National Mining Association

Experimental Determination of Radon Fluxes over Water

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Introduction

- This presentation will:
  - Discuss prior information regarding radon fluxes from water surfaces
  - Discuss laboratory research funded by the National Mining Association (NMA) regarding radon fluxes from water surfaces.
  - Compare the results of the research with previously reported data.
  - Show that radon fluxes from most water surfaces at uranium recovery operations are insignificant and approximate background soil fluxes for most areas.

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Prior Work

- Information regarding radon fluxes from water surfaces has been presented on the following two (2) occasions:
  - *Radon Emissions From Tailings Ponds* - Dr. Douglas B. Chambers - July 2, 2009
  - *Radon Flux from Evaporation Ponds* – Dr. Kenneth R. Baker, Ph.D. Environmental Restoration Group, Inc and Alan D. Cox - Homestake Mining Company of California

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Prior Work - *continued*

- *Radon Emissions From Tailings Ponds* - Dr. Douglas B. Chambers - July 2, 2009
  - Discussed Rn-222 gas exchange via diffusion from the surface of a small lake (Experimental lakes, Ontario)
  - Concluded that Radon-222 releases were low as shown in the table below:

Ra-226 (pCi/L)	Depth of Turbulent Mixing (cm)	Rn-222 ($pCi/m^2 \cdot s$)
10	10	0.002
	50	0.01
100	10	0.02
	50	0.1
1000	10	0.2
	50	1

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Prior Work - *continued*

- *Radon Flux from Evaporation Ponds* – Dr. Kenneth R. Baker, Ph.D. Environmental Restoration Group, Inc and Alan D. Cox - Homestake Mining Company of California
  - Measured radon flux from an evaporation pond using modified floating Large Area Activated Charcoal Canisters (LAACCs)
  - Concluded that radon fluxes obeyed the Stagnant Film Model (SFM) and that flux rates in picoCuries per meter2-second were approximately 0.01 times the Radium-226 activity of the water. The Radon-222 activity of the water was not measured in this experiment and was assumed to be in equilibrium with the dissolved Radium-226.
  - A picture of the floating Large Area Activated Charcoal Canister (LAACC) used is shown below:

Discussion of Prior Work

- Both prior experiments were performed in outdoor environments specifically in experimental lakes or evaporation ponds under non-laboratory conditions.
- No specific data regarding actual Radon-222 activity of the water was provided for either experiment.

Purpose of this Research

- This current research was performed to determine Radon-222 flux at the surface of water containing Radium-226 and Radon-222 under controlled laboratory conditions using an accepted method of determining Radon – 222 flux, specifically using Large Area Activated Charcoal Canisters (LAACCs) as described in *Radon Flux Measurements on Gardiner and Royster Phosphogypsum Piles Near Tampa and Mulberry, Florida* since this is the currently accepted method of determining radon flux in Method 115 referenced in 40 CFR Part 61.253 *Determining compliance*.
- In this way, data gathered in the course of this study can be effectively compared with other data collected in prior compliance monitoring work using Large Area Activated Charcoal Canisters (LAACCs) since the measurement method is the same.

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Testing Protocol

- Five (5) barrels containing deionized water with the following Radium-226 activities were created using a traceable Radium-226 standard:
  - 0 picoCuries per liter (water with no added Radium-226)
  - 5,000 picoCuries per liter
  - 10,000 picoCuries per liter
  - 15,000 picoCuries per liter
  - 20,000 picoCuries per liter

The solutions were placed in barrels as shown below:

The Radium – 226 in the solutions in the barrels was allowed to attain radiometric equilibrium with the Radon-222 by being allowed to sit covered for forty (40) days (slightly over ten (10) half lives for Radon-222).

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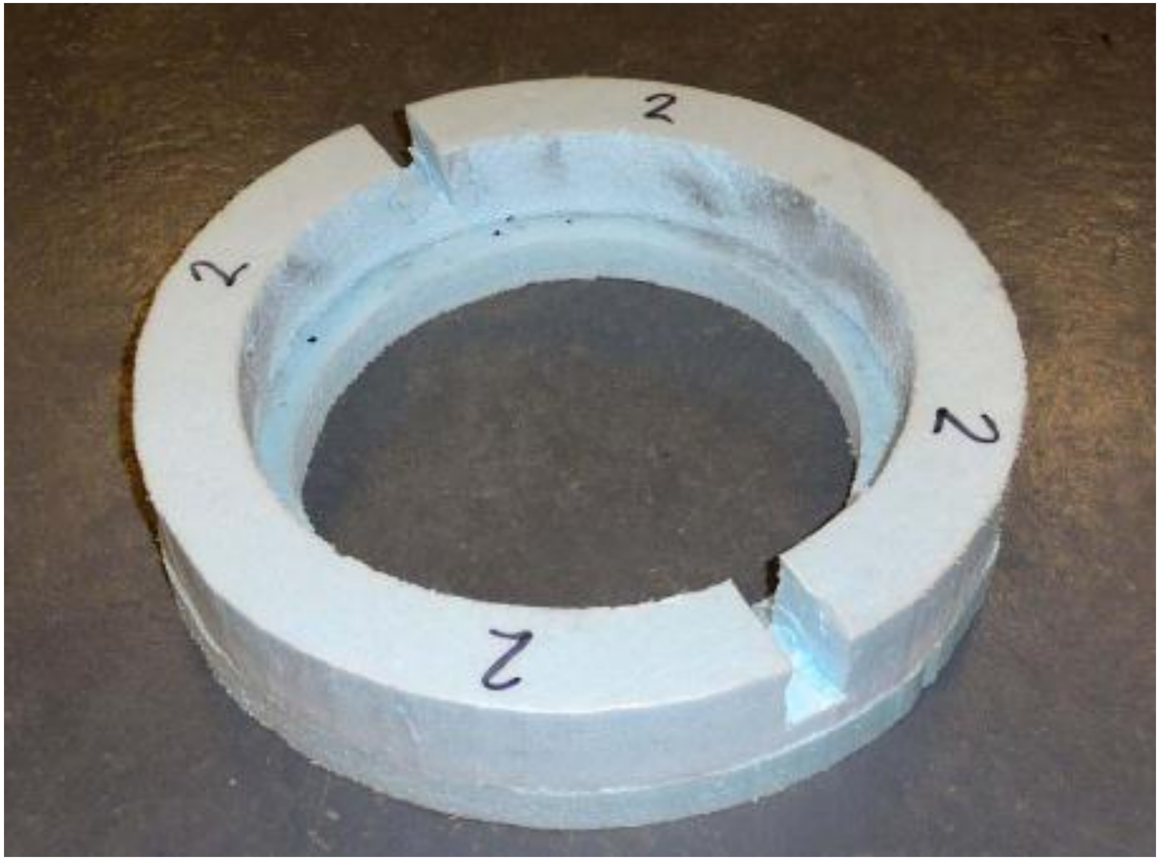
Testing Protocol *continued*

- Styrofoam floats were created to float the Large Area Activated Charcoal Canisters (LAACCs) over the water in the barrels as shown below:



Testing Protocol *continued*

- The Large Area Activated Charcoal Canisters (LAACCs) were installed in the floats as shown below:

The Large Area Activated Charcoal Canisters (LAACCs) fit snugly in the float to create a seal.
They are similar in appearance to the ones used by Dr. Kenneth R. Baker.

Testing Protocol continued

- The Large Area Activated Charcoal Canisters (LAACCs) were floated on top of the Radium-226/Radon-222 bearing water in the barrels as shown below:

The weight of the Large Area Activated Charcoal Canister (LAACC) unit presses the float into the water creating a seal between the water and the float.

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Testing Protocol *continued*

- Barrels of Radium-226 solution were prepared.
- The analysis results for the barrels were as follows:

Barrel Number	Prepared Radium-226 Activity	Measured Radium-226 Activity	Measured Radon-222 Activity
	pCi/L	pCi/L	pCi/L
1	0.0	-0.5	32. 4
2	5,000.	4,580.	5500.
3	10,000.	9,450.	11000.
4	15,000.	13,900.	16600.
5	20,000.	19,200.	21500.

•The barrels were allowed to attain radiometric equilibrium for forty (40) days (slightly over ten (10) half lives for Radon-222).
•A very high Radium-226 activity (higher than would be encountered in operations) was used to test relationships under extreme conditions.
•Data reported to the number of significant figures provided in final report.

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Testing Results

Test Summary								
	Date Canister Set	Date Canister Removed	Radium-226 Activity Reported	Radium-226 Activity Used	Radon-222 Activity	Reported Flux Rate	Flux rate Used
			pCi/L	pCi/L	pCi/L	pCi/M2-sec	pCi/M2-sec
Day 1	7/31/11	8/1/11	-0.5	0.0	32. 4	<0.5	0.0
Day 1	7/31/11	8/1/11	4,580.	4,580.	5500.	2.8	2.8
Day 1	7/31/11	8/1/11	9,450.	9,450.	11000.	5.6	5.6
Day 1	7/31/11	8/1/11	13,900.	13,900.	16600.	8.8	8.8
Day 1	7/31/11	8/1/11	19,200.	19,200.	21500.	12.	12.
Day 2	8/1/11	8/2/11	-0.5	0.0	32. 4	<0.5	0.0
Day 2	8/1/11	8/2/11	4,580.	4,580.	5500.	2.4	2.4
Day 2	8/1/11	8/2/11	9,450.	9,450.	11000.	4.3	4.3
Day 2	8/1/11	8/2/11	13,900.	13,900.	16600.	6.8	6.8
Day 2	8/1/11	8/2/11	19,200.	19,200.	21500.	8.3	8.3
Day 3	8/2/11	8/3/11	-0.5	0.0	32. 4	<0.5	0.0
Day 3	8/2/11	8/3/11	4,580.	4,580.	5500.	2.2	2.2
Day 3	8/2/11	8/3/11	9,450.	9,450.	11000.	4.6	4.6
Day 3	8/2/11	8/3/11	13,900.	13,900.	16600.	6.8	6.8
Day 3	8/2/11	8/3/11	19,200.	19,200.	21500.	8.9	8.9
Day 4	8/3/11	8/4/11	-0.5	0.0	32. 4	<0.5	0.0
Day 4	8/3/11	8/4/11	4,580.	4,580.	5500.	1.9	1.9
Day 4	8/3/11	8/4/11	9,450.	9,450.	11000.	3.7	3.7
Day 4	8/3/11	8/4/11	13,900.	13,900.	16600.	5.5	5.5
Day 4	8/3/11	8/4/11	19,200.	19,200.	21500.	7.3	7.3
Day 5	8/4/11	8/5/11	-0.5	0.0	32. 4	<0.5	0.0
Day 5	8/4/11	8/5/11	4,580.	4,580.	5500.	2.0	2.0
Day 5	8/4/11	8/5/11	9,450.	9,450.	11000.	3.5	3.5
Day 5	8/4/11	8/5/11	13,900.	13,900.	16600.	4.8	4.8
Day 5	8/4/11	8/5/11	19,200.	19,200.	21500.	7.9	7.9
Day 6	8/5/11	8/6/11	-0.5	0.0	32. 4	<0.5	0.0
Day 6	8/5/11	8/6/11	4,580.	4,580.	5500.	2.0	2.0
Day 6	8/5/11	8/6/11	9,450.	9,450.	11000.	3.5	3.5
Day 6	8/5/11	8/6/11	13,900.	13,900.	16600.	5.0	5.0
Day 6	8/5/11	8/6/11	19,200.	19,200.	21500.	6.6	6.6

Notes:
- Reported Radium-226 activity of -0.51 set to zero for calculation purposes.
- Reported Radon-222 flux of <0.5 set to zero for calculation purposes
- Data reported to the number of significant figures provided in final report.

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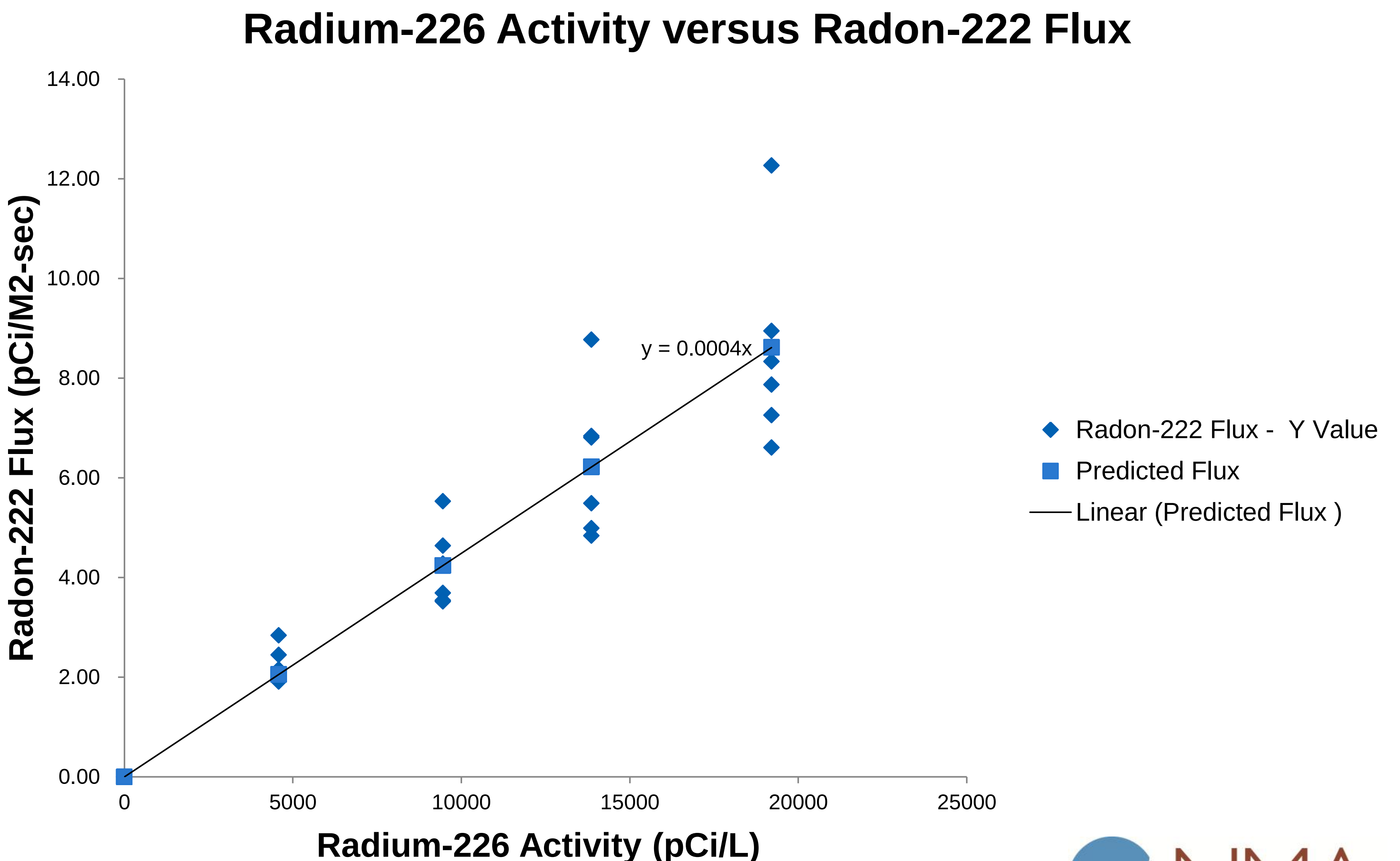
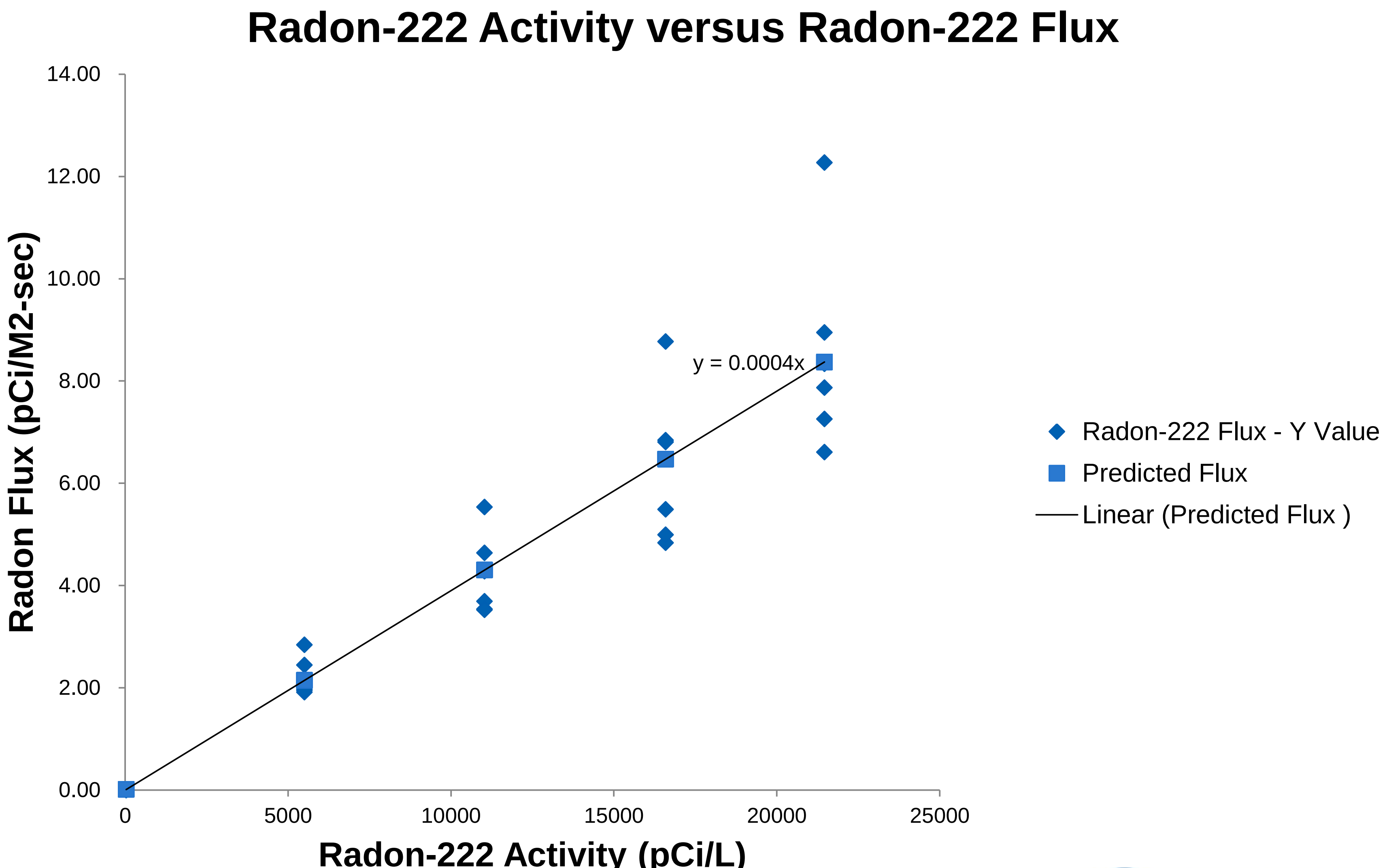
Radium-226 Activity versus Radon-222 Flux Rate



Note: The R^2 (correlation coefficient squared) value is 0.96, showing good linear correlation.

Radon-222 Activity versus Radon-222 Flux Rate



Note: The R^2 (correlation coefficient squared) value is 0.96, showing good linear correlation.

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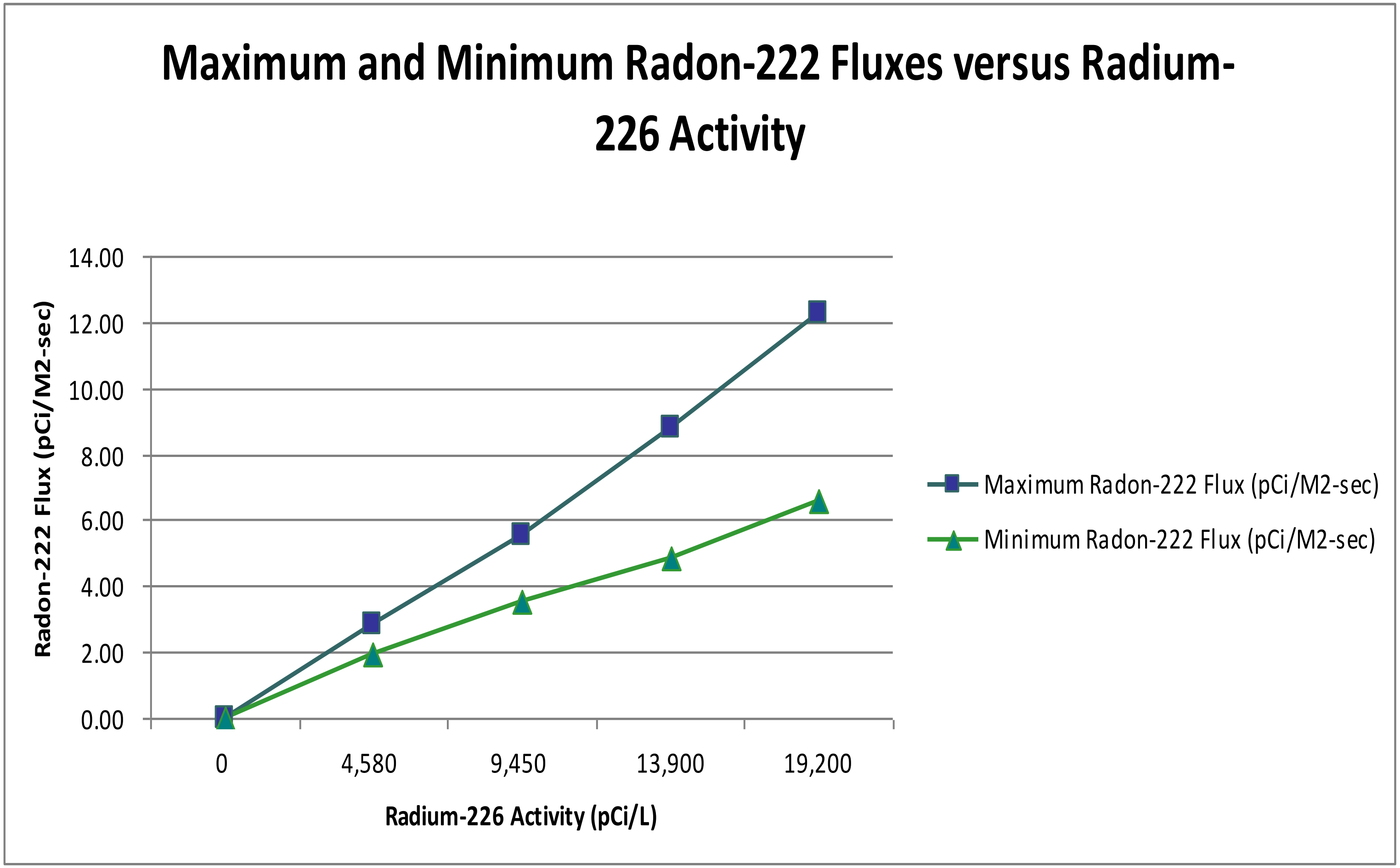
Maximum and Minimum Radon-222 Fluxes versus Radium-226 Activity of the Water



Maximum Slope = 0.00064
Minimum Slope = 0.00034
Average Slope = 0.0004 (previous slide)

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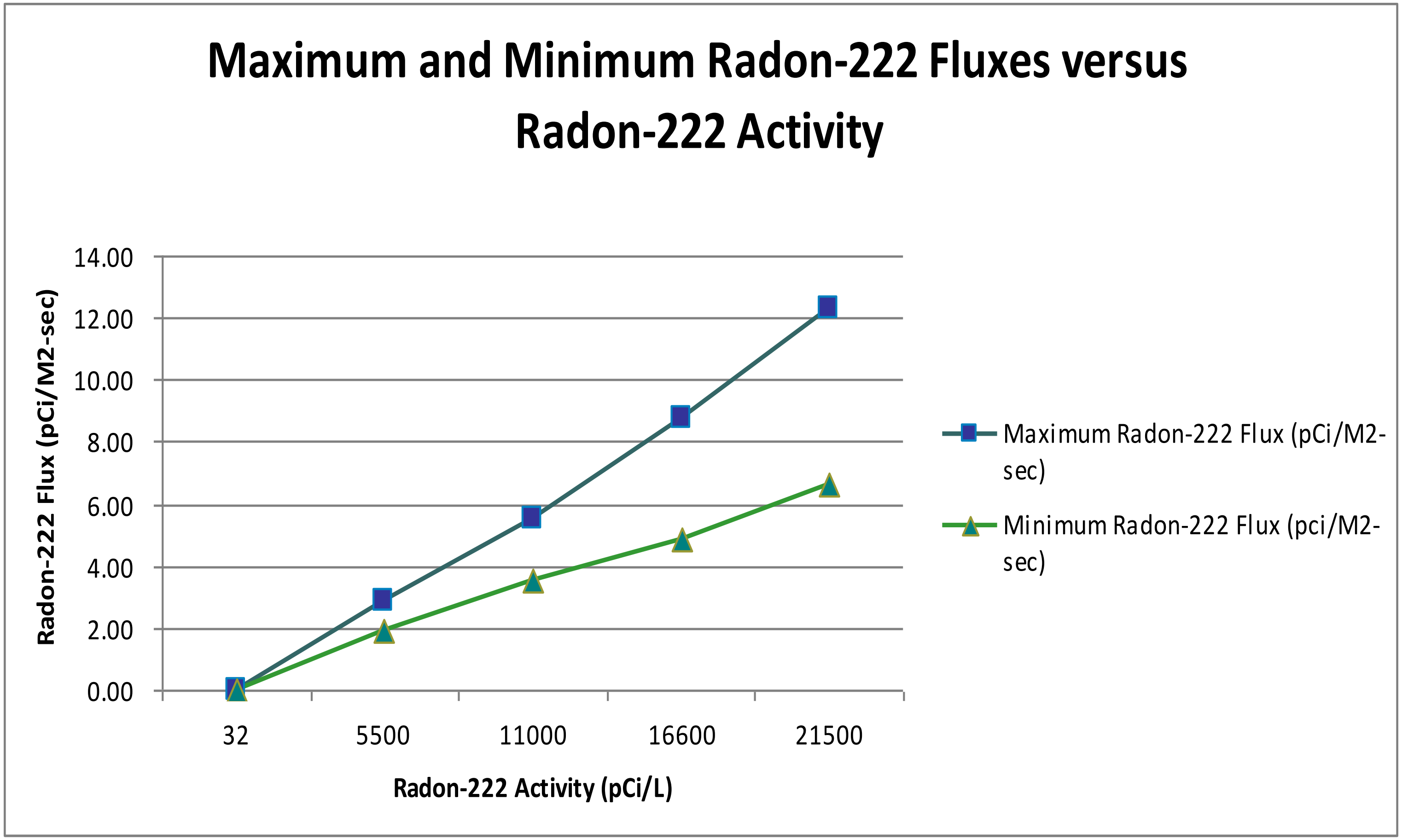
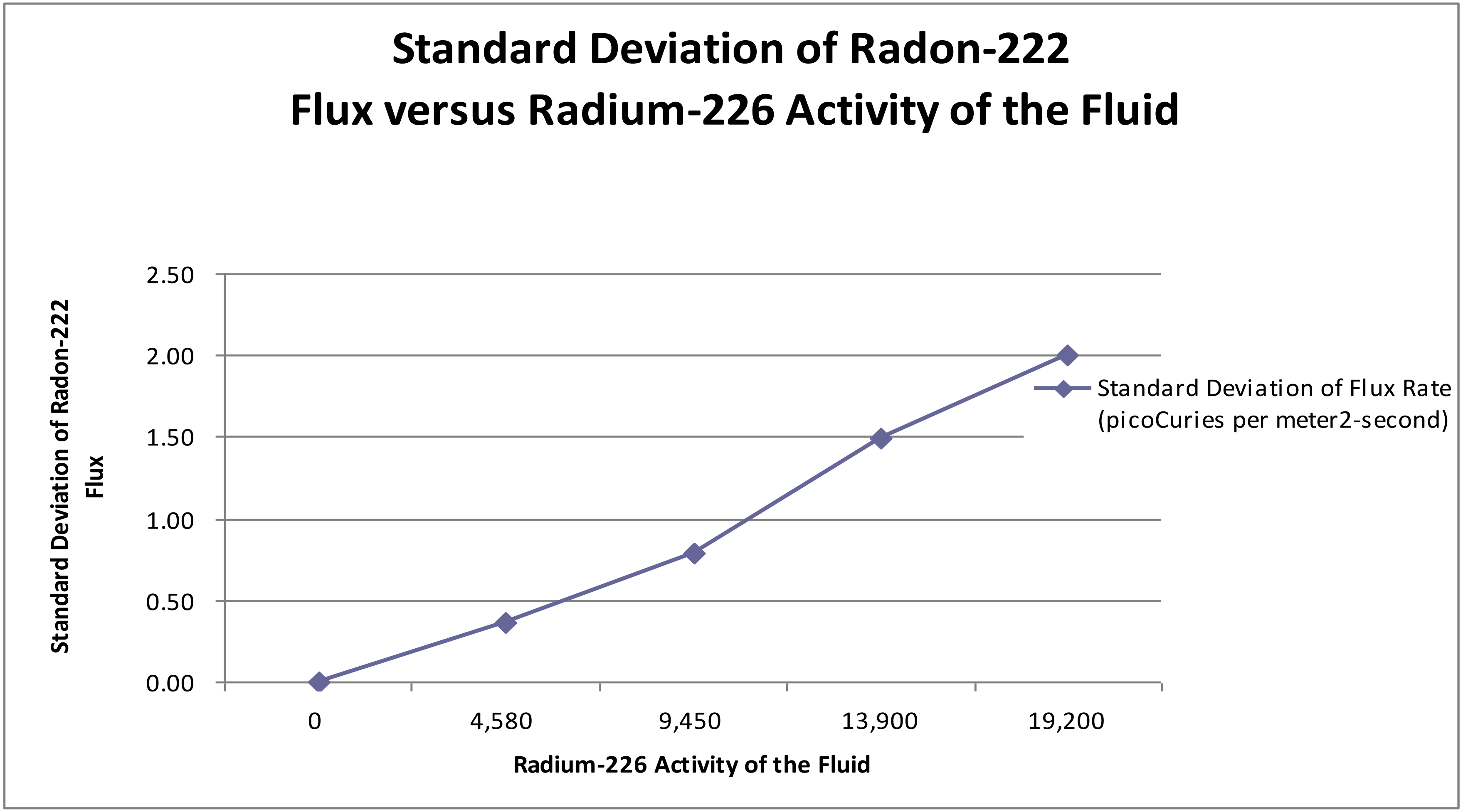
Maximum and Minimum Radon-222 Fluxes versus Radon-222 Activity of the Water



Maximum Slope = 0. 00057
Minimum Slope = 0.00031
Average Slope = 0.0004 (previous slide)

Standard Deviation of Radon-222 Flux versus Radium-226 Activity of the Water



Standard deviation of the Radon-222 flux equals approximately 0.0001 times the Radium-226 activity of the fluid.

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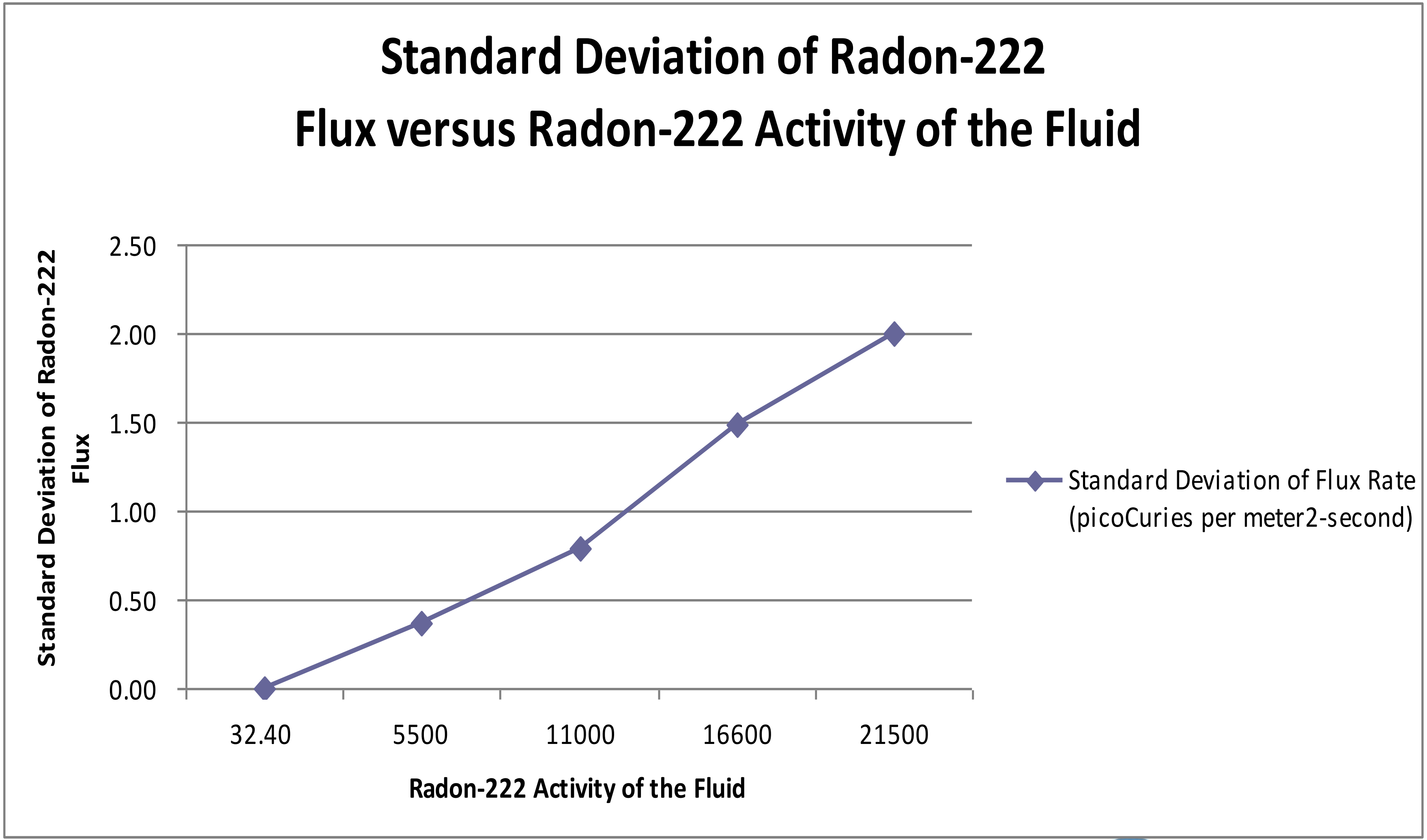
Standard Deviation of Radon-222 Flux versus Radon-222 Activity of the Water



Standard deviation of the Radon-222 flux equals approximately 0.0001 times the Radon-222 activity of the fluid.

Conclusions

- Radon-222 flux is linearly dependent upon Radon-222 activity of the fluid even at high fluid Radon-222 activities.
- Standard deviation of the flux rate is also linearly dependent upon the Radon-222 activity of the fluid approximating 0.0001 times the Radon-222 activity.
- In a normal distribution, 95.4% of the measurements will lie within two (2) standard deviations from the mean.
- The mean of the flux rate is related linearly to the Radon-222 activity of the fluid approximating 0.0004 times the Radon-222 activity.
- For the measured Radon-222 activities of the fluid in the barrels, 95.4% of the measured flux rates at the fluid surface can be calculated by the following equation:
    - Radon-222 Flux = 0.0004*(Radon-222 Activity) +/- 2*(0.0001)*(Radon-222 Activity) which simplifies to:
    - Radon-222 Flux = 0.0004*(Radon-222 Activity) +/-0.0002(Radon-222 Activity)
- This equates well with the relationship between the maximum flux rates and Radon-222 activity of 0.00057*(Radon-222 Activity)

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Conclusions *continued*

•This experimental data does not correlate well with fluxes derived from application of the Stagnant Film Model (SFM). The Stagnant Film Model (SFM) appears to be too conservative, over estimating fluxes by at least an order of magnitude.

•This data however correlates fairly well with data presented by Dr. Douglas Chambers regarding the experimental lake, shown again below:

Ra-226 (pCi/L)	Depth of Turbulent Mixing (cm)	Rn-222 ($pCi/m^2 \cdot s$)
10	10	0.002
	50	0.01
100	10	0.02
	50	0.1
1000	10	0.2
	50	1

The experimental data lies between the Radon-222 fluxes from turbulent mixing depths of 10 and 50 centimeters.

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Conclusions *continued*

- The above discussed experimental data fits well with the Radon-222 flux data obtained by another uranium recovery licensee in tests conducted in its tailings impoundment in August 2010 that was recently submitted to the Environmental Protection Agency (EPA).
- Radon-222 fluxes from water surfaces even in the case of high Radium-226 and Radon-222 activities are minimal and in the case of fluid Radium-226 activities up to 5,000 pCi/L are within the range and variability of natural background assuming a *typical planet wide background flux of 1 - 2 pCi/m2 - sec* (Steven H Brown, CHP, SENES Consultants Limited – November 7, 2010).
- Construction of a fluid retention impoundment and filling it with water containing up to 5,000 pCi/L Radium-226 would just displace normal background surface flux in most areas.

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