QUALIFICATION OF TENSIONED METASTABLE FLUID DETECTORS FOR SPECTROSCOPIC RADON & PROGENY DETECTION UNDER RANGE OF ENVIRONMENTAL CONDITIONS

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Abstract

Radon gas is an alpha emitting nuclide often found in homes and buildings from the U-238 decay chain. The US-Environmental Protection Agency (EPA) estimates that radon and its progeny are the cause of over 21,000 annual deaths from lung cancer in the United States alone. It is known that the accuracy in radon measurements can be affected by environmental conditions such as temperature and humidity. Purdue University, together with Sagamore Adams Laboratories LLC have developed the tensioned metastable fluid detector (TMFD) sensor technology for efficient and cost-effective Rn and progeny spectroscopic detection in a variety of environmental conditions. For radon detection, radon gas mixed with air is sparged through the TMFD detection fluid. This radon-bearing fluid is then placed into a tensioned metastable state. Under tailored metastable state, the fluid becomes sensitive to the recoil nuclei during alpha decay. When recoil nuclei deposit enough energy over nanometer scales into the sensitive fluid, the intermolecular bond energies are overcome resulting into a transient (microsecond) bubble growing to macroscopic dimensions; an audible-visible cavitation detection event is created and recorded. TMFDs are blind to gamma and beta radiation while operating with high (>95%) intrinsic detection efficiencies enabling alpha spectroscopy as well. TMFDs were used to measure the concentration of radon and radon progeny in air for the environmental test conditions set forth by the American Association of Radon Scientists and Technologists-National Radon Proficiency Program (AARST-NRPP) Device Evaluation Program (DEP). These test conditions include measurements from: temperatures spanning 13° C to 26° C, noncondensing relative humidity spanning 15% to 95%, atmospheric pressure spanning 70 kPa to 106 kPa, background photon radiation, nonionizing external EM fields, shock and vibration, and air movement from 0 m s^{-1} to 0.2 m s^{-1}. In most tests, measurements were taken at radon concentrations ranging from 37 Bq m^{-3} (1 pCi L^{-1}) to 1480 Bq m^{-3} (40 pCi L^{-1}). It was found that temperature affects the radon collection process, for which, a dynamic compensation algorithm was developed - for, accurate radon measurements below and above the US EPA action level of 148 Bq m^{-3} (4 pCi L^{-1}). Remaining AARST parametric influences were found to have small or negligible effect on the radon collection process and associated measurements. This paper will discuss details of the TMFD based spectroscopic Rn/progeny detection assessments and results, thereof.

Introduction

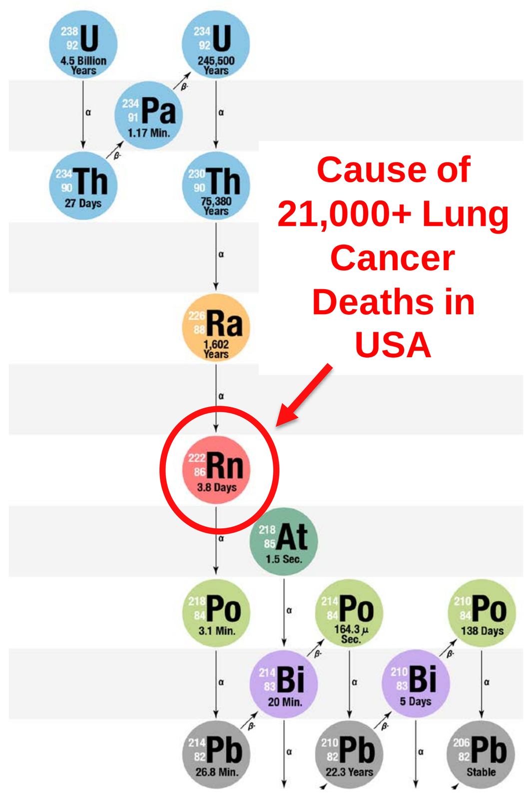

Fig 1. Radon-222 Decay Scheme

$$p_{neg} = 2 * \pi^2 * \rho * r^2 * f^2 - p_{amb}$$

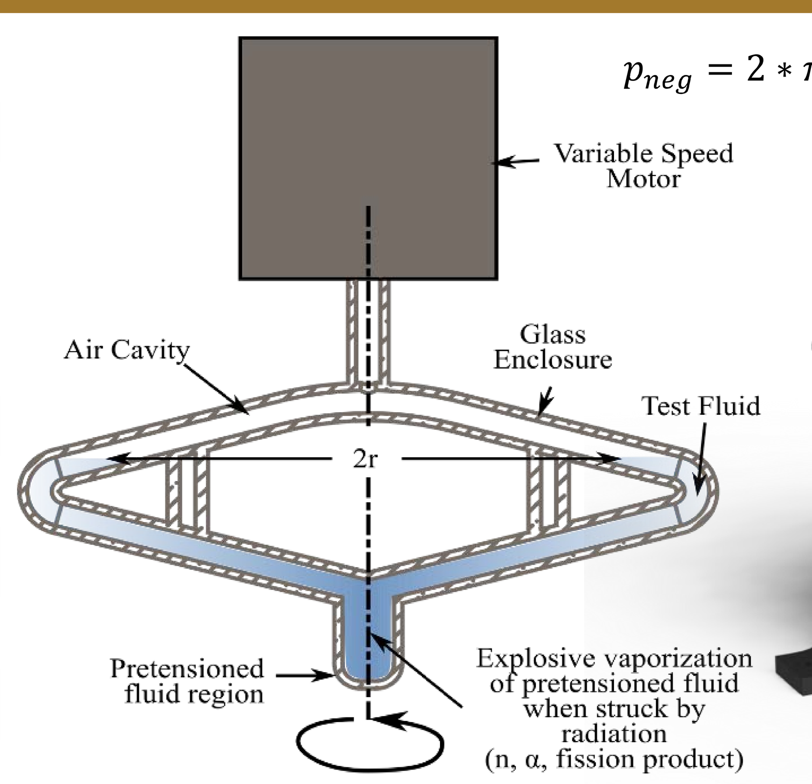

Fig 2. Centrifugally Tensioned Metastable Fluid Detector (CTMFD) Schematic

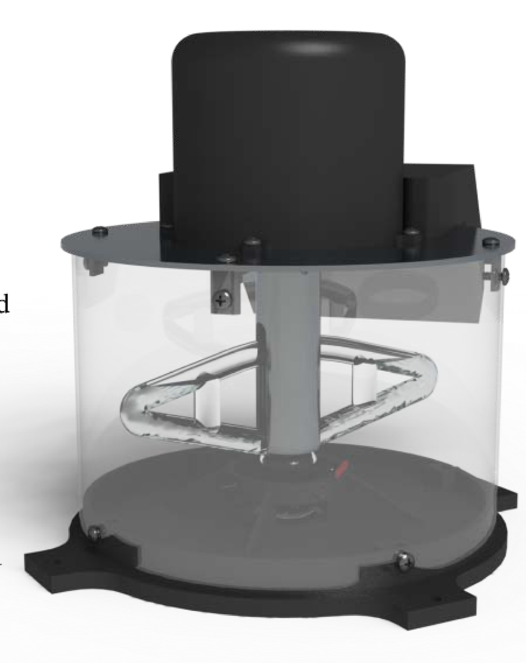

Fig 3. CTMFD Prototype

Methodology

- Insulated environment chamber used to achieve stable temperature and humidity (Fig. 4)
- Capture radon via diffusion stone on radon sparger device (Fig. 5)
- Fill glassware with radon-bearing fluid (Fig. 2)

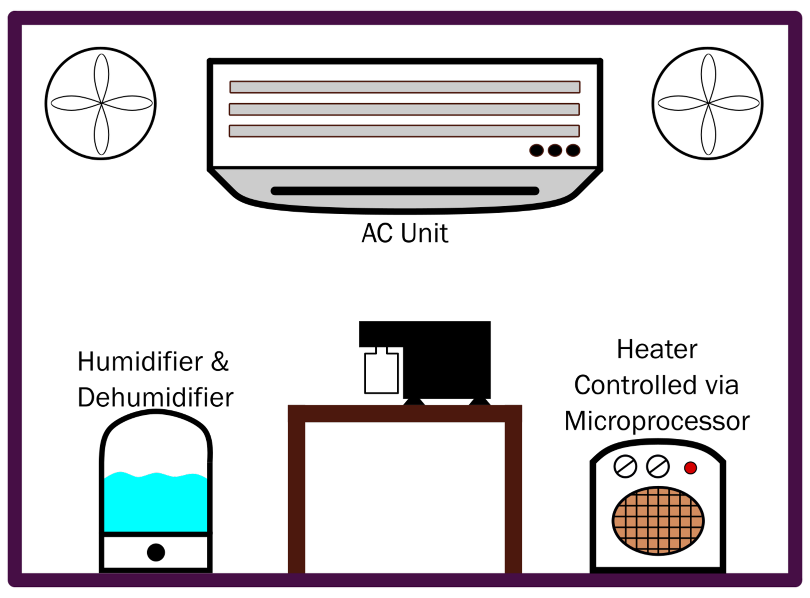

Fig 5. Insulated Environment Chamber

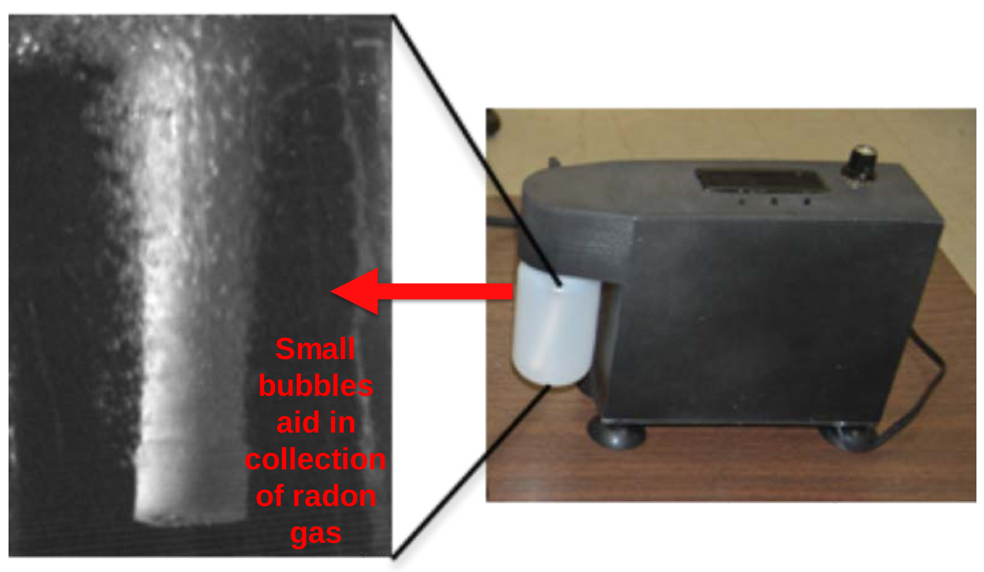

Fig 4. Radon Sparger and Close Up of Diffusion Stone

- To achieve different atmospheric pressures, samples were taken in a small piper warrior plane at varying altitudes
- Thermocouple used to monitor temperature in cabin and volume correction applied to Tedlar bag

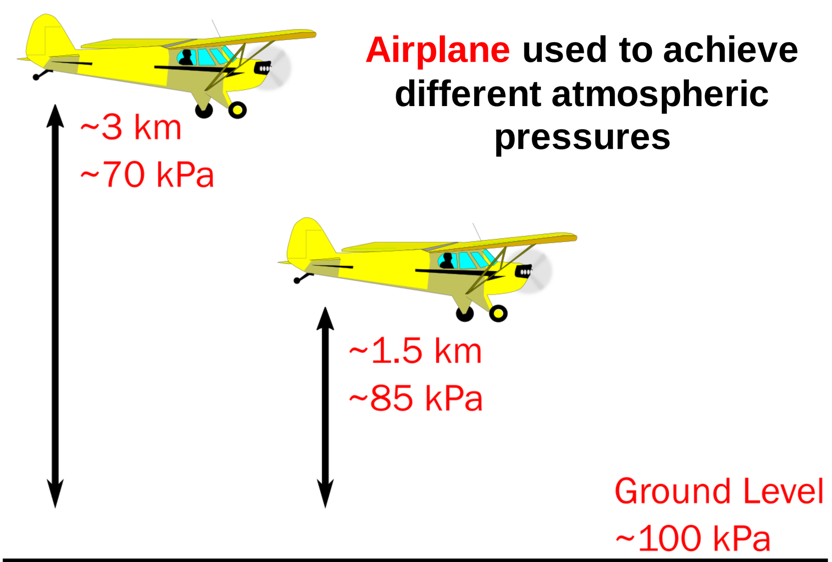

Fig 6. Pressure Tests Done In Airplane

Fig 7. Photo at Altitude of 3 Kilometers

- The effect of air flow over the system was done with a 100 L sealed acrylic box
- Fans placed strategically to vary flow rate over the exit nozzle
- Vibration was tested via a 10cm drop test

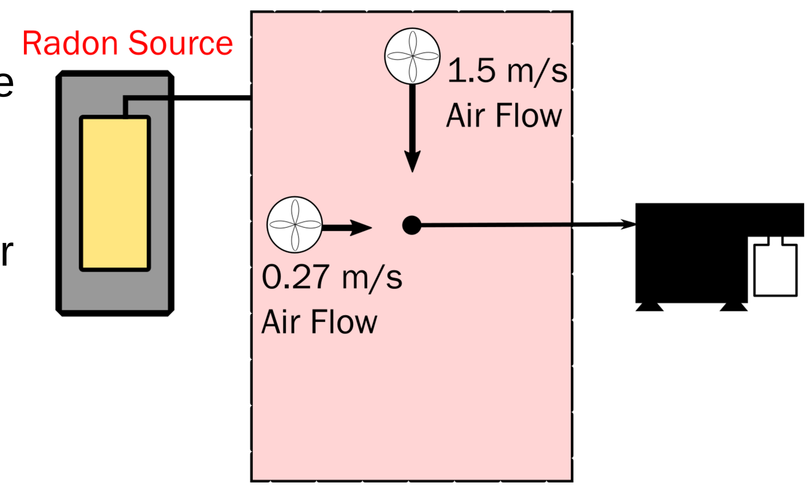

Fig 8. Air Movement Test Experimental Setup

Temperature and Humidity Effects on Radon Collection

- **Increased Radon Capture at Decreased Collection Temperature**
- **Negligible Effect of Environmental Humidity**

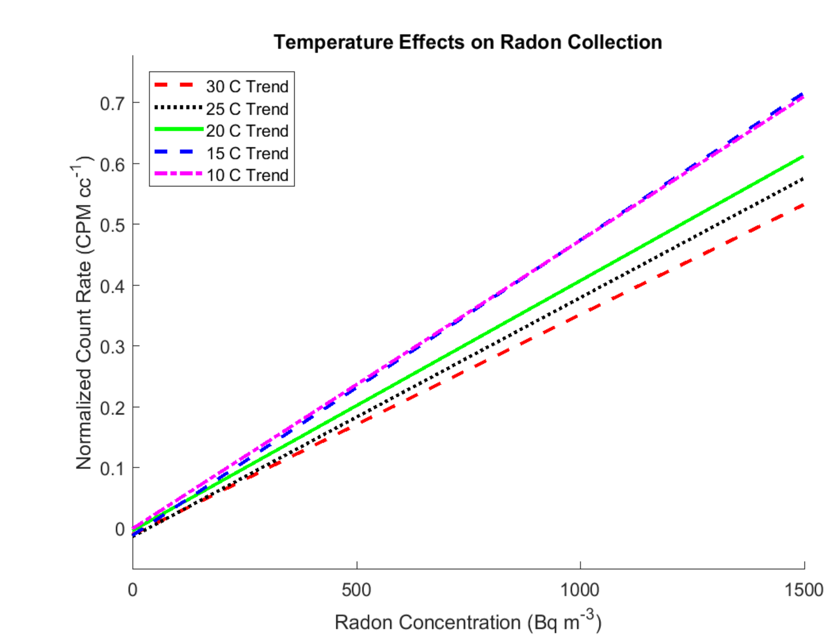

Figure 9: Temperature and Concentration Effect on Count Rate

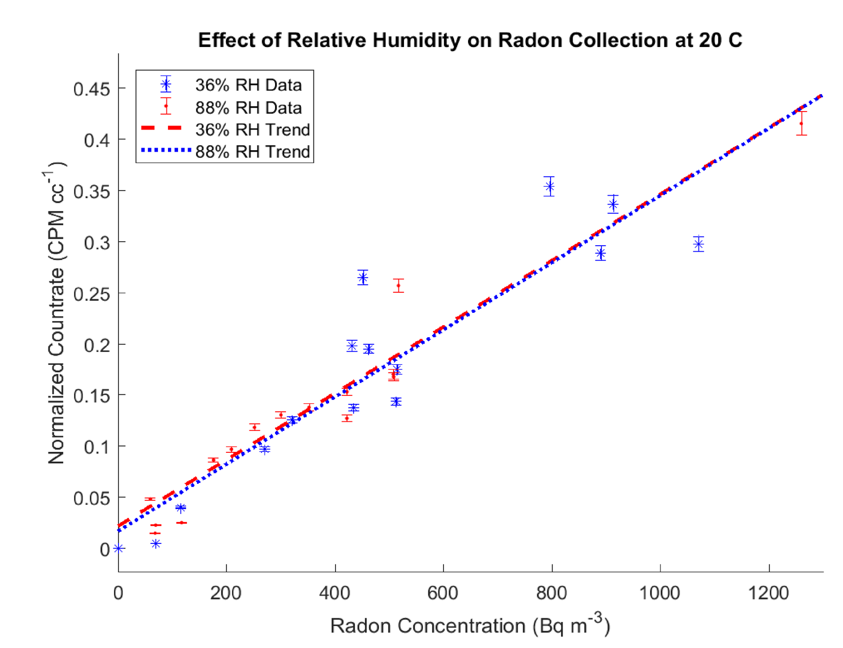

Figure 10: Relative Humidity Effect on Count Rate

Impact of Ambient Pressure and Air Flow

Table 1: Atmospheric Pressure/Altitude Effect on Count Rate

P (kPa)	Altitude (km)	Lucas Cell Reference (Bq m^{-3})	CTMFD Output (Bq m^{-3})	IRE (%)
~70	3	422.93	362.41	14.31
~85	1.5	506.35	408.11	19.40

Table 2: Air Movement and Concentration Effect on Count Rate

Air Movement (m s^{-1})	CTMFD Output (Bq m^{-3})	IRE (%)
Trial 1: 5517 Bq m^{-3}, T = 23.1 °C		
0	5345	3.12
0.27	5367	2.72
1.5	5631	2.07
Trial 2: 2072 Bq m^{-3}, T = 20.3 °C		
0	2083	0.52
0.27	1991	3.92
1.5	2008	3.08
Trial 3: 688.2 Bq m^{-3}, T = 23.1 °C		
0	727.3	5.67
0.27	697.4	1.34
1.5	713.1	3.61

- **Pressure/Altitude change found to have negligible effect on radon collection**
- **Environment air movement found to have negligible effect on radon collection**
- **All measurements in both tests were below the 25% IRE threshold set by the AARST-NRPP standards**

Dynamic Compensation Algorithm for Error Control

- **AARST-NRPP standards require individual relative error (IRE) to remain:**
  - **< 50% below 111 Bq m^{-3}**
  - **< 25% above 111 Bq m^{-3}**
- **Algorithm meets standards with success rate of 94%**

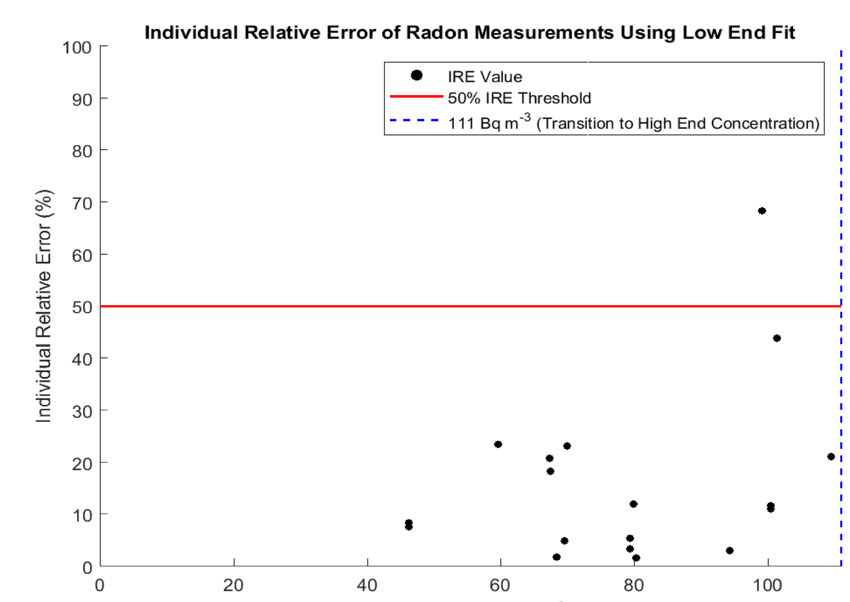

Figure 11: Data Below 111 Bq m^{-3} Relative to 50% IRE Threshold

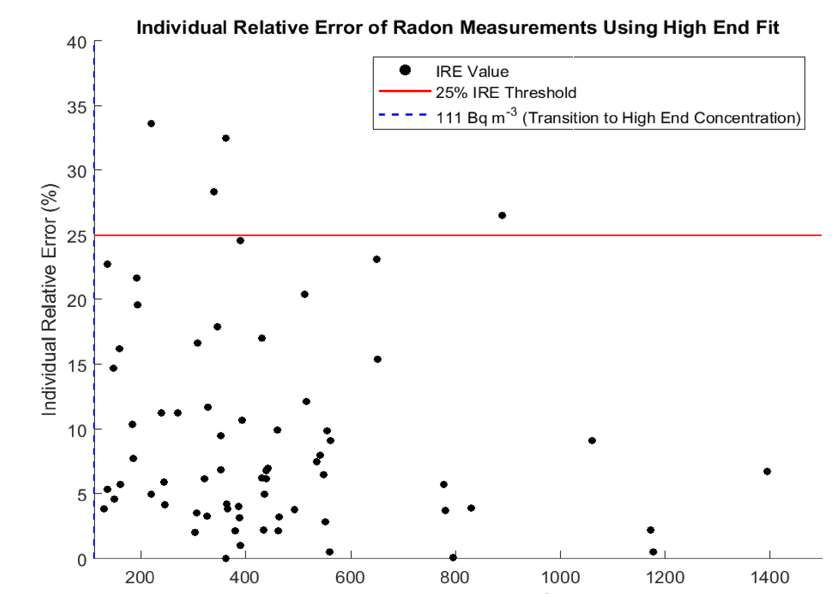

Figure 12: Data Above 111 Bq m^{-3} Relative to 25% IRE Threshold

Conclusions & Comparison vs State-of-Art

- **CTMFD-Radon Technology Successfully Developed for Application Under AARST-Range: Pressure, Temperature, Humidity, and Air Movement**
- **Temperature Effects accounted for with a Dynamic Compensation Algorithm**
- **Accurate Rn concentration measurements with > 94%success rate**

CTMFD Radon Monitor Technical Specifications (vs state-of-art)

- Rapid collection time: 2 min (2+min. feasible)
- Rapid measuring time: 0.5+ h
- Detection Range: 40-1,400 Bq m^{-3}
- Background Effects: 100% γ-β blind
- Spectroscopic Enabled: 1 keV res.

→ Resolve: Rn-222, Po-214, Po-218,..

Sensitivity (CPM/pCi/L) vs State-of-Art:

- CTMFD: 0.25 - 2+
- Femtotech: 0.3
- Sun Nuclear 1027: 0.045
- Durridge RAD7: 0.25 - 0.5

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