

# NCS Approach for Decommissioning Low and Intermediate Level Waste Soils and Subterranean Piping Using the LaBr Detector



**NCS Topical Meeting**  
**October 2013**



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**Nuclear Safety Associates**

# Hematite Decommissioning Project

Former nuclear fuel cycle facility currently undergoing decommissioning. Scope includes remediation of unlined burial pits and subsurface piping with chemical and radiological contaminants.

- ✓ NCS Program based on surveys by HP technicians
  - "gamma walkover" for in-situ
  - "non-conforming item" measurements
  - 5 gallon bucket measurements (in NCS control)
  - intact container measurements

- ✓ All limits based on MCNP calibration for NaI

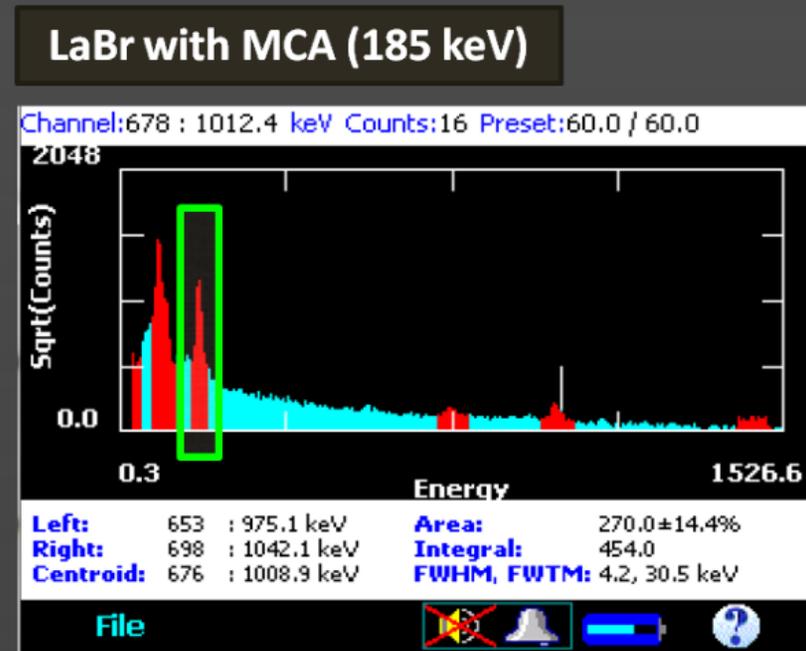
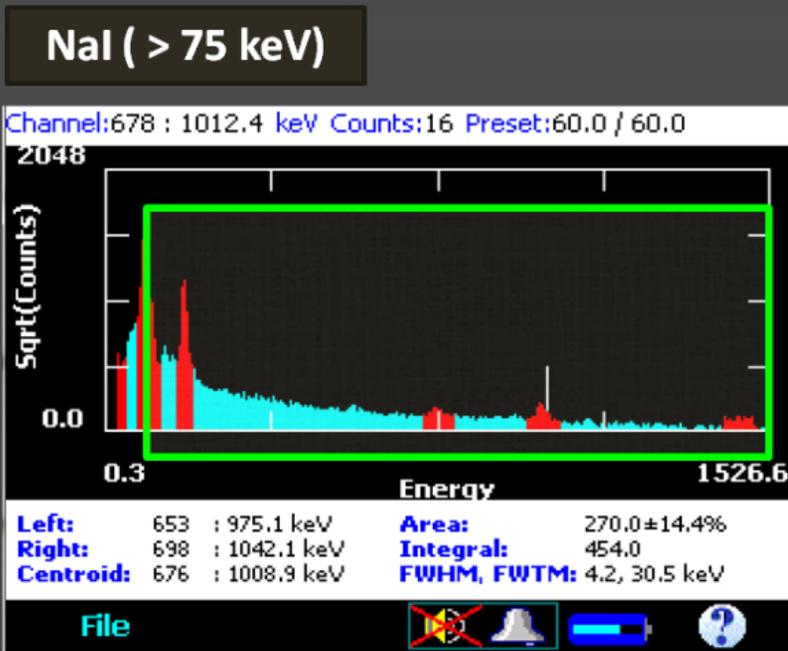
- ✓ Final U-235 gram determination from ISOCS/HPGe



# NCS Program

The NCS program relies on in-situ 2x2 NaI measurements based on bounding U-235 assumptions built into Monte Carlo calculations.

NCS Controls commence at 0.1 g U-235/L



Example LaBr UO<sub>2</sub> spectra with windows highlighted

NCS program is used as a vehicle to drive compliance in alternate disposal

# Initial Survey Program

- ✓ NCS Program based on surveys by HP technicians
  - "gamma walkover" for in-situ
  - "non-conforming item" measurements
  - 5 gallon bucket measurements (in NCS control)
  - intact container measurements
- ✓ All limits based on MCNP calibration for NaI
- ✓ Final U-235 gram determination from ISOCS/HPGe



- > 15 g U-235 (on site); or
- > 0.1 g U-235/L; and
- > 0.96 wt.% U-235 (disposal)



volume and spacing control

and...



and...

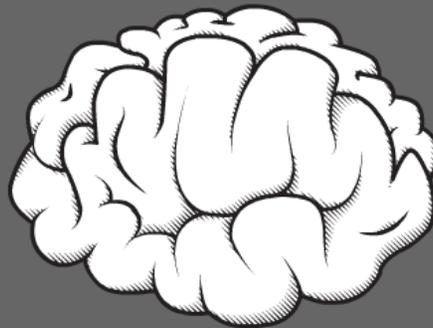


Which results in...



Undermines NCS program

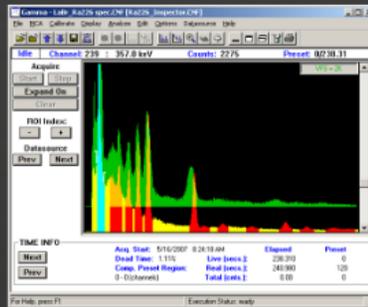
# How Can I Qualify & Quantify Uranium Mass or Concentration Real-Time in the Field to Avoid Unnecessary NCS Controls and Assay Time?



# Sell an idea to Westinghouse...



- 1 Portable multi-channel analyzer with resolution high enough to depict the 185 keV photopeak
- 2 Technical basis to assign U-235 mass or enrichment values from counts
- 3 Quick results



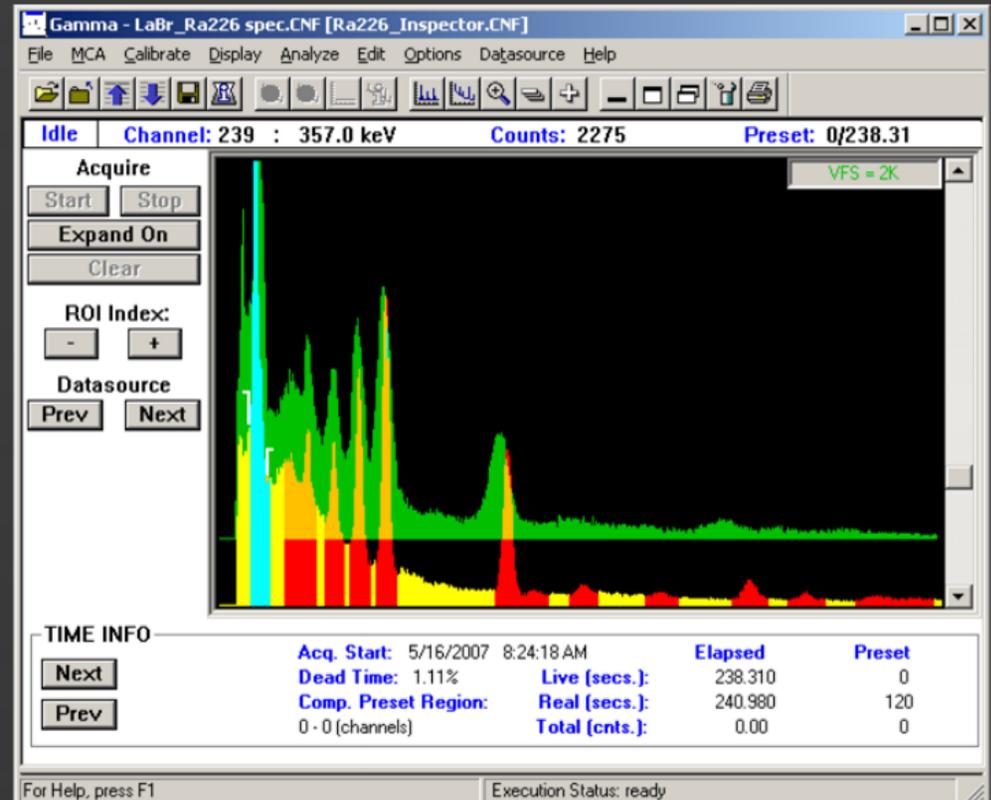
## Why InSpector 1000

- Sourceless, stabilized gamma probe
- Operation in extreme temperature variations (LaBr more robust)
- Full spectral analysis available
  - multiple efficiency calibrations, libraries, and analysis sequences
- LaBr offers excellent energy resolution and high light yield





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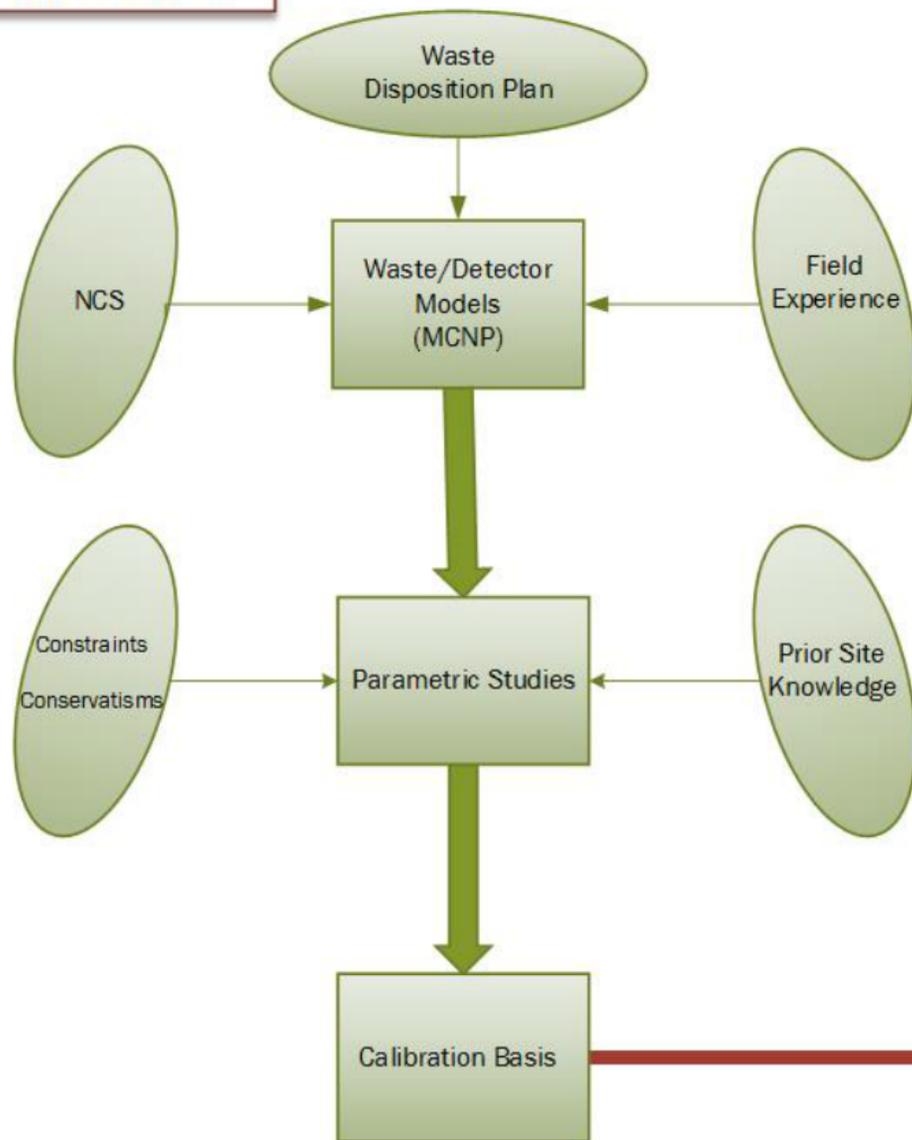


Need basis to quantify U-235 mass and enrichment for common geometries-in the field

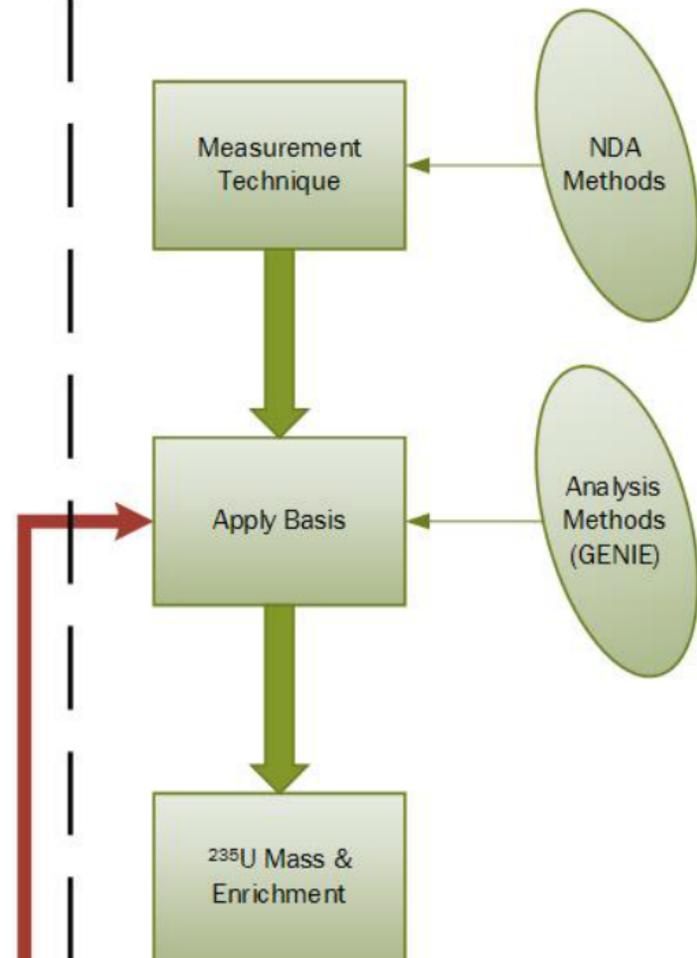
SUCH AS

- typical bucket
- bounding lump condition
- uniform distribution
- subterranean pipe

## DEVELOPMENT



## IMPLEMENTATION



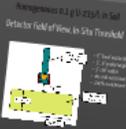
# Technical Basis

## CALIBRATION ANALYSIS

### MCNP Models

UO<sub>2</sub> and Dry Soil Lump

2.4, 6, and 8 inch rad depths



20 L Bucket With Homogeneous Mix

- 75%
- 50%
- 25%
- 100% full

Subsurface Pipe Models

### Assumptions

- 100 wt%, 5 wt% U-235/total U
- UO<sub>2</sub> particulate at full density, 10.96 g/cc
- UO<sub>2</sub> tap density of 3.5 g/cc
- 50 year decayed UO<sub>2</sub> source term with Bremsstrahlung
- 186 keV uncollided photon bin tally
- reported results are...

# Chemical Das

## CALIBRATION ANALYSIS

### NP Models

Homogeneous 0.1 g U-235/L in Soil  
Detector Field of View, In-Situ Threshold

• 6" fixed waste depth  
• 3', 6" probe height  
• 2-36" radius  
• dry and saturated soil  
• 100% enrichment

PREZI

20 L Bucket With Homogeneous Mix

1 25%,  
2 50%,  
3 75%,  
4 95% full

enrichment = 5% - 100%

### Assumptions

- 100 wt%, 5 wt% U-235/total U
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- 186 keV uncollided photon bin tally
- reported results are at 97.7% confidence interval

CIVIL

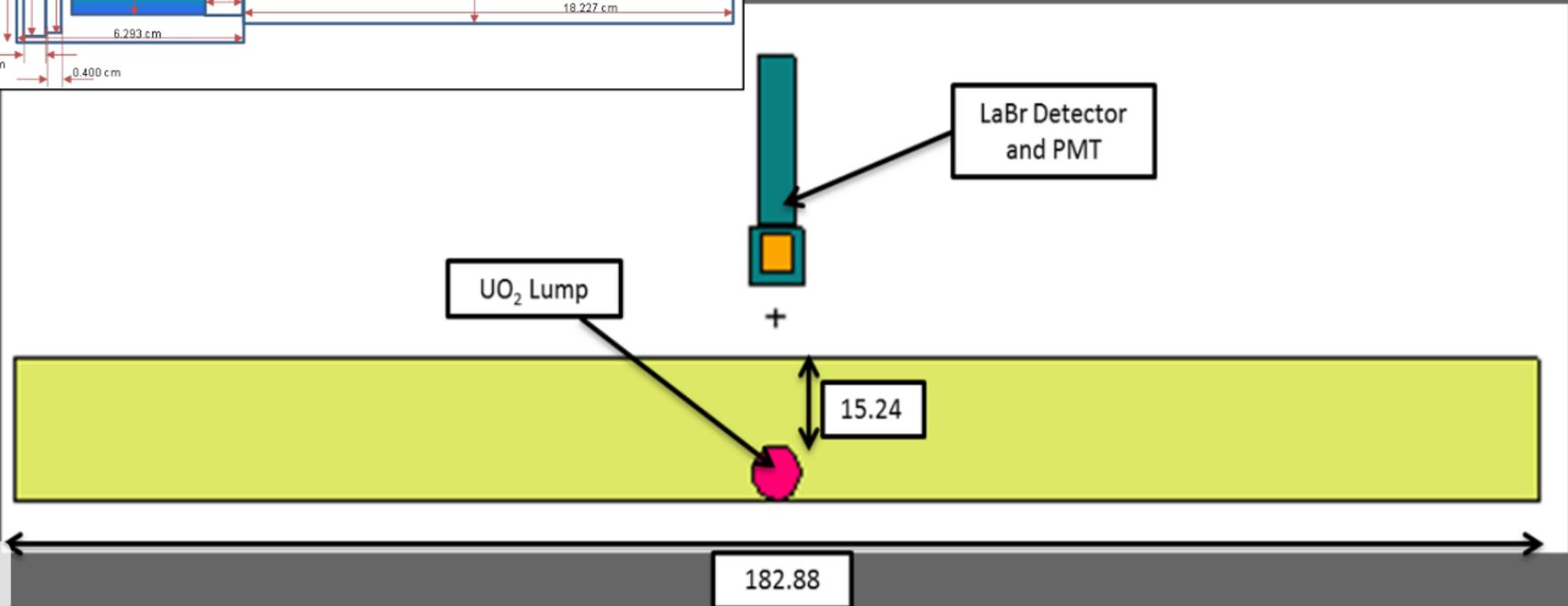
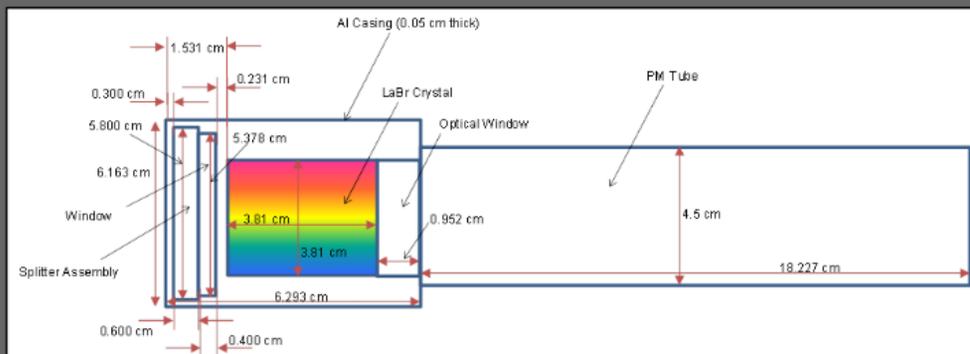
# MCNP Models

Homogeneous 0.1 g U-235/L in Soil  
Detector Field of View, In-Situ Threshold

# UO<sub>2</sub> and Dry Soil Lump

2, 4, 6, and 8 inch cut depths

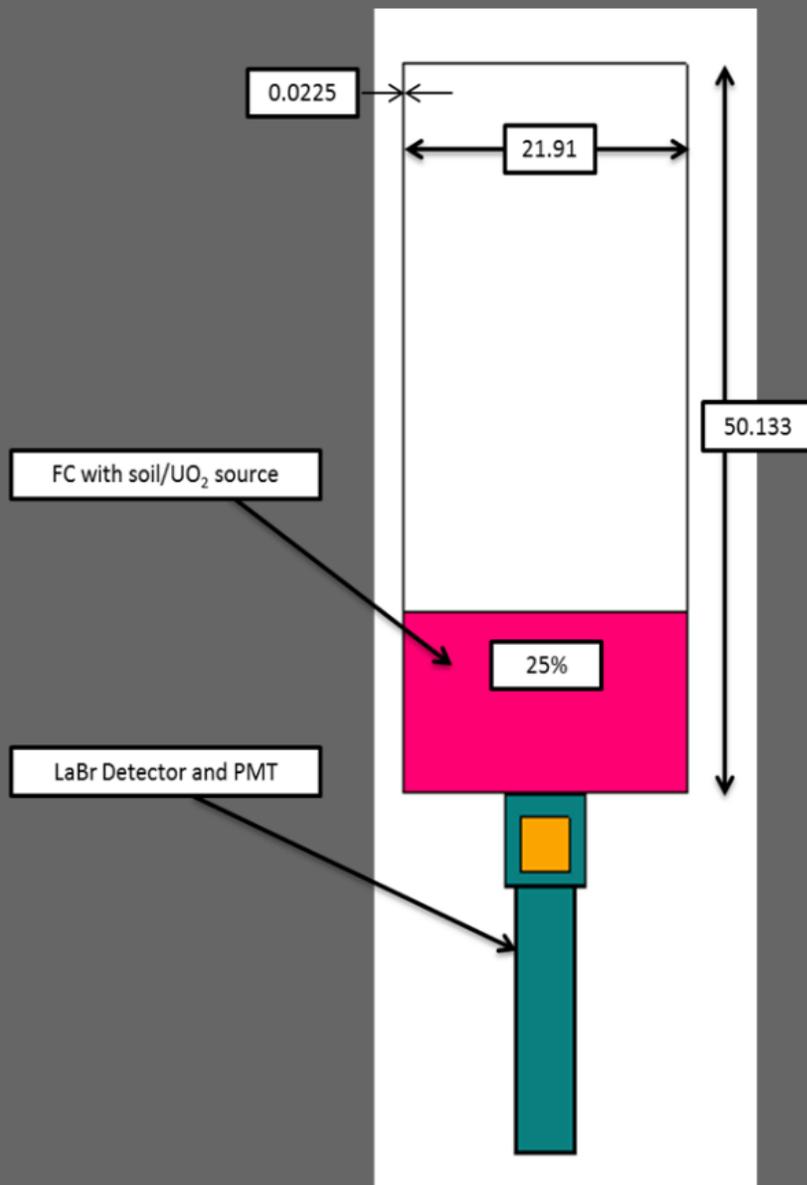
enrichment=100%



Threshold

fixed waste depth  
5" probe height  
6" radius  
and saturated soil  
6% enrichment

# 20 L Bucket With Homogeneous Mix

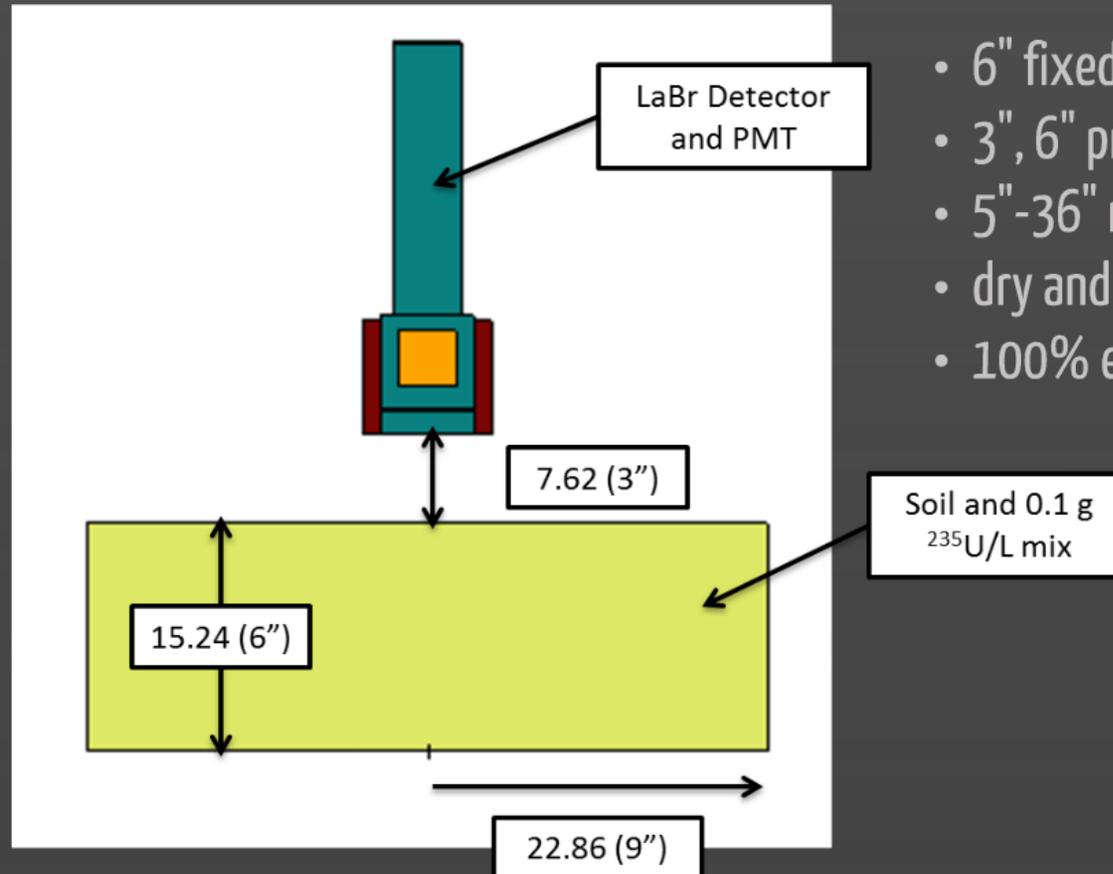


- 1 25%,
- 2 50%,
- 3 75%,
- 4 95% full

enrichment= 5%, 100%

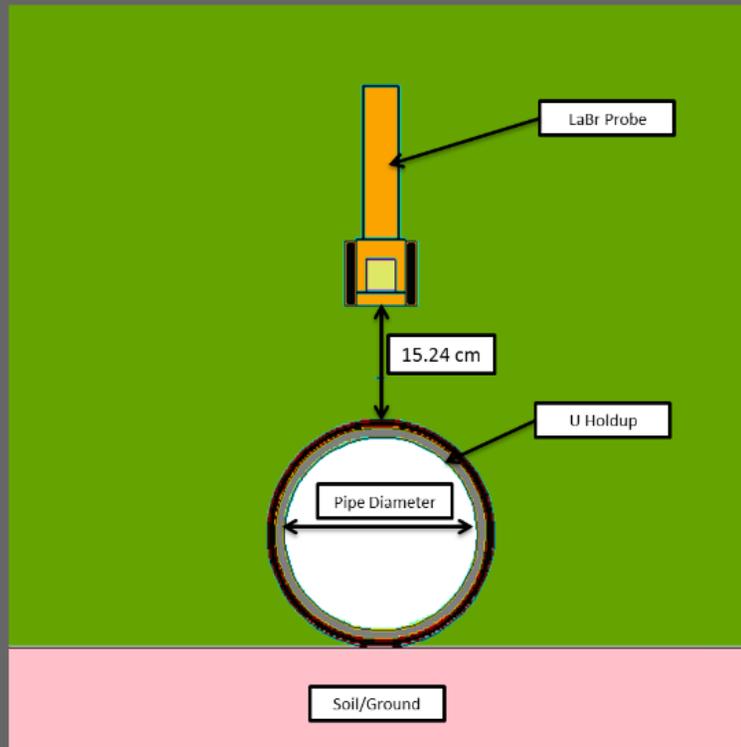
# Homogeneous 0.1 g U-235/L in Soil

## Detector Field of View, In-Situ Threshold



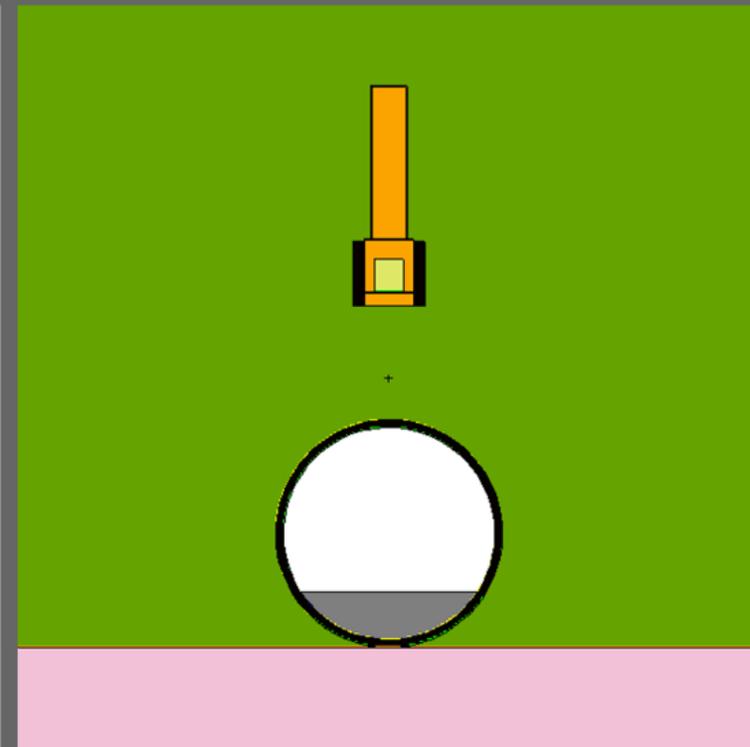
- 6" fixed waste depth
- 3", 6" probe height
- 5"-36" radius
- dry and saturated soil
- 100% enrichment

# Subsurface Pipe Models



## Annular

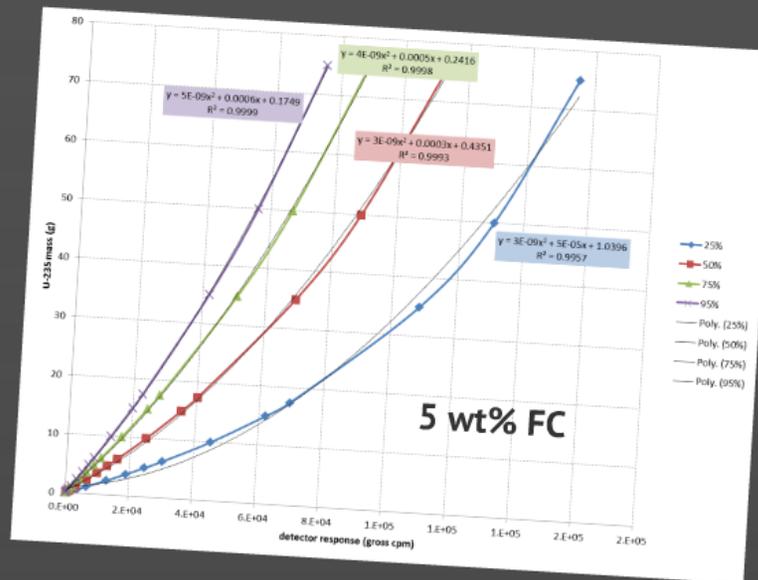
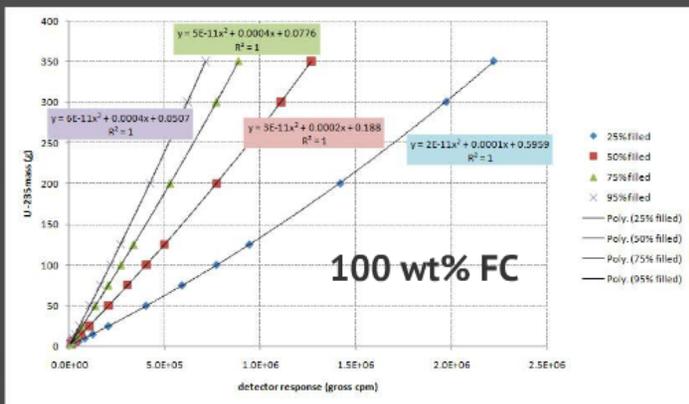
- PVC, carbon steel
- 4.5" - 18"



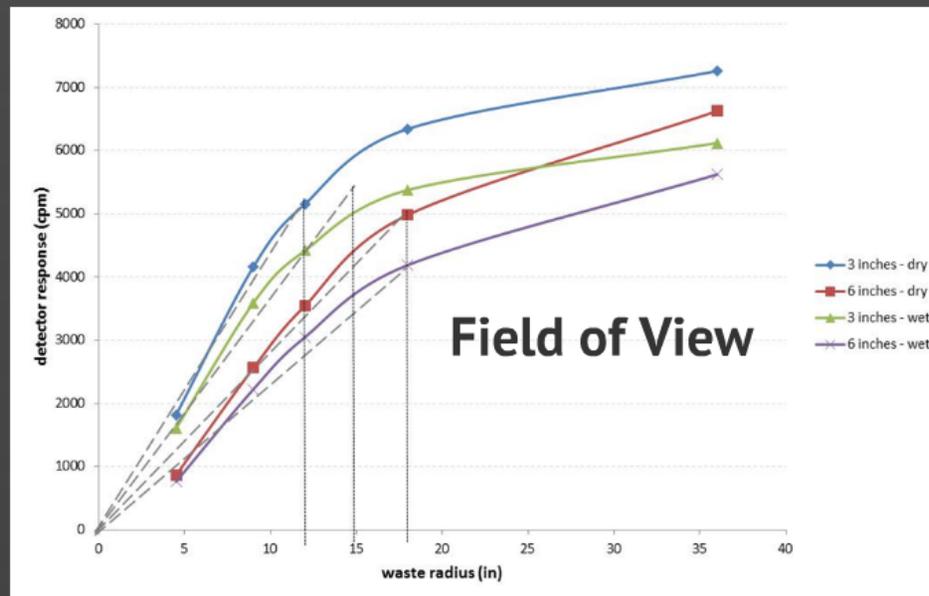
## Segmented

- collimated, not collimated
- 0.1 g U235 - 700 g U235

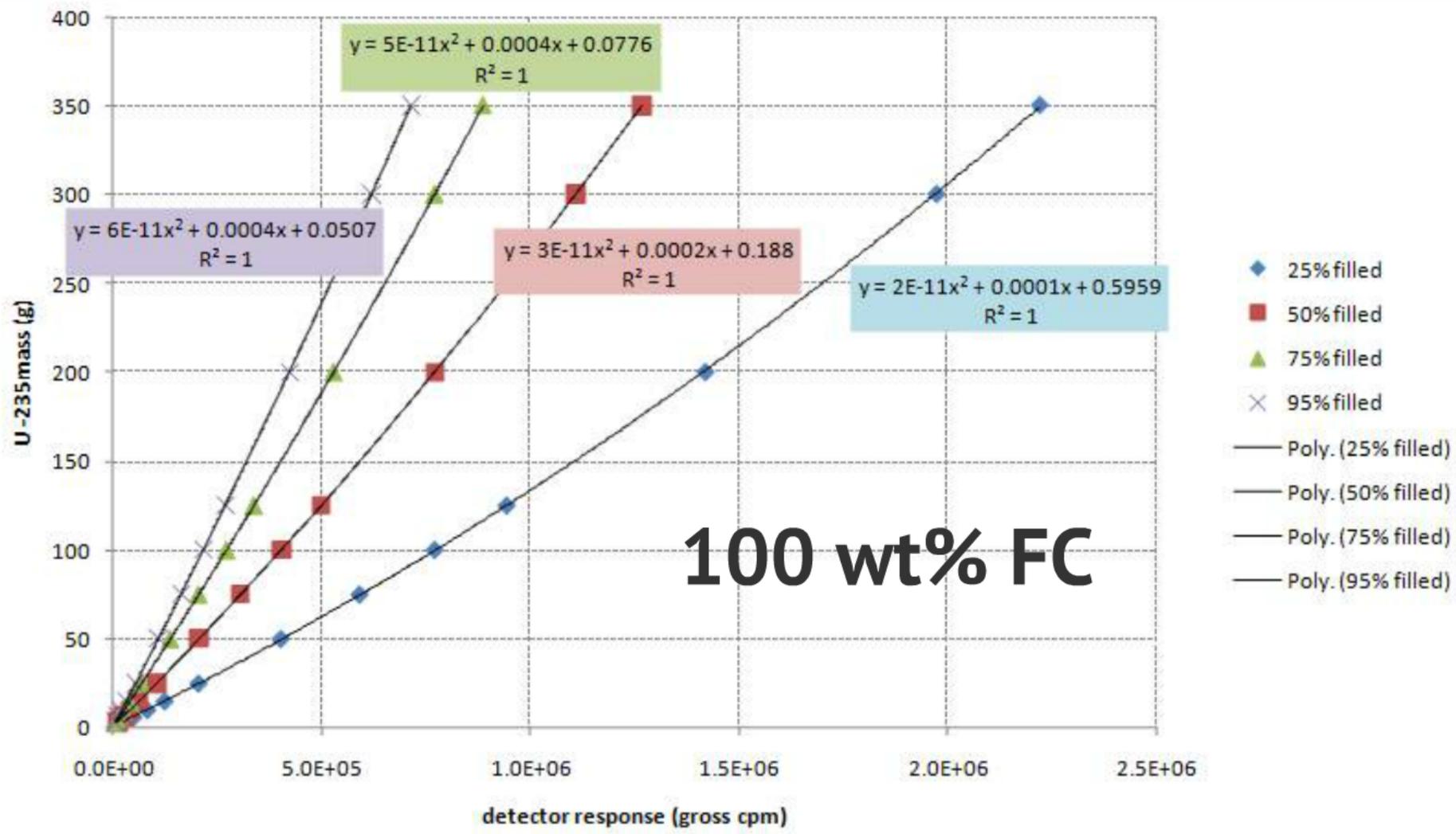
# Soil Waste Results

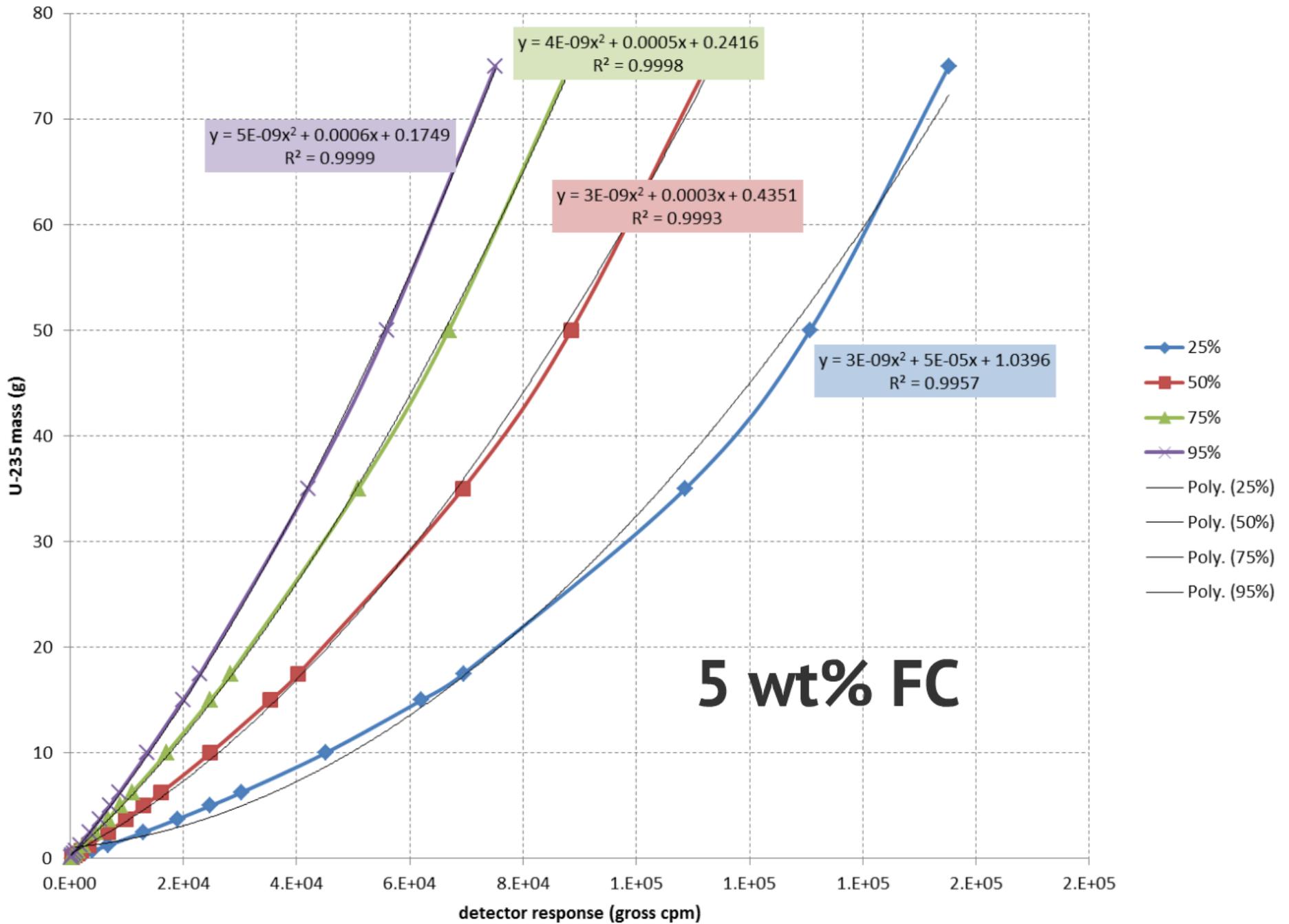


Enr.	Geometry	Variation	Best Fit Equation
100%	Lump	5.08 cm	$g^{235}U = -5E-10 * cpm^2 + 0.0005 * cpm - 0.4795$
		10.16 cm	$g^{235}U = -4E-09 * cpm^2 + 0.0025 * cpm + 2.8362$
		15.24 cm	$g^{235}U = -1E-07 * cpm^2 + 0.0128 * cpm + 1.622$
		20.32 cm	$g^{235}U = -2E-06 * cpm^2 + 0.0588 * cpm + 0.8825$
		25.40 cm	$g^{235}U = -2E-11 * cpm^2 + 0.0001 * cpm + 0.5959$
5%	Field Container	25%	$g^{235}U = 3E-11 * cpm^2 + 0.0002 * cpm + 0.188$
		50%	$g^{235}U = 5E-11 * cpm^2 + 0.0004 * cpm + 0.0776$
		75%	$g^{235}U = 6E-11 * cpm^2 + 0.0004 * cpm + 0.0507$
		95%	$g^{235}U = 2E-11 * cpm^2 + 0.0001 * cpm + 0.5959$

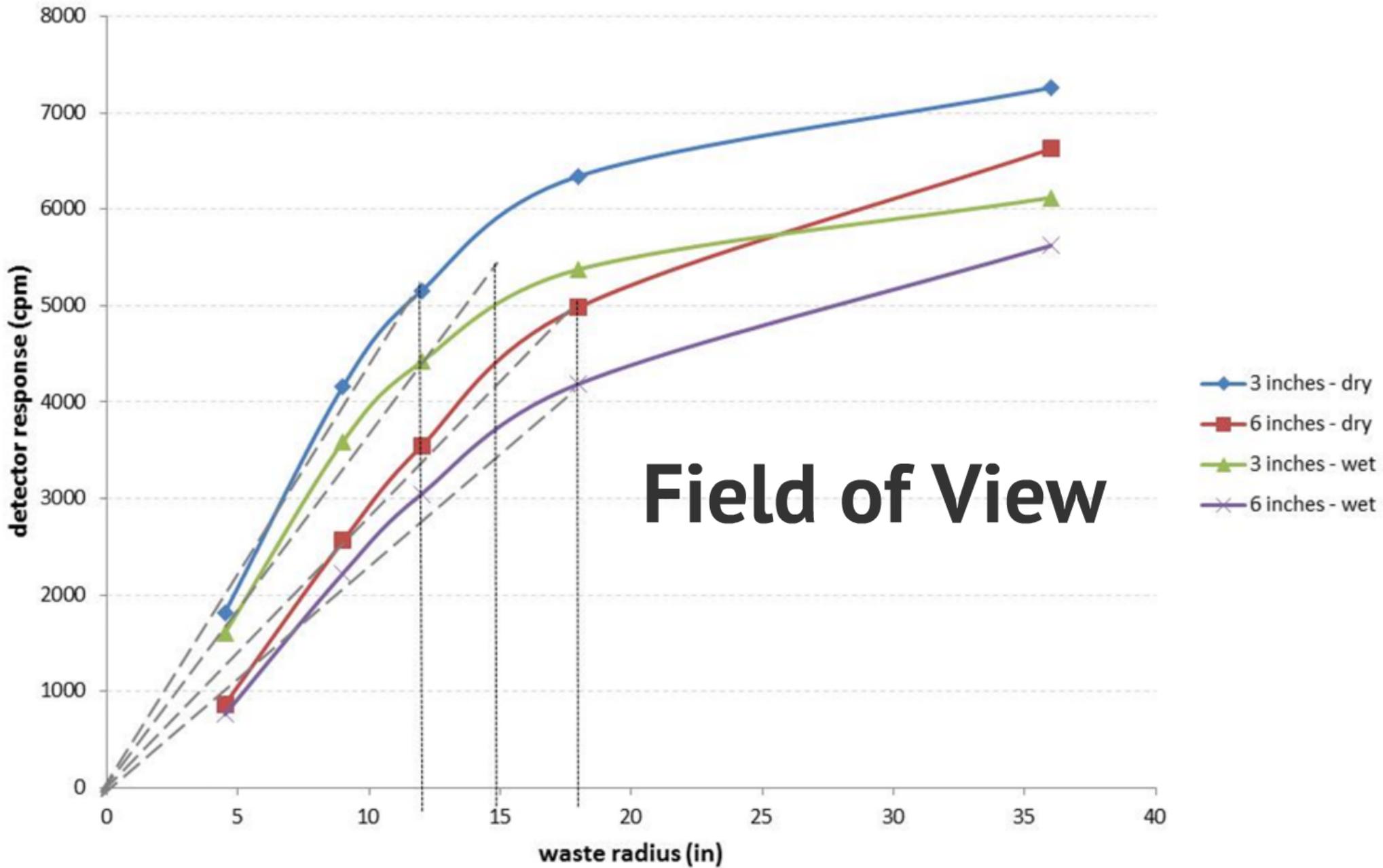


100



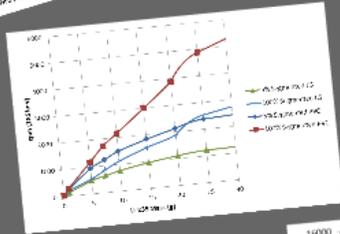
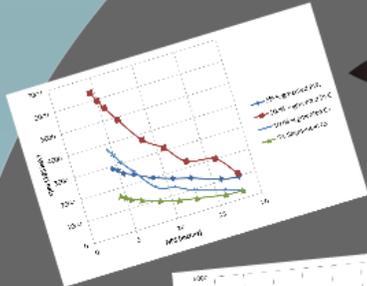


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# Subterranean Piping Results

Segmented ; Collimated



## Effect of Pipe Material

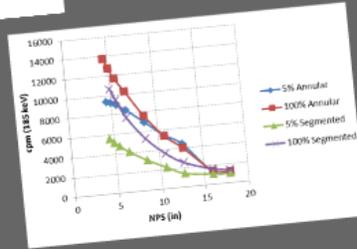
- CS conservative for all NPS above 6.625"
- PVC conservative for smaller pipe sizes but only at 5% enrichment
- CS conservative for mass values below ~22 g U-235
- CS chosen for final calibration basis

## Effect of Enrichment

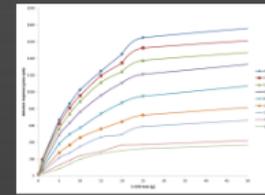
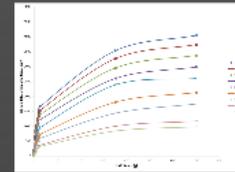
- 5% conservative for all NPS with typical fissile mass loading limits
- 5% conservative for all mass loadings in 6.625"

## Effect of Distribution

- Segmented always conservative



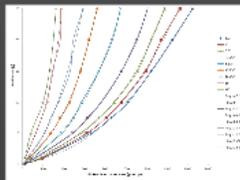
## Final Piping Correlations

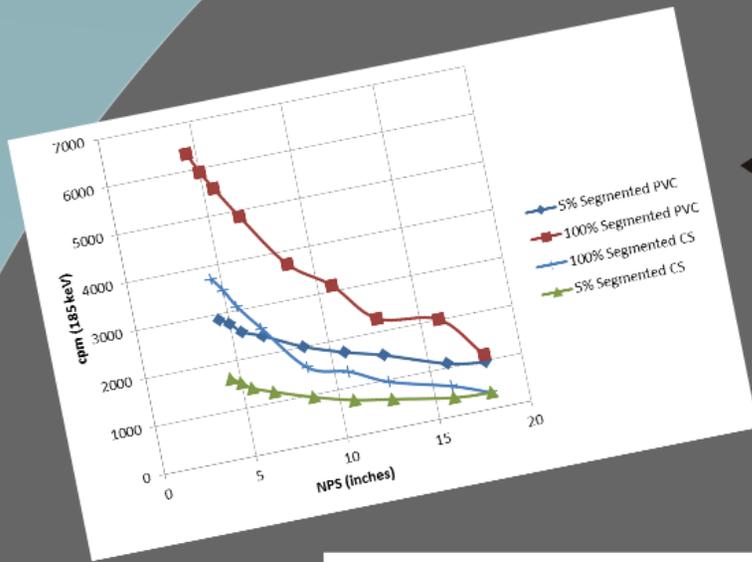


U-235	U-235	U-235	U-235
0.0	0.0	0.0	0.0
0.1	0.1	0.1	0.1
0.2	0.2	0.2	0.2
0.3	0.3	0.3	0.3
0.4	0.4	0.4	0.4
0.5	0.5	0.5	0.5
0.6	0.6	0.6	0.6
0.7	0.7	0.7	0.7
0.8	0.8	0.8	0.8
0.9	0.9	0.9	0.9
1.0	1.0	1.0	1.0
1.1	1.1	1.1	1.1
1.2	1.2	1.2	1.2
1.3	1.3	1.3	1.3
1.4	1.4	1.4	1.4
1.5	1.5	1.5	1.5
1.6	1.6	1.6	1.6
1.7	1.7	1.7	1.7
1.8	1.8	1.8	1.8
1.9	1.9	1.9	1.9
2.0	2.0	2.0	2.0

## Pipe Loading Estimate Calibration

- ground is dry compacted soil
- carbon steel pipe material
- tungsten silicone collimator
- probe is 6" from pipe outer surface
- debris is UO<sub>2</sub> at 3 g/cc
- UO<sub>2</sub> in segmented distribution
- 5 wt.% enrichment
- equations represent relationship up to 15.9 g/ft





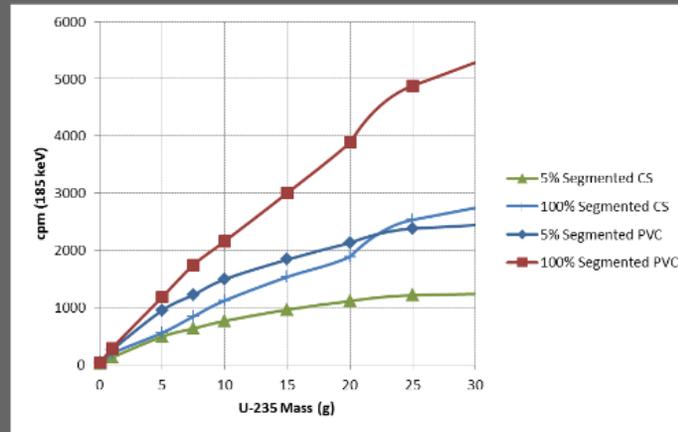
-Function of NPS  
-25 g U-235

-Function of Mass  
-6.625" NPS



### Effect of Pipe Material

- CS conservative for all NPS above 6.625"
- PVC conservative for smaller pipe sizes but only at 5% enrichment
- CS conservative for mass values below ~22 g U-235
- CS chosen for final calibration basis

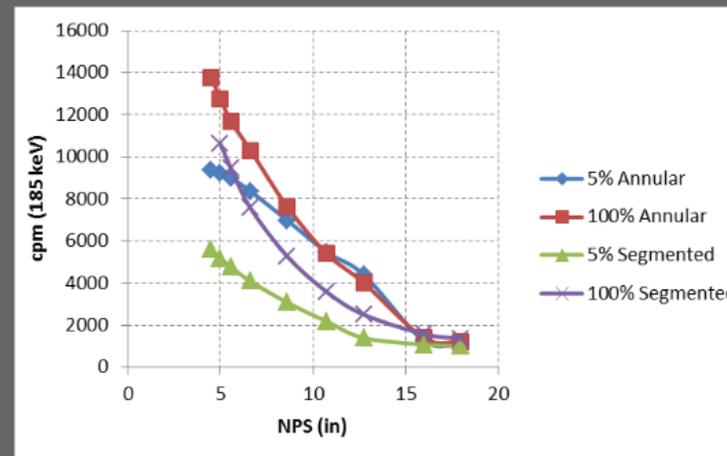


### Effect of Enrichment

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### Effect of Distribution

- Segmented always conservative



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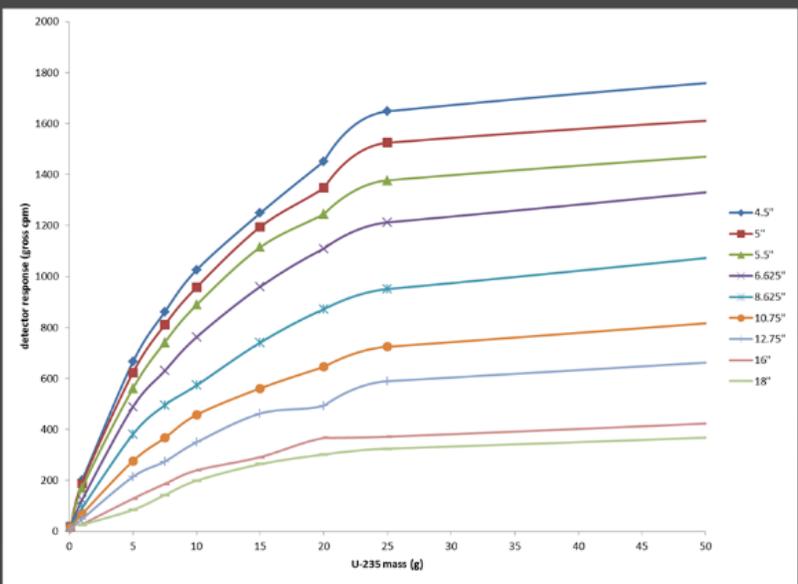
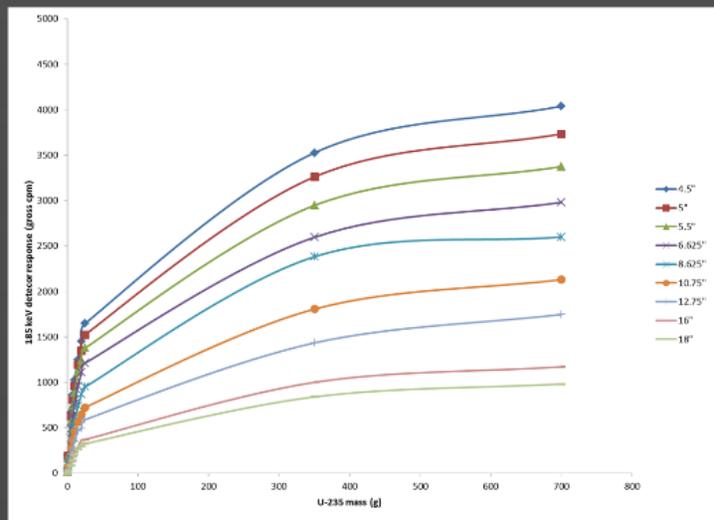
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above 6.625"  
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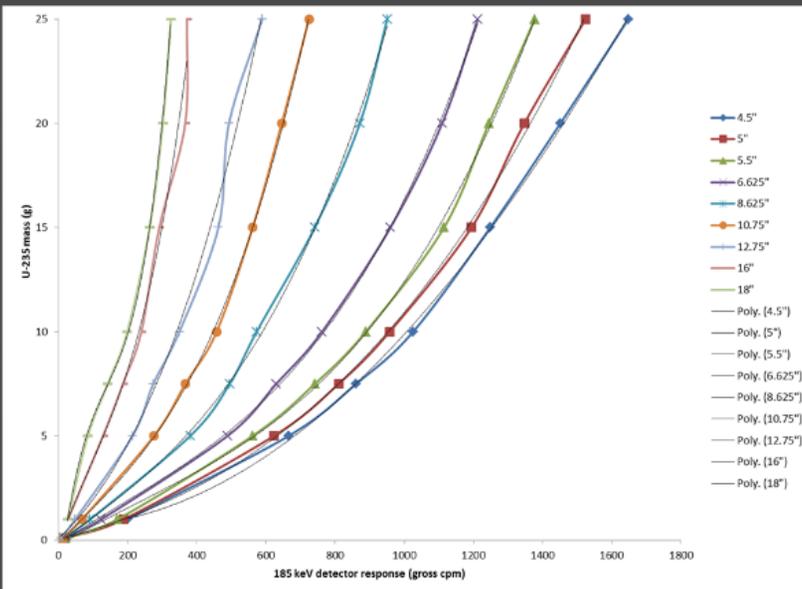
5% Annular  
100% Annular  
5% Segmented  
Prezi

# Final Piping Correlations



# Pipe Loading Estimate Calibration

NPS	Best Fit Equation	R <sup>2</sup>
4.5	$g^{235}\text{U} = -3\text{E}-10 * \text{cpm}^3 + 1\text{E}-5 * \text{cpm}^2 + 3\text{E}-5 * \text{cpm} + 0.6524$	0.9994
5	$g^{235}\text{U} = 3\text{E}-9 * \text{cpm}^3 + 4\text{E}-6 * \text{cpm}^2 + 0.0044 * \text{cpm} + 0.0232$	0.9992
5.5	$g^{235}\text{U} = 9\text{E}-9 * \text{cpm}^3 - 6\text{E}-6 * \text{cpm}^2 + 0.0099 * \text{cpm} - 0.026$	0.9992
6.625	$g^{235}\text{U} = 1\text{E}-8 * \text{cpm}^3 - 6\text{E}-6 * \text{cpm}^2 + 0.0112 * \text{cpm} - 0.1865$	0.9995
8.625	$g^{235}\text{U} = 2\text{E}-8 * \text{cpm}^3 - 2\text{E}-6 * \text{cpm}^2 + 0.0112 * \text{cpm} - 0.1216$	0.9987
10.75	$g^{235}\text{U} = 4\text{E}-8 * \text{cpm}^3 - 6\text{E}-6 * \text{cpm}^2 + 0.0167 * \text{cpm} - 0.1191$	0.9995
12.75	$g^{235}\text{U} = 3\text{E}-8 * \text{cpm}^3 + 3\text{E}-5 * \text{cpm}^2 + 0.0158 * \text{cpm} + 0.059$	0.9909
16	$g^{235}\text{U} = 4\text{E}-7 * \text{cpm}^3 - 0.0001 * \text{cpm}^2 + 0.0477 * \text{cpm} - 0.2445$	0.9770
18	$g^{235}\text{U} = 2\text{E}-6 * \text{cpm}^3 - 0.0007 * \text{cpm}^2 + 0.1347 * \text{cpm} - 2.1399$	0.9994

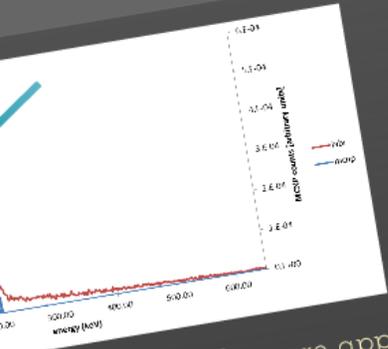


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- debris is UO<sub>2</sub> at 3 g/cc
- UO<sub>2</sub> in segmented distribution
- 5 wt.% enrichment
- equations represent relationship up to 15.9 g/ft



What about traditional methods using activity and attenuation factors?





HEU Waste  
+  
MCNP simulated

Counts from 185 line are applied to entire photopeak above Continuum

### InInspector 1000 Activities Verification ISOCS Geometry Composer and Standard Mixed Gamma

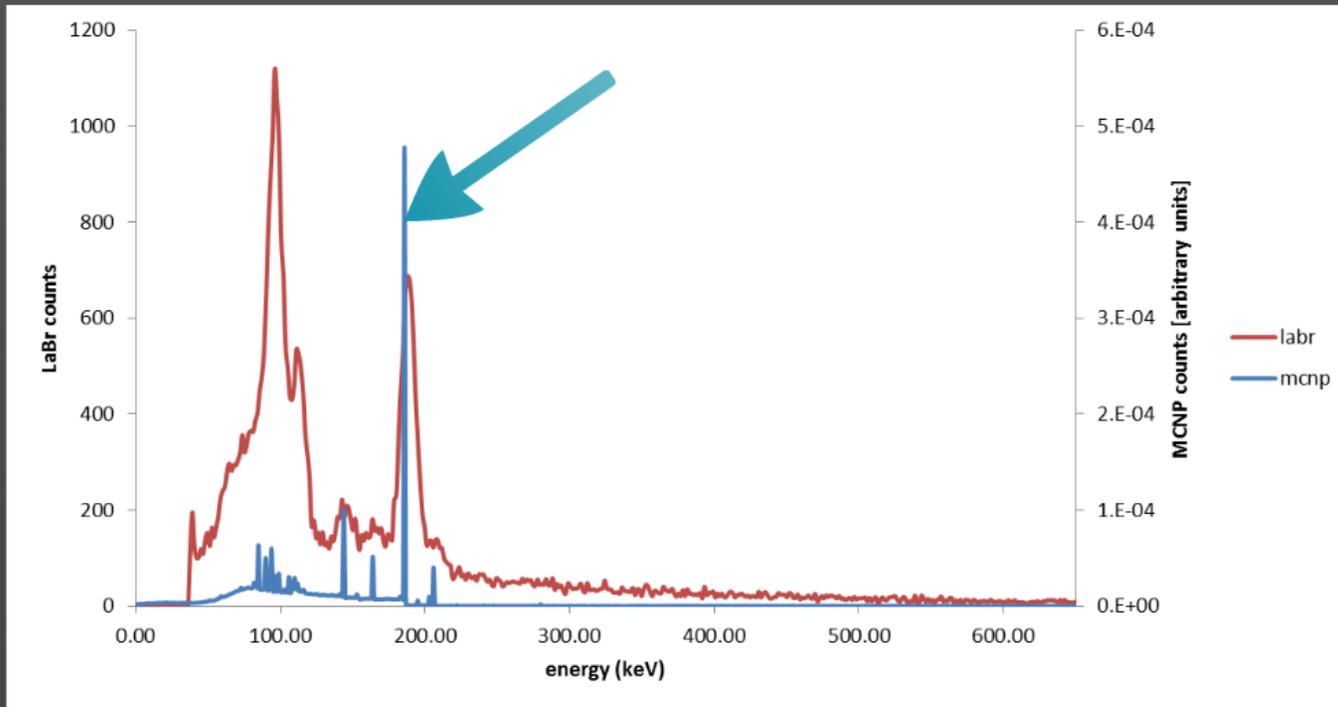
Nuclide	MIST Traceable Marinelli			14hr - Default InInspector 1000 Report			ratio
	Weighted Mean Activity (uCi/Amli)	Weighted Mean Activity Uncertainty (%)	Weighted Mean Activity Uncertainty (uCi)	Weighted Mean Activity (uCi/Amli)	Weighted Mean Activity Uncertainty (%)	Weighted Mean Activity Uncertainty (uCi)	
Ca-57	0.011	7.86	0.001	0.010	15.2	0.002	1.1 ± 0.188
Ce-60	0.056	4.33	0.002	0.038	5.8	0.002	1.5 ± 0.066
Ce-109	0.750	10.03	0.075	0.777	11.4	0.085	2.0 ± 0.147
Sm-145	0.018	11.84	0.001	0.015	32.2	0.002	1.6 ± 0.242
Ce-137	0.041	6.57	0.003	0.029	16.1	0.005	1.4 ± 0.169
Ca-139	0.007	22.44	0.0002	0.006	20.1	0.001	1.2 ± 0.251
Am-241	0.092	10.00	0.009	0.110	17.3	0.014	0.8 ± 0.122
Y-88	not identified			0.010	22	0.002	N/A

# Validation for Use

## Results : MCNP Efficiency and ISOCS Efficiency for U-235 photons

% U	ISOCS		MCNP		Comparison	
	Efficiency	σ (%)	Efficiency	σ (%)	% Variation	Ratio
1.00	1.22E-03	0.08	1.36E-03	0.0008	10.03%	1.11 ± 0.089
0.52	6.37E-04	0.08	7.12E-04	0.0011	10.58%	1.12 ± 0.089
0.35	4.30E-04	0.08	4.82E-04	0.0013	10.72%	1.12 ± 0.090
0.27	3.42E-04	0.08	3.81E-04	0.0017	10.87%	1.17 ± 0.090
0.00	2.17E-04	0.08	2.76E-04	0.0024	21.29%	1.27 ± 0.102
0.52	1.16E-04	0.08	1.49E-04	0.0029	22.29%	1.29 ± 0.103
0.35	7.91E-05	0.08	1.07E-04	0.0029	22.51%	1.29 ± 0.103
0.27	6.31E-05	0.08	8.15E-05	0.0049	22.53%	1.29 ± 0.101

- ISOCS
  - includes Canberra detector characterization
  - interpolated efficiency grid
  - macrosource described in Geometry Composer
  - material attenuation factors
- Materials (Z) almost identical



HEU Waste  
+  
MCNP simulated

Counts from 185 line are applied to entire photopeak above Continuum

# InSpector 1000 Activities Verification



## ISOCS Geometry Composer and Standard Mixed Gamma

Nuclide	NIST Traceable Marinelli			LaBr - Default InSpector 1000 Report			ratio
	Weighted Mean Activity (uCi/unit)	Weighted Mean Acitivity Uncertainty (%)	Weighted Mean Acitivity Uncertainty (uCi)	Weighted Mean Activity (uCi/unit)	Weighted Mean Acitivity Uncertainty (%)	Weighted Mean Acitivity Uncertainty (uCi)	
Co-57	0.011	7.86	0.001	0.010	15.2	0.002	1.1 ± 0.188
Co-60	0.056	4.33	0.002	0.038	5.8	0.002	1.5 ± 0.106
Cd-109	0.750	10.03	0.075	0.777	11.4	0.089	1.0 ± 0.147
Sn-113	0.008	11.84	0.001	0.005	32.7	0.002	1.6 ± 0.542
Cs-137	0.041	6.52	0.003	0.029	10.1	0.003	1.4 ± 0.169
Ce-139	0.007	22.44	0.002	0.006	20.3	0.001	1.2 ± 0.353
Am-241	0.092	10.00	0.009	0.115	12.3	0.014	0.8 ± 0.127
Y-88	not identified			0.010	22	0.002	N/A

## Results : MCNP Efficiency and ISOCS Efficiency for U-235 photons

Parameter			ISOCS			MCNP		Comparison	
Fill	Energy	Mass U	% U	Efficiency	$\sigma$ (%)	Efficiency	$\sigma$ (%)	% Variation	Ratio
25%	185.7	100	1.00	1.22E-03	0.08	1.36E-03	0.0008	10.03%	1.11 ± 0.089
50%	185.7	100	0.52	6.37E-04	0.08	7.12E-04	0.0011	10.58%	1.12 ± 0.089
75%	185.7	100	0.35	4.30E-04	0.08	4.82E-04	0.0013	10.72%	1.12 ± 0.090
95%	185.7	100	0.27	3.42E-04	0.08	3.83E-04	0.0023	10.87%	1.12 ± 0.090
25%	143.8	100	1.00	2.17E-04	0.08	2.76E-04	0.0017	21.29%	1.27 ± 0.102
50%	143.8	100	0.52	1.16E-04	0.08	1.49E-04	0.0024	22.29%	1.29 ± 0.103
75%	143.8	100	0.35	7.91E-05	0.08	1.02E-04	0.0029	22.53%	1.29 ± 0.103
95%	143.8	100	0.27	6.31E-05	0.08	8.15E-05	0.0049	22.53%	1.29 ± 0.103

### ISOCS

- includes Canberra detector characterization
  - interpolated efficiency grid
- macrosources described in Geometry Composer
  - material attenuation factors
- Materials (Z) almost identical to MCNP

**MCNP > ISOCS which results in more conservative gram estimates**

### MCNP

- F8 photon tally
  - uncollided source photon interaction in crystal
  - direct result is overall efficiency (intrinsic +)
- can calculate intrinsic efficiency (entering crystal volume/interact in crystal volume)



# IMPLEMENTATION AT HDP



Burial Pits



Process wastes,  
garbage



In situ Field Measurements



Field Measurements



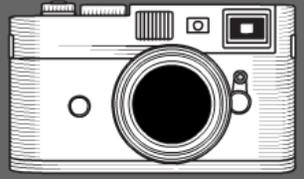
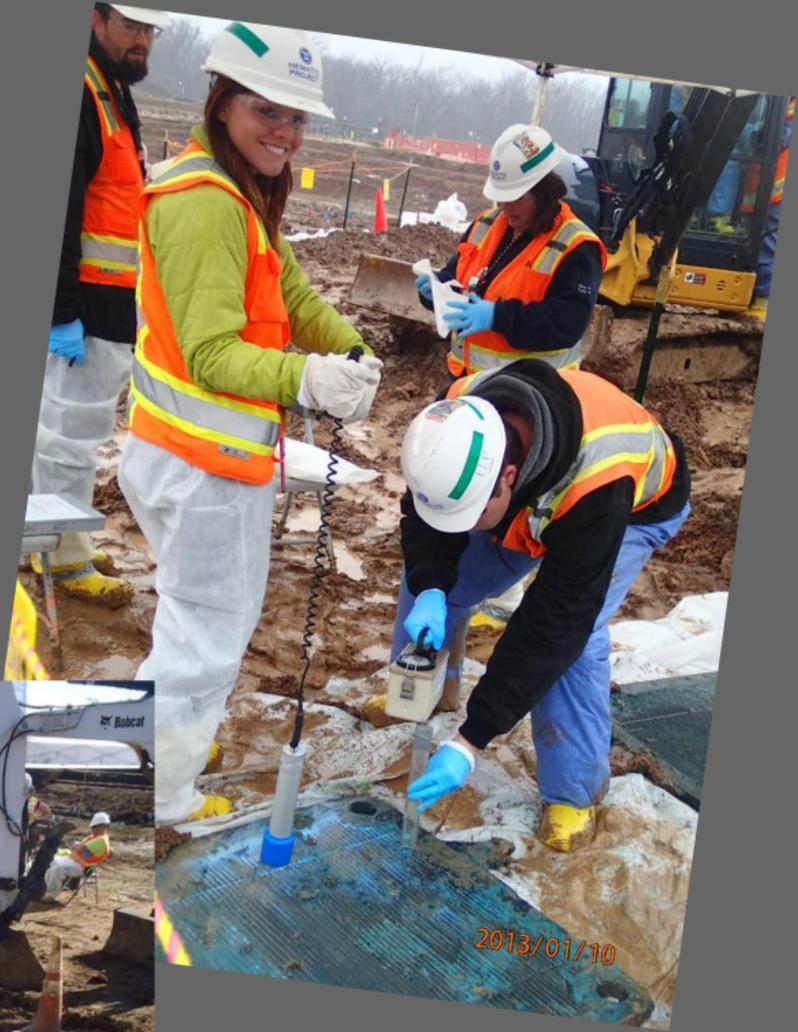
Subsurface Piping



Non-Conforming Items,  
Intact Containers



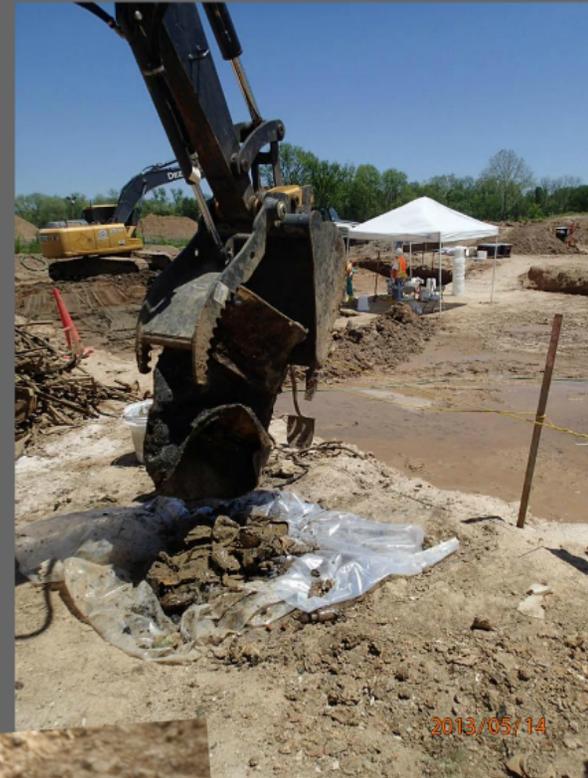
# Field Measurements



# In-situ Field Measurements



# Burial Pits



Process wastes,  
garbage



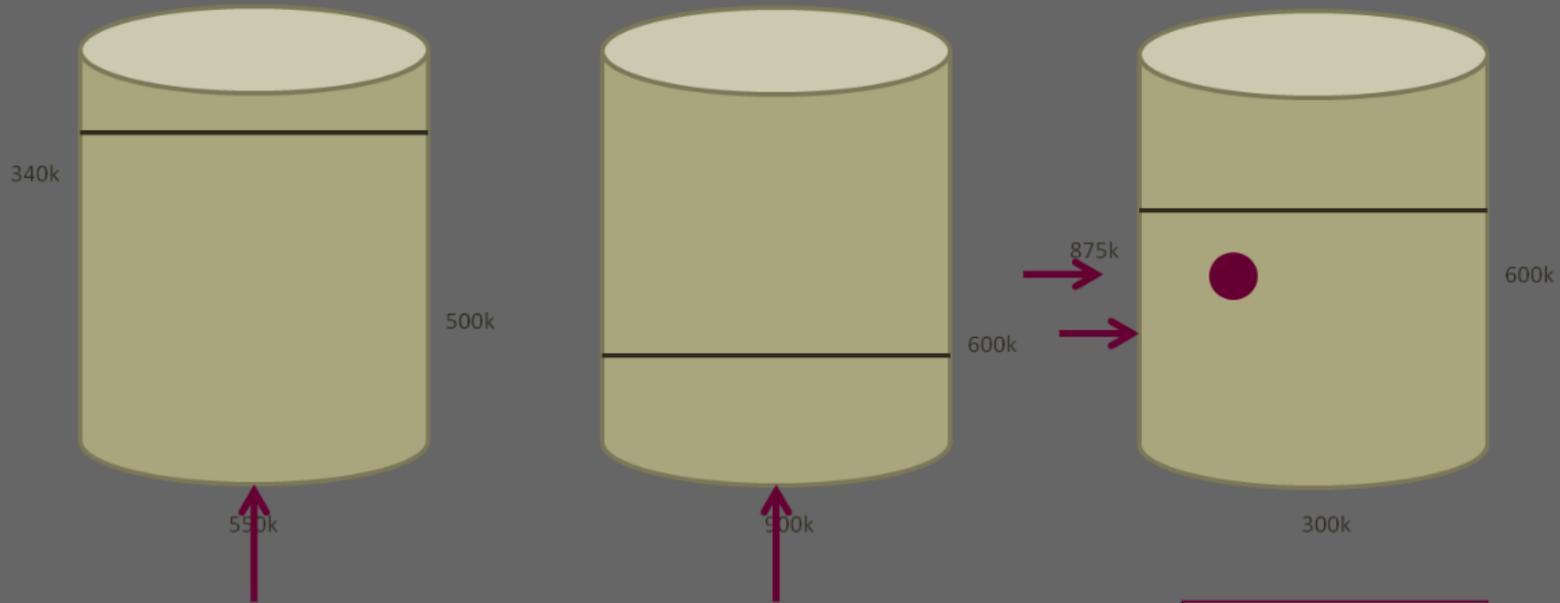
# Non-Conforming Items, Intact Containers



# Subsurface Piping



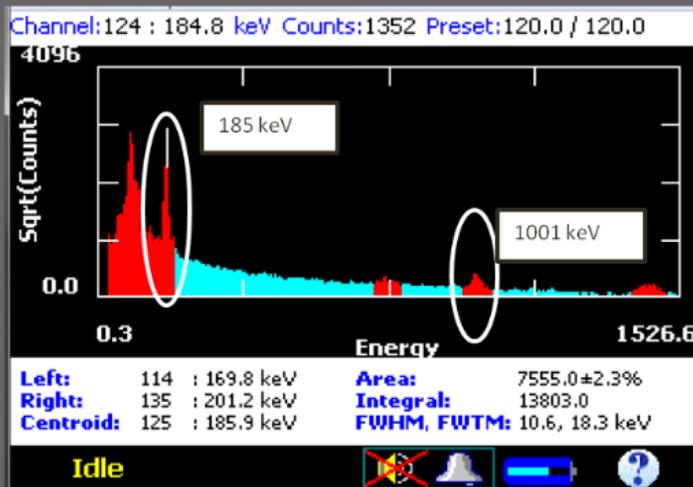
# Example Measurements



FC model  
95% full

FC model  
25% full

2" or 4" lump  
model; FC  
model 75% full



$$E_{nr} = \frac{\text{cpm (1001 keV)}}{\text{cpm (185 keV)}}$$

# CONCLUSIONS

- InSpector 1000 with the LaBr probe is excellent for quick, in-field gamma measurements
- Identify nuclides and quantities of concern for NCS in real-time
- Enhances integrity of NCS program
- Multiple methods to quantify fissile material and enrichment
- MCNP and ISOCS software methods have good agreement for efficiency

