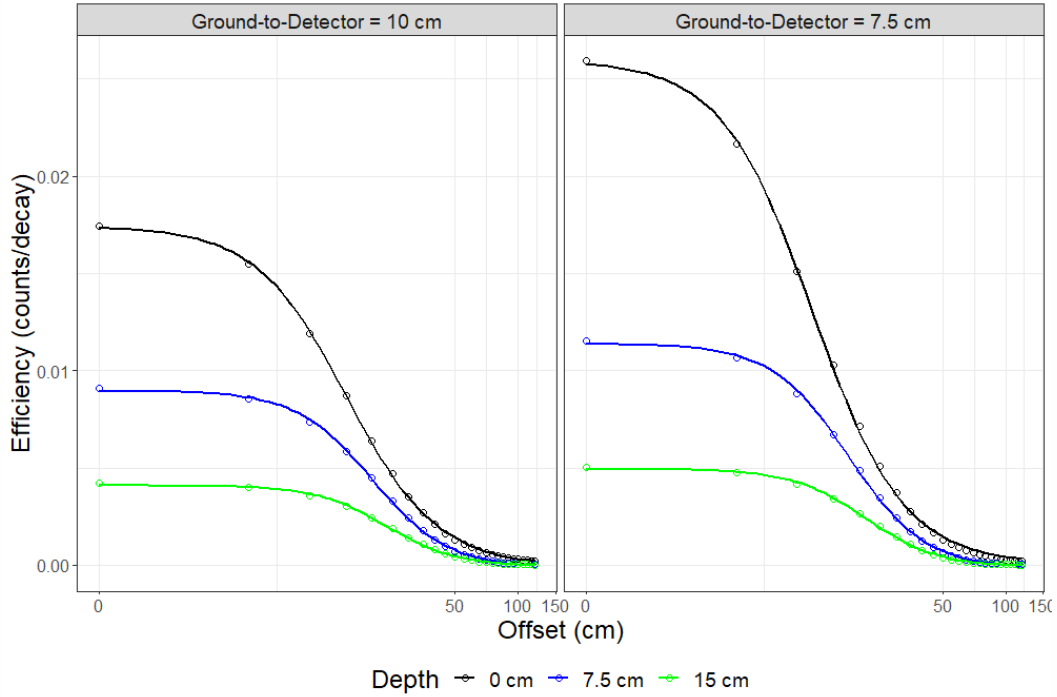
2. Detector Efficiency – MCNP Model

- MCNP® version 6.2 was used to model NaI detector response using F8 tally
- Multiple runs were completed where the DRP location is varied by an offset
  - 5 cm offset intervals from 0 cm to 110 cm
- Tally errors were generally less than 10%
  - In general, statistics were worse for problems with more attenuation
  - Am-241 results were only generated for a surface level DRP



2. Detector Efficiency

- MCNP® results were used to construct an efficiency curve (corrected for photon intensity)
- Efficiency data fitted to a loglogistic function use R



$$EFF(\delta) = c + \frac{(d-c)}{\left(1+exp\left(b\left(ln(\delta)-ln(e)\right)\right)\right)^{f}}$$

Where:

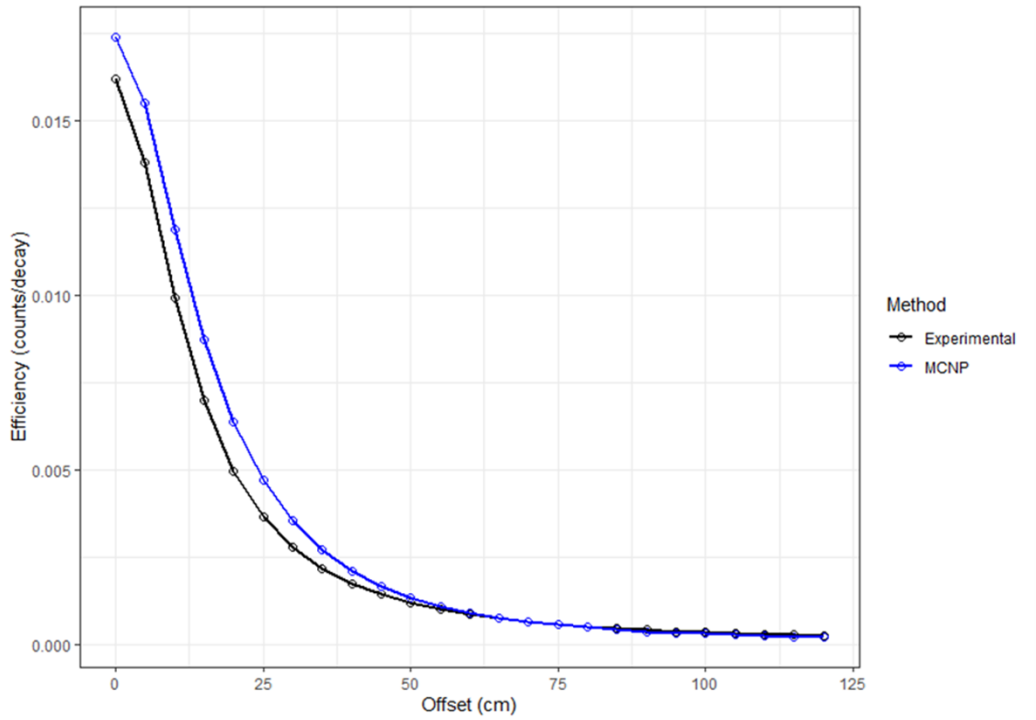
EFF(δ) = NaI detector response efficiency function (counts/decay), *δ* = lateral distance or offset from the detector to the DRP (cm), and *b, c, d, e, f* = coefficients for the log-logistic curve.

Aside - Workflow

- 600+ MCNP® runs were performed
- Preparation and extraction of MCNP® files can be tedious
- Employed Python to generate input decks based on a template input deck
- MCNP® utility MCTAL was used extract data
  - Python extensions were built from MCNP Tools library
- Additionally, Python extraction script evaluated relative tally error and statistical checks
  - Flagged input decks were written to a text file for additional evaluation/re-run

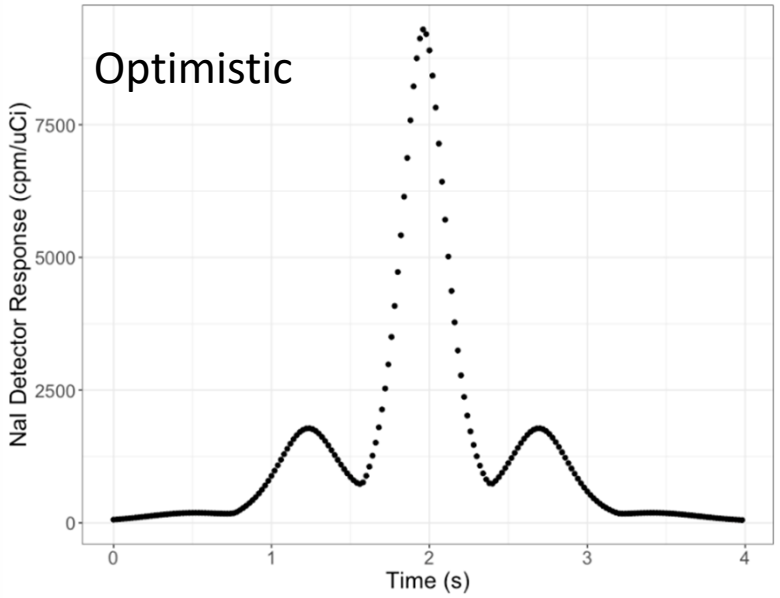
2a. Detector Efficiency - QC

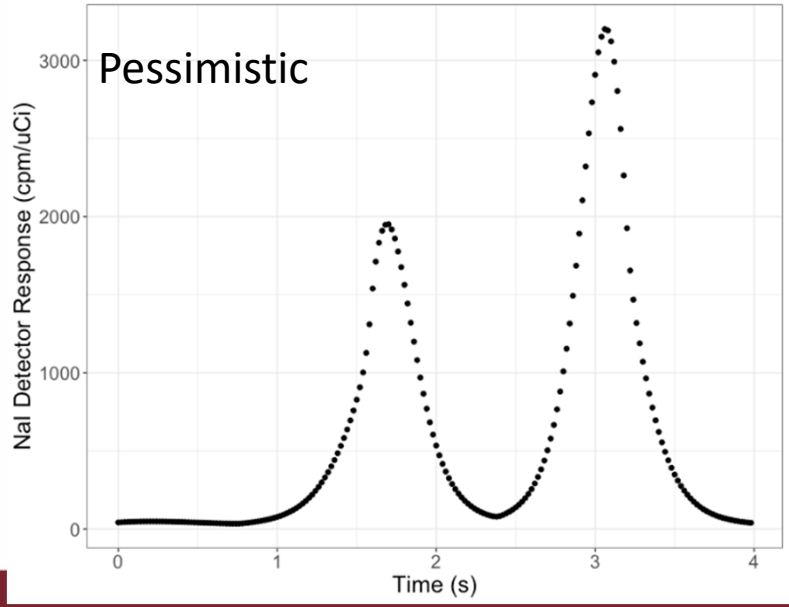
- Experimental measurements were collected with a 2-inch by 2-inch NaI detector
- Detector response to a Co-60 source was recorded at 5 cm offset intervals
- Efficiency was calculated based on source activity
- Resulting experimental and MCNP® efficiency curves have same shape
- Some limitations with the experimental data set



3. Detector Response

- Once the efficiency curve is established the detector response to the DRP can be calculated at each point on the sine curve



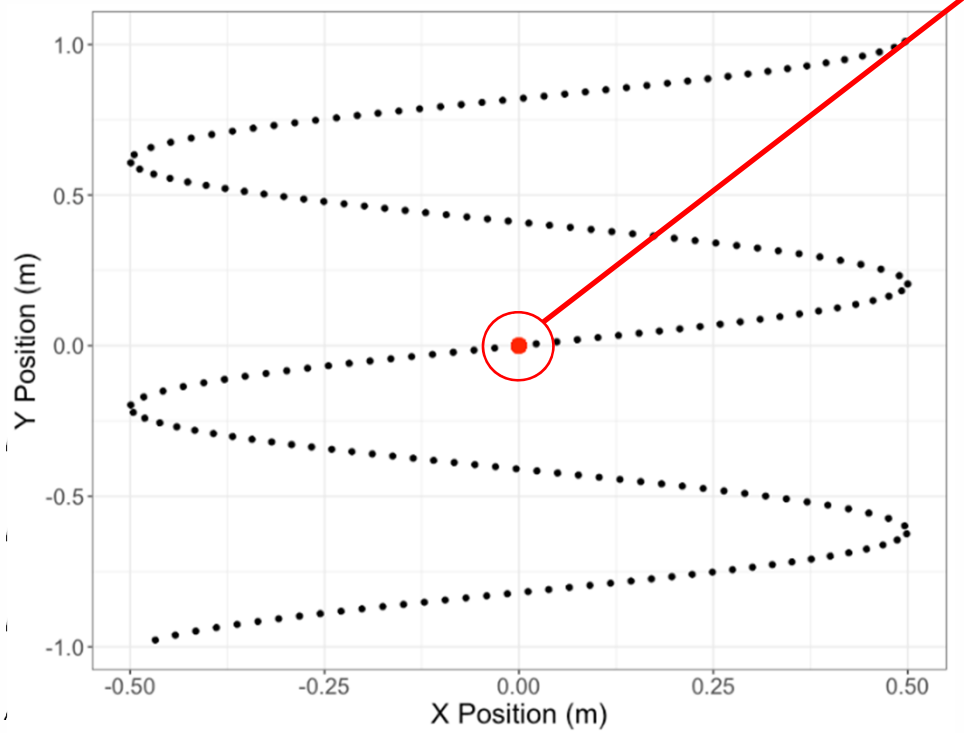


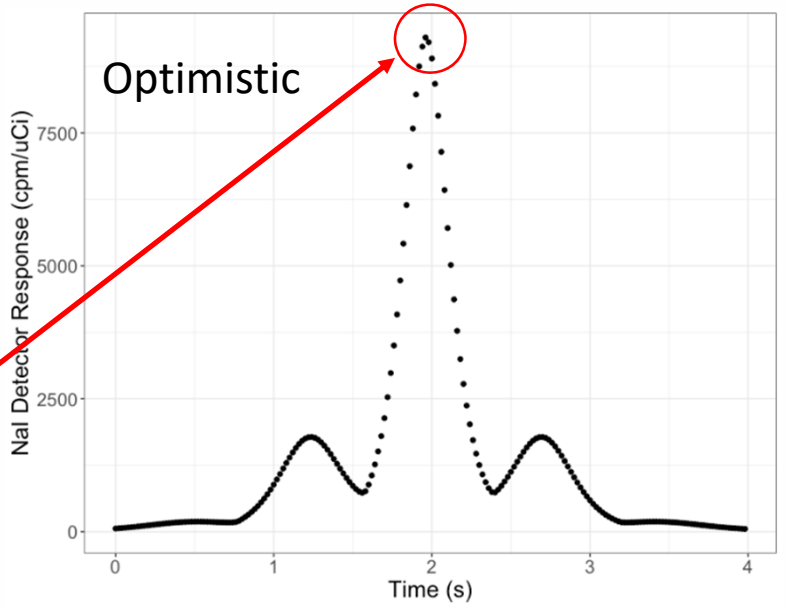
$$R(\delta, t) = K \times A \times EFF(\delta, t)$$ Where:

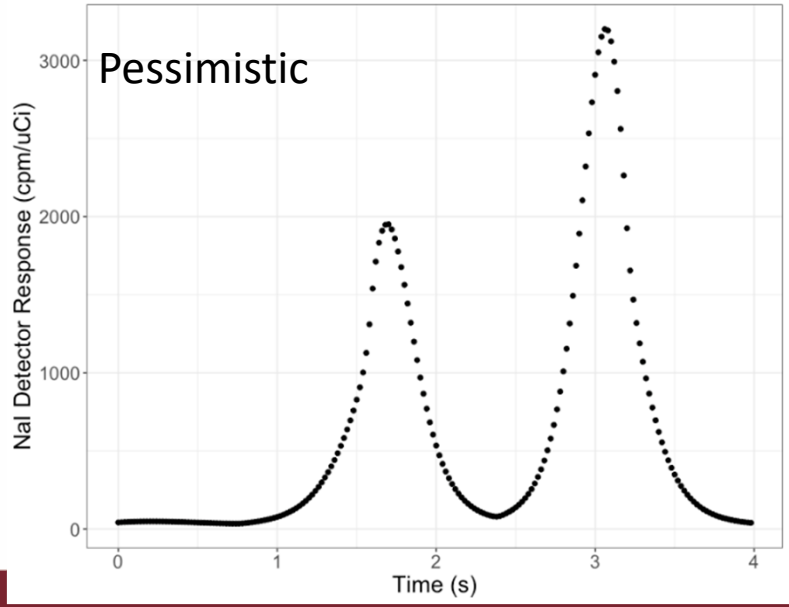
R(δ,t) = NaI detector response efficiency function (cpm/µCi) at a specified point/time (t),
EFF(δ,t) = NaI detector response efficiency function (counts/decay) at a specified point/time (t),
K = unit conversion factor (1 decay/sec/Bq × 37,000 Bq/µCi × 60 sec/min), and
A = the DRP activity (µCi).

3. Detector Response

- Once the efficiency curve is established the detector response to the DRP can be calculated at each point on the sine curve







4. Total Integrated Response

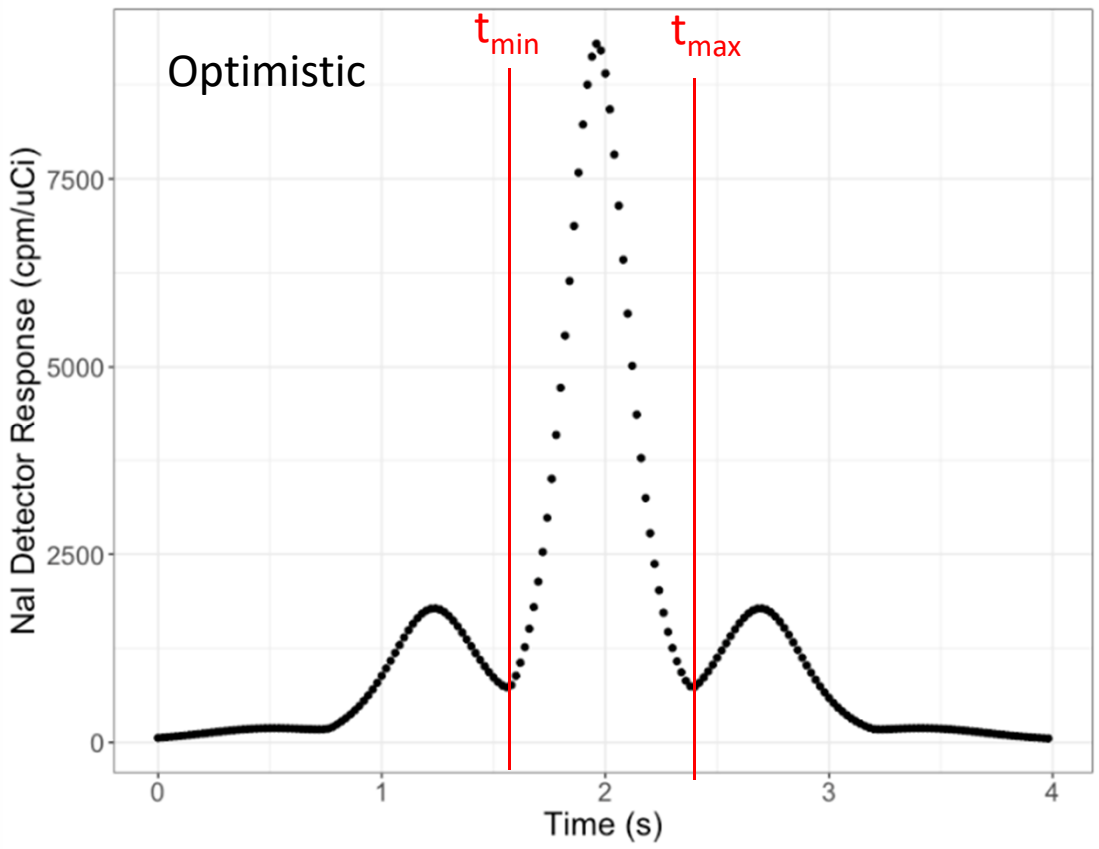
- Area under the response curve integrated using trapezoid method
  - The maximum peak was integrated
- Integration method results in a dynamic observation interval

$$IR(i) = \int_i R(\delta, t)\, d\delta\, dt$$

Distance is fixed, equation simplifies

$$IR(i) = K \times A \times \int_{tmin}^{tmax} R(t)\, dt$$

4. Total Integrated Response



$i = t_{max} - t_{min}$

$$IR(i) = \int_i R(\delta, t)\, d\delta\, dt$$

Distance is fixed, equation simplifies

$$IR(i) = K \times A \times \int_{tmin}^{tmax} R(t)\, dt$$

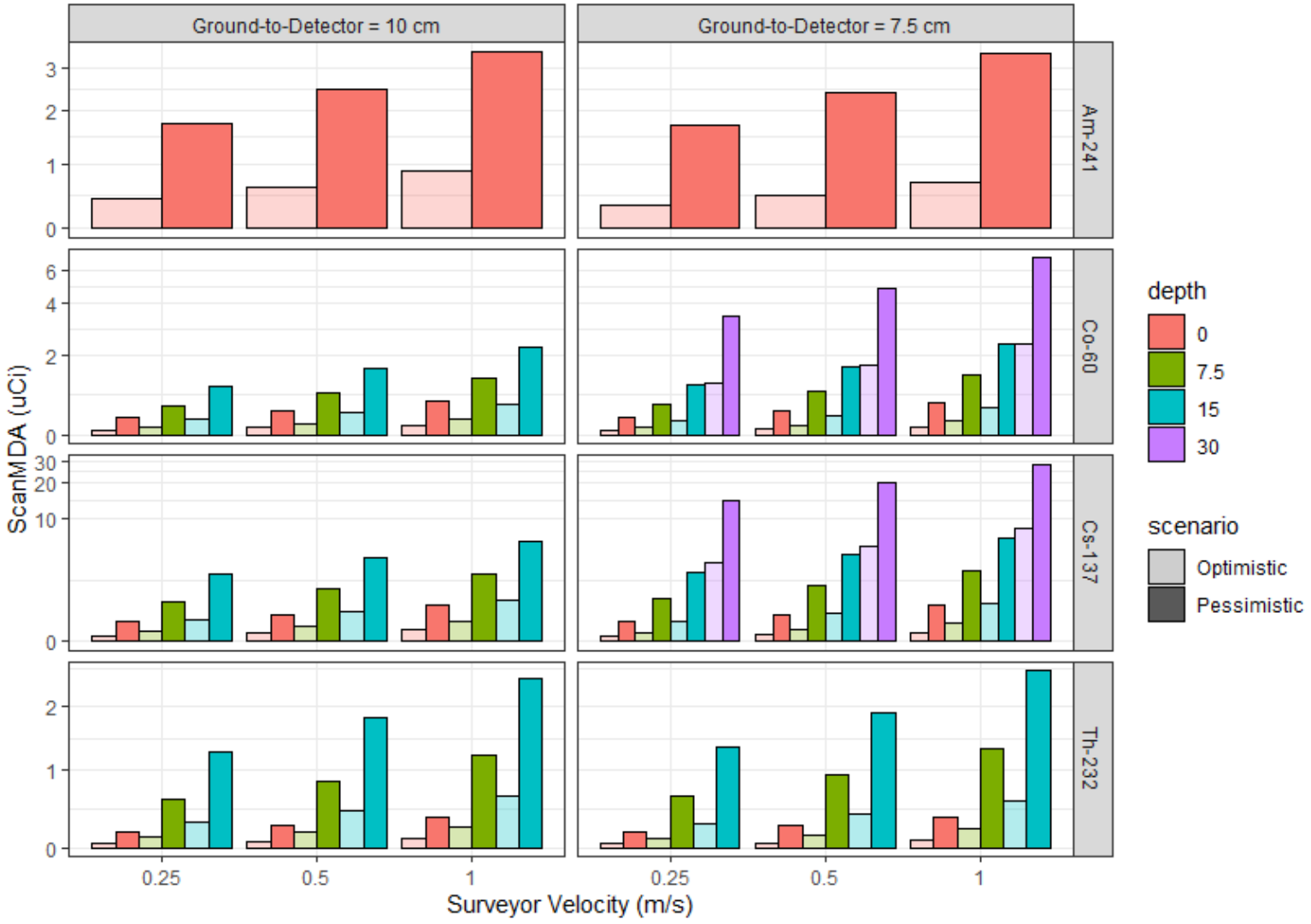
5. Scan MDA Calculation

- Scan MDA calculation is similar to that presented in NUREG-1507
- MDCR no longer applies, replaced by the minimum detectable count in the observation interval MDCt
- d’ and p are determined by project DQOs

$$scan\ MDA = \frac{MDCt}{\sqrt{p} \cdot IR} = \frac{d' \sqrt{b_i}}{\sqrt{p} \cdot IR}$$ Where:

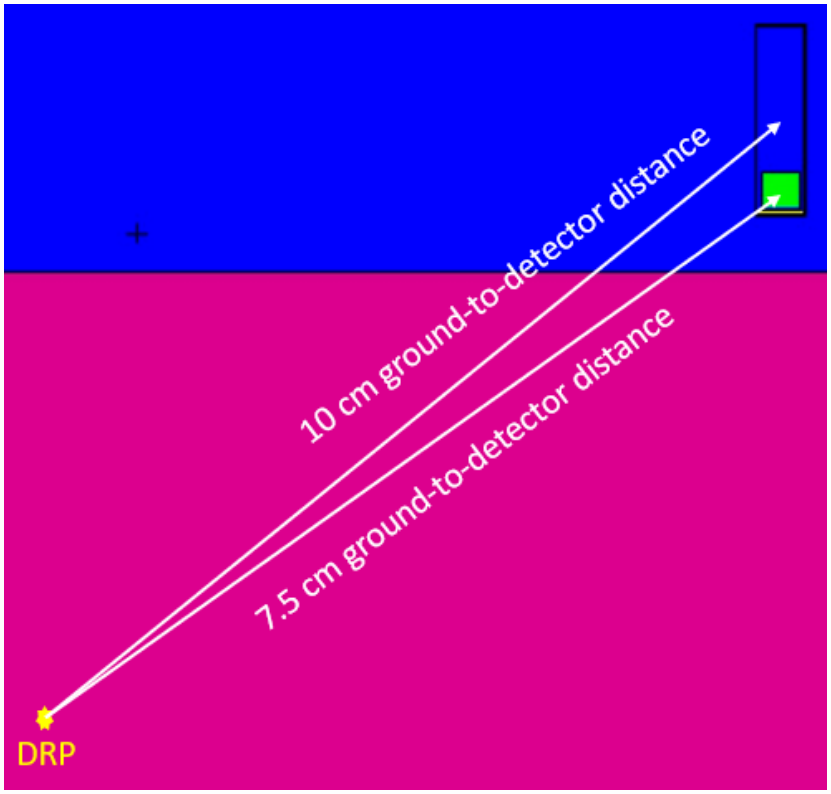
scan MDA = scan minimum detectable activity (µCi),
MDCt = minimum detectable counts (counts),
d’ = index of sensitivity, 1.64 used here (unitless),
b_i = background counts during observation interval (counts); a background count rate of 10,000 cpm was assumed,
i = observation interval (seconds),
IR = integrated detector response [$R(\delta, t)$] over observation interval (cpm/µCi s), and
p = surveyor efficiency, 0.5 used here (unitless).

Results


Ground-to-Detector = 10 cm
Ground-to-Detector = 7.5 cm
Am-241
Co-60
Cs-137
Th-232
ScanMDA (uCi)
Surveyor Velocity (m/s)
0.25
0.5
1
depth
0
7.5
15
30
scenario
Optimistic
Pessimistic

Results - Discussion

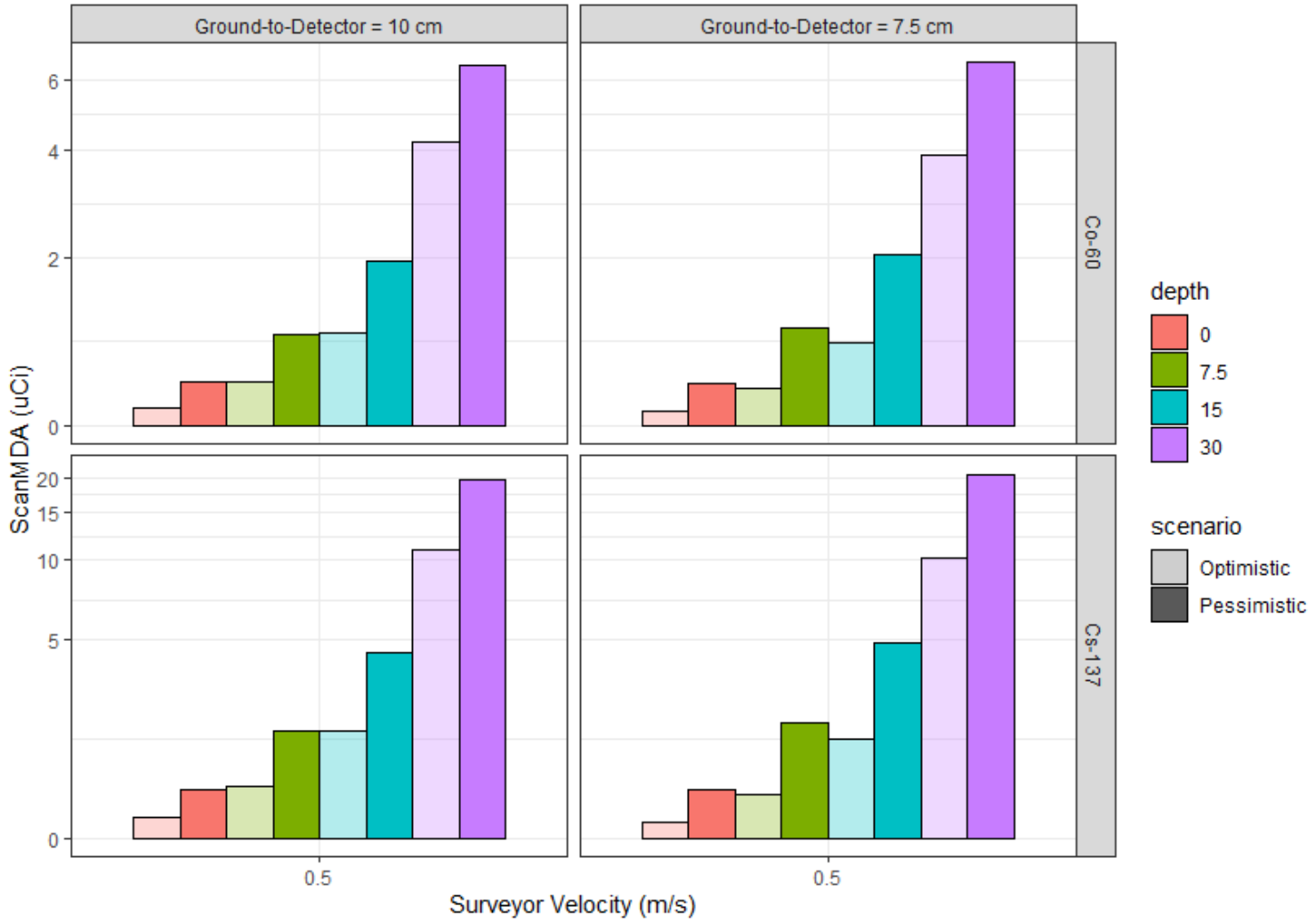
- Scan MDAs for ground-to-detector distance of 10 cm slightly lower than corresponding 7.5 cm values under certain pessimistic scenarios
- Two possible causes:
  - Pessimistic detector responses are calculated based on the tail of the efficiency curve, where fit is worse
  - Slightly higher soil attenuation (figure to the right) – raw efficiency values are higher for 10 cm ground-to-detector distance than 7.5 cm



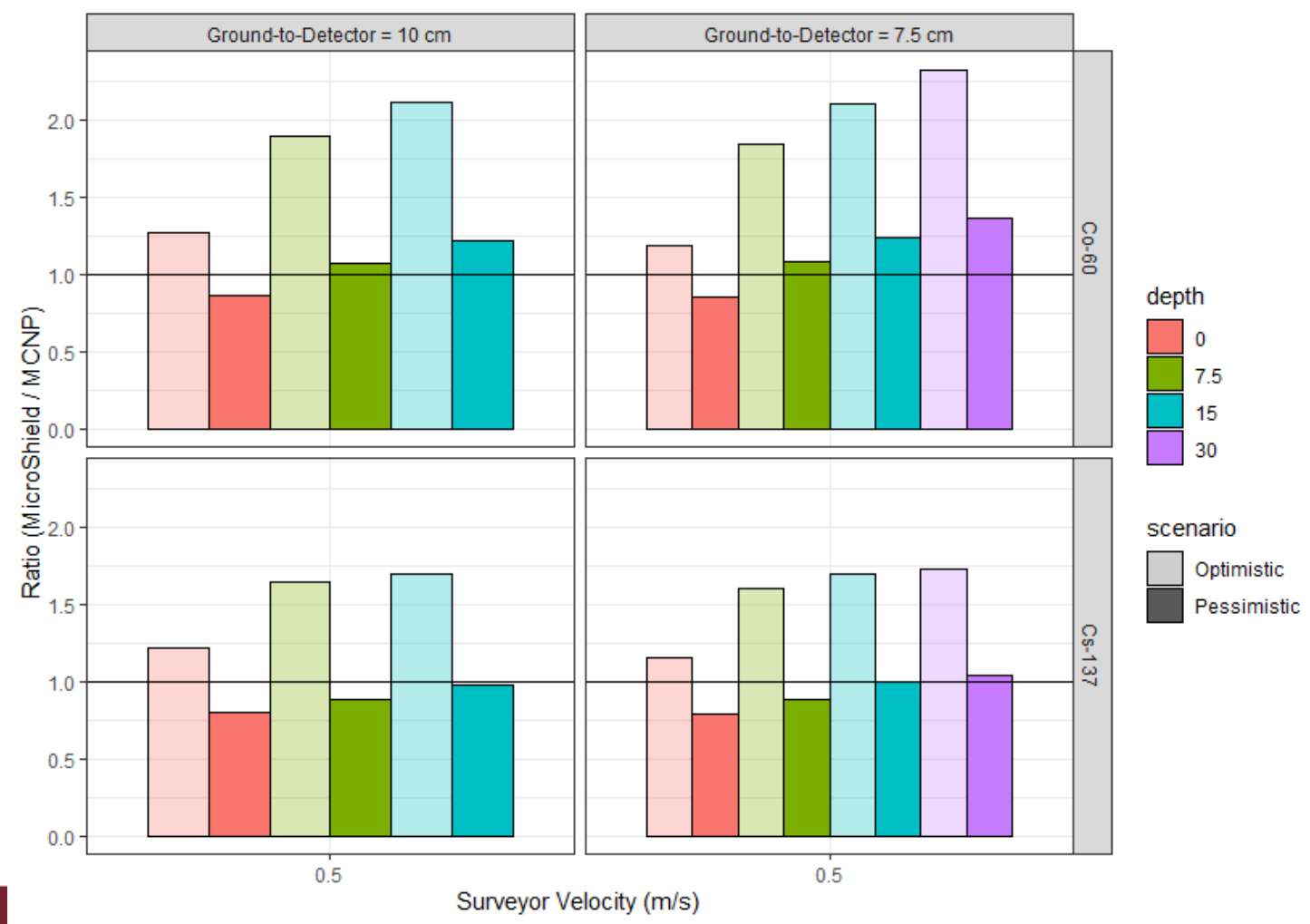
MicroShield®

- Similar analysis was completed using MicroShield® instead of MCNP® to generate efficiency curves
  - Detector response not calculated directly; converted from exposure rate to response using values in NUREG-1507
- Conditions evaluated:
  - Radionuclides: Co-60, Cs-137
  - Ground-to-detector distance: 7.5 cm and 10 cm
  - Surveyor speed: 0.5 m/s
  - DRP depth in soil: surface, 7.5 cm, and 15 cm.
    - Depths of 30 cm evaluated for Co-60 and Cs-137 at a ground-to-detector distance of 7.5 cm
  - DRP position: detector passes directly over DRP (optimistic scenario) and detector does not pass over DRP (pessimistic scenario)

Results – MicroShield®



MCNP® vs MicroShield®



Conclusions

- In general, lowest scan MDAs occur when the detector is positioned closest to the ground, the surveyor walks as slow as possible, the DRP is positioned on the surface, and the detector passes directly above the DRP
- A surveyor velocity of 0.25 m/s may be unreasonable in real-world applications, i.e., surface terrain prevents the surveyor from traversing this slowly
  - Optimization of the survey design may include a scan MDA based on a surveyor velocity of 0.25 m/s for small areas receiving follow-up investigations.
- Thickness of soil cover greatly influences the scan MDA, DRP investigation surveys should occur prior to any site actions that have the potential to re-distribute DRPs into deeper soil strata
- For the conditions evaluated, MicroShield® is a reasonable alternative to MCNP® for efficiency curve generation
- Future work could investigate impact of a collimated NaI detector on the scan MDA

References

NRC 2020. Minimum Detectable Concentrations with Typical Radiation Survey for Instruments for Various Contaminants and Field Conditions. NUREG-1507 Revision 1. U.S. Nuclear Regulatory Commission. Washington, D.C. August.

Ablequist 2014. Decommissioning Health Physics a Handbook for MARSSIM Users, Second Edition. Taylor & Francis Group. Boca Raton, Florida.

Questions?