PUR-1 DETECTION SYSTEM FOR SUB-PICOCURIE PER CC CONCENTRATIONS OF Ar-41 IN AIR

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Project Background

10 CFR 20 Derived Air Concentrations (DACs) and Effluent Concentration Limits

- Occupational Values (DAC): 3E-06 µCi/ml
- Effluent Concentrations (Air): 1E-08 µCi/ml

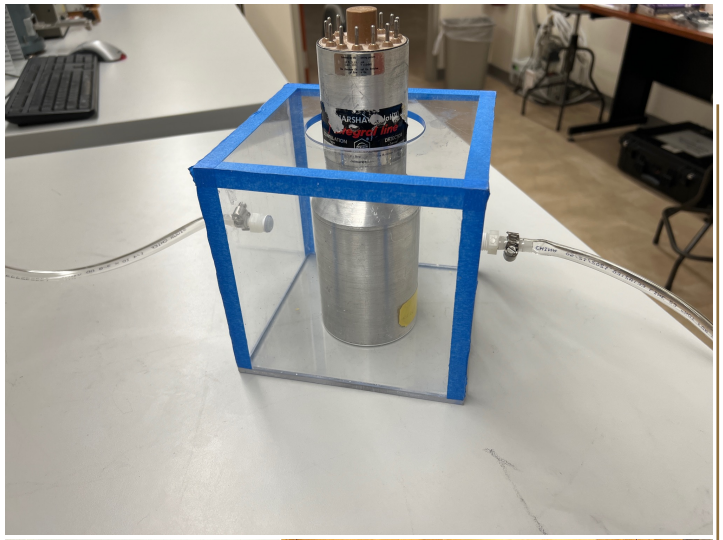
Purdue FSAR

- Analytical calculation based on conservative values of pool circulation, water to air gas exchange, Ar-40 solubility etc.
- Conservative estimate of maximum steady-state Ar-41 concentration in reactor room of:
  2.085 E-07 µCi/ml = 0.0077 Bq/cc
- Goal to develop measurement system sensitive down to 1 mBq/cc

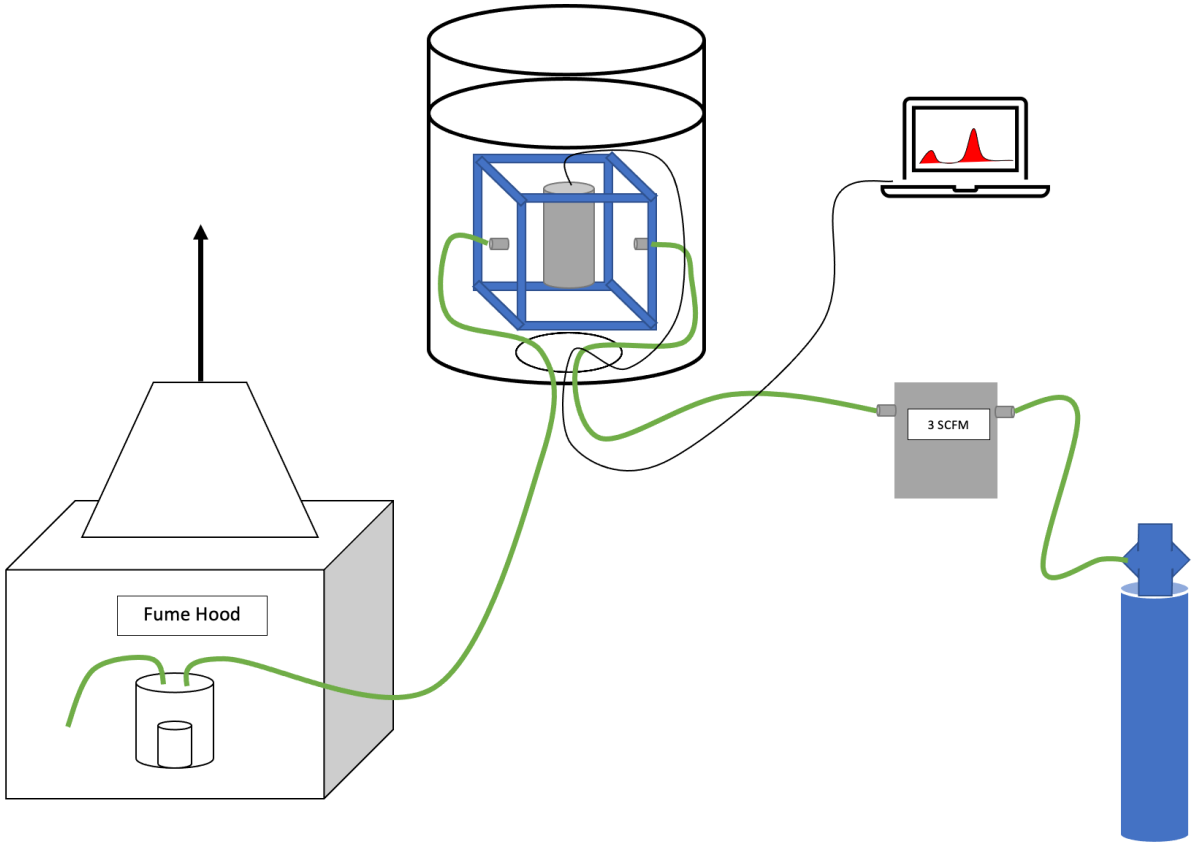
Detection System Components

Components

- 460 mL DOT-3E type compressed air cylinder w/ gas regulator
- Sierra Instruments SmartTrak 50 Digital Flowmeter
- 17cm x 17cm airtight acrylic box with inlet and outlet nozzles (net ~4 L volume)
- 3″ Harshaw 12SW12-W3 NaI(Tl) Scintillation Detector
- ORTEC GEM 25210 HPGe Detector
- Canberra Ultra-Low Background Shield
- 1 L marinelli beaker
- Laptop with MAESTRO MCA software installed
- ¼″ clear tubing



Detection System Layout



Ar-41 Calibration Source Production

Air Irradiation

- Cylinder filled with air to ~1500 PSI
- 16 gold foils spaced equally, both axially and radially, used to determine the flux the air was exposed to
- Cylinder lowered adjacent to PUR-1 core in 3″ PVC drop tube and irradiated at a predetermined flux to generate known Ar-41 concentration samples

Ar-41 Calibration Source

Ar-41 Activity Calculations

- Flux from gold foil activation determined by:

$$\phi = \frac{A_{0,198} \cdot \rho}{N \cdot \sigma \cdot m(1-e^{\lambda t_{irr}})e^{-\lambda t_d}}, \quad A_{0,198} = \frac{\dot{C} e^{\lambda t_d}}{B.R \cdot \epsilon}$$

- Ar-41 concentration determined by:

$$A_{0,41} = N_{40}\sigma_{40}\lambda\phi(1 - e^{\lambda t_{irr}})$$

Parameters		
$\frac{mol_{Ar}}{mol_{air}}$	0.00934	--
N_{40}	2.33861E+17	#/cm^3
σ_{40}	6.60E-25	cm^2
$t_{1/2,40}$	109.61	min
λ	0.00632376	min^-1

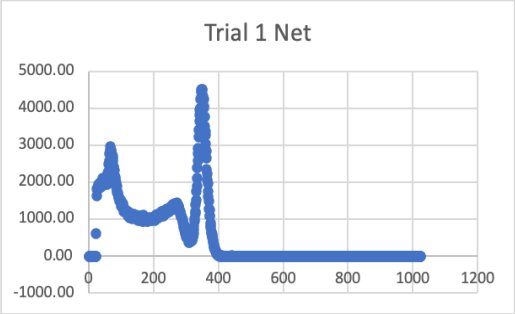
Trial	Average Power (% FP)	Average Flux (n/cm^2-s)	t_irr (min)	t_d (min)	Bq/cc (Ar-41)
1	10.0565%	1.53E+08	10.0	58.583	0.997171
2	0.9998%	1.42E+07	10.0	48.733	0.098341
4	0.0960%	1.37E+06	10.0	46.700	0.009613
5	0.0100%	1.49E+06	5.0	59.283	0.004906
6	0.00101%	1.41E+05	10.0	48.467	0.000980

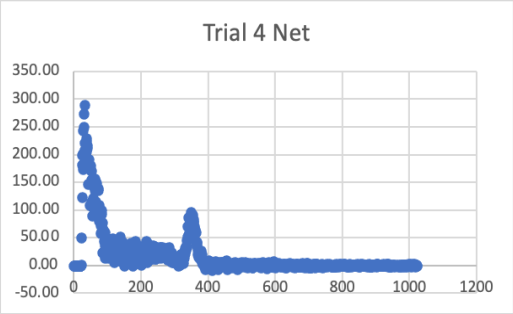
Detector Calibration Curve

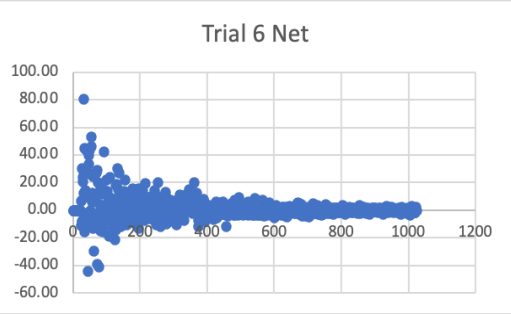
Correlating recorded CPS to Activity

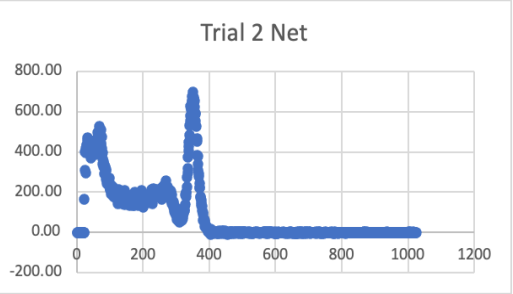
- 5 samples ranging in activity from 1 Bq/cc to 0.001 Bq/cc sent through detection system.
- Gamma spectrum recorded for 1 hour each
- 2-hour background recorded and subtracted from sample spectrum
- Resulting net counts in the 1294 keV Ar-41 peak determined and plotted against calculated Ar-41 activities
- Experimental sample then taken from reactor room after 8-hour run at full power (10 kW) and sent through detection system and plotted on calibration curve

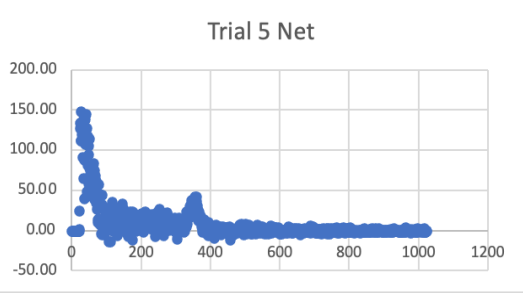
NaI(Tl) Detector Results

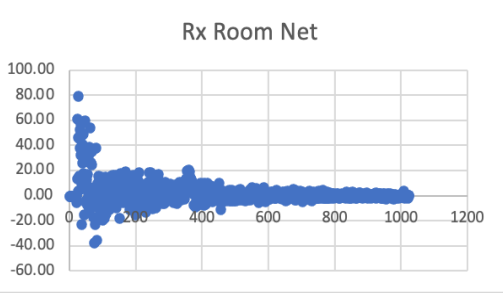




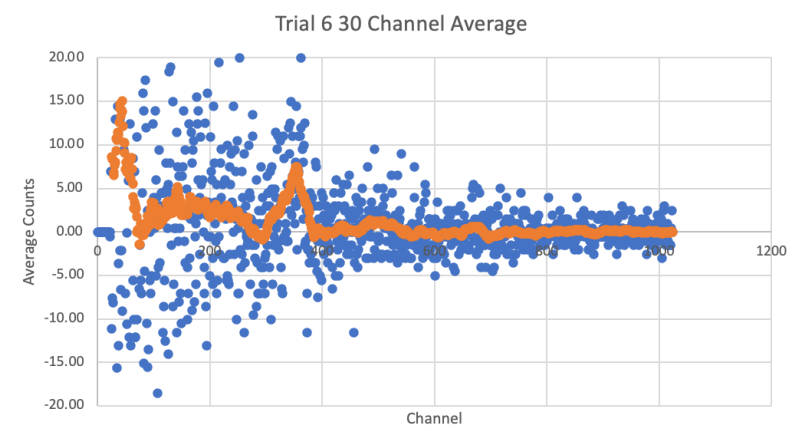


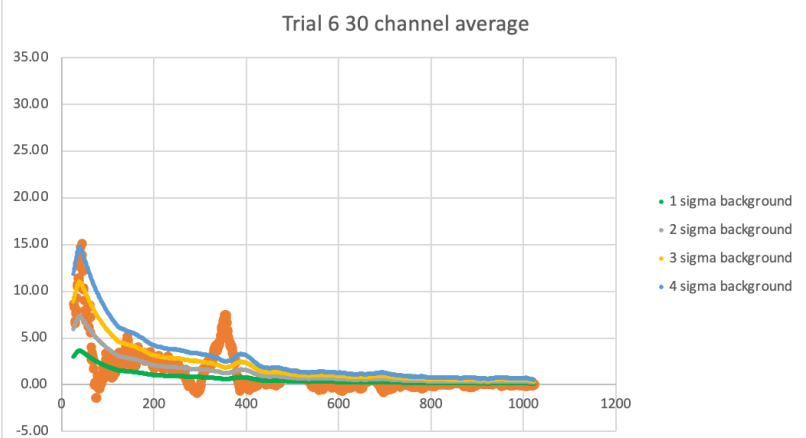


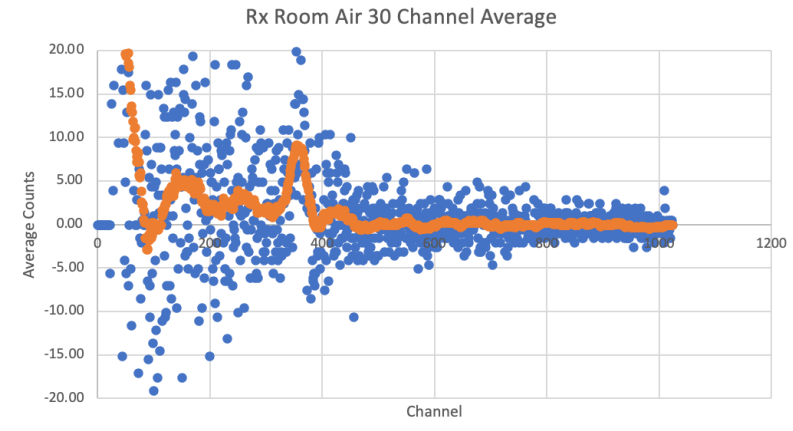


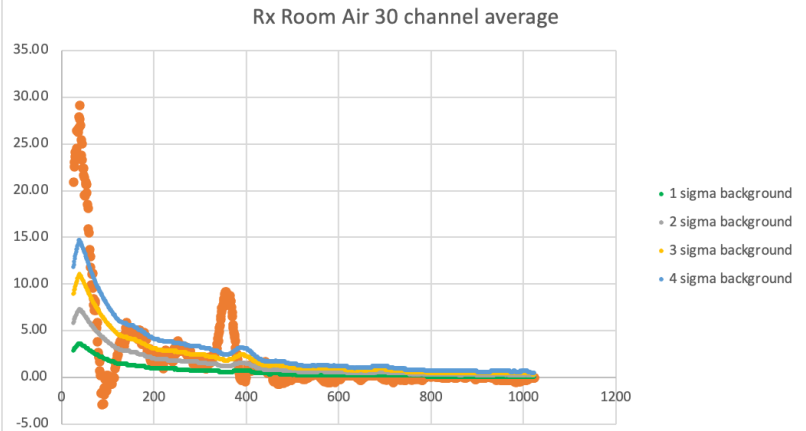


NaI(Tl) Detector Results





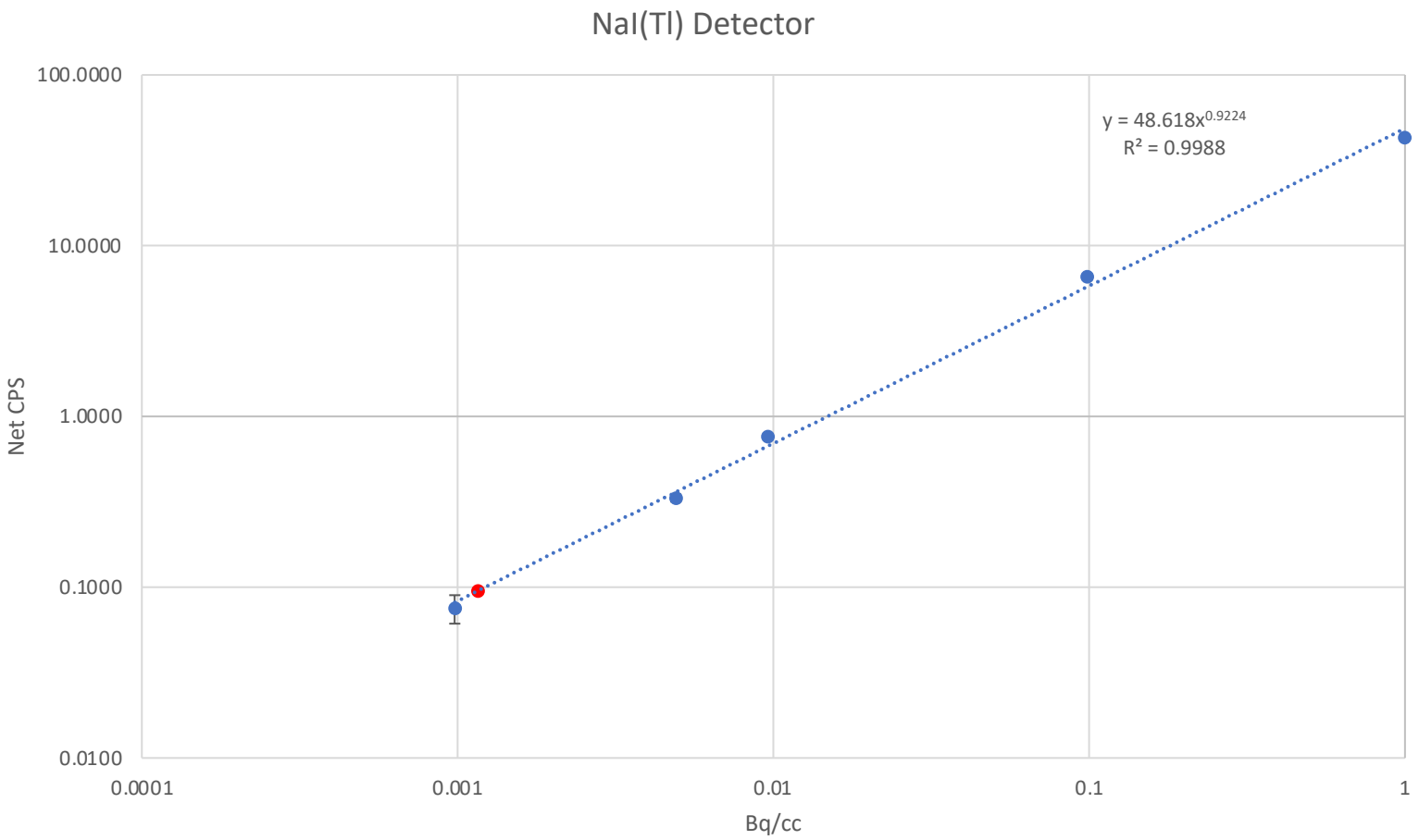




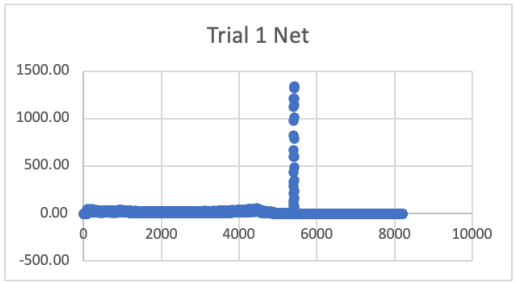
NaI(Tl) Detector Results

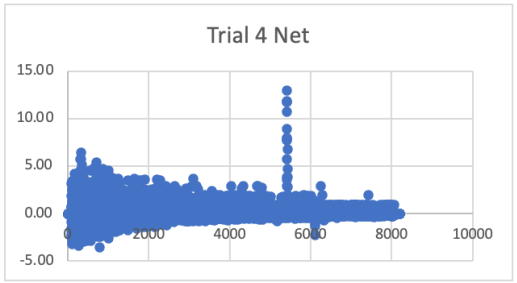
	Gross Counts	+/-	Net Counts	+/-	Measurement Time (live) (s)	Net CPS	+/-	Bq/cc
Trial 1	156371	395.44	154780.77	423.63	3600.52	42.988	0.110	0.997171
Trial 2	25357	159.24	23766.68	187.43	3600.72	6.600	0.045	0.098341
Trial 4	4344	65.91	2753.68	94.10	3600.72	0.765	0.020	0.009613
Trial 5	2867	53.54	1233.85	81.74	3697.7	0.334	0.016	0.004906
Trial 6	1862	43.15	271.77	71.35	3600.52	0.076	0.014	0.000980
Rx Room	1933	43.97	343.00	72.16	3600	0.095	0.015	0.001160

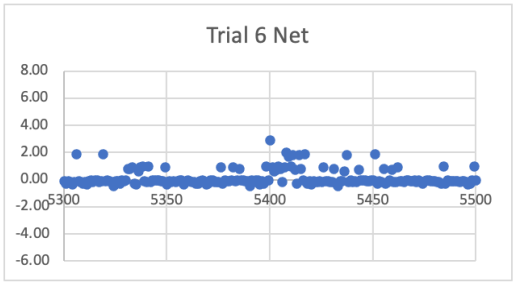
NaI(Tl) Detector Results

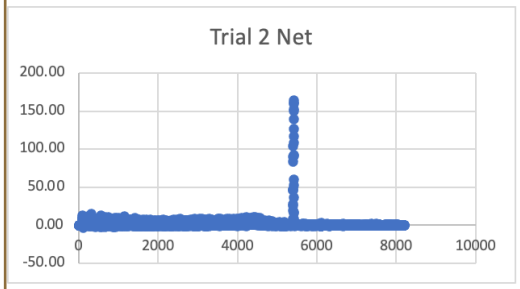


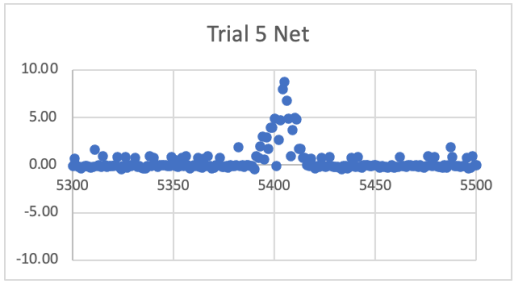
HPGe Detector Results

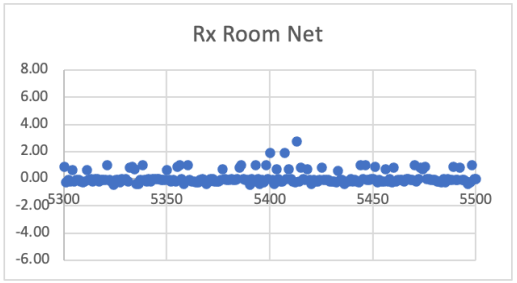








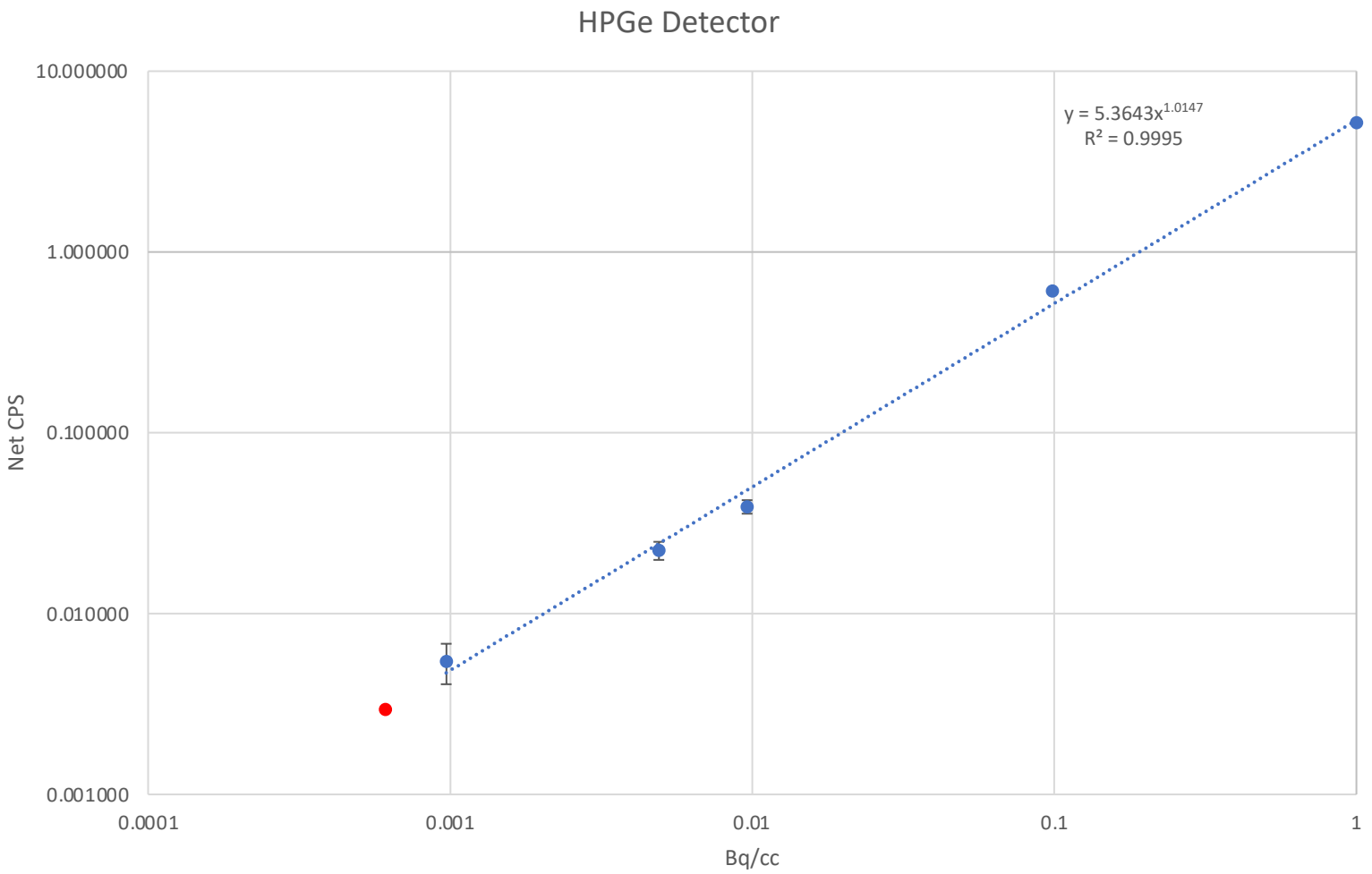




HPGe Detector Results

	Gross Counts	+/-	Net Counts	+/-	Measurement Time (live) (s)	Net CPS	+/-	Bq/cc
Trial 1	18960	137.70	18732.58	138.30	3600	5.203495	0.0382	0.997171
Trial 2	2191	46.81	2186.58	47.41	3600	0.607384	0.0130	0.098341
Trial 4	145	12.04	140.58	12.65	3600	0.039051	0.0033	0.009613
Trial 5	85	9.22	80.58	9.83	3600	0.022384	0.0026	0.004906
Trial 6	24	4.90	19.58	5.51	3600	0.005440	0.0014	0.000980
Rx Room	15	3.87	10.58	4.48	3600	0.002940	0.0011	0.000611

HPGe Detector Results



Results and Conclusions

- NaI scintillation detector found to work better than HPGe detector due to its' greater sensitivity

- A final reactor room concentration, after 8-hours at full power, was found to be 0.0016243 Bq/cc = 4.39E-08 µCi/ml

Case	Ar-41 Concentration
Occupational Limit (DAC)	3E-06 µCi/ml
Average Effluent Concentration Limit	1E-08 µCi/ml
Conservative Calculation	2.085E-07 µCi/ml
Measured (Peak) Concentration	4.39E-08 µCi/ml
Average Annual Effluent Concentration *	5.01E-10 µCi/ml

* Assuming a conservative equivalent 100 hours at full power per year (1000 kWh/yr)

THANK YOU

Questions?