FLUID-BASED SYSTEM FOR RADON MITIGATION

Kenny Gross, Reactor Analysis Division
Francis Markun, Chemical Technology Division
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439

I. ABSTRACT

Argonne National Laboratory (ANL) recently discovered that a class of inexpensive and biologically benign fluids absorb radon gas with a high efficiency at room temperature, and release radon at slightly elevated temperatures (50-60 °C). This has led to the development of simple and inexpensive devices for continuous removal of radon from air. Such devices offer numerous advantages over conventional cryogenic charcoal systems for the removal of radon and thoron for DOE site remediation activities, and for decontamination and decommissioning of reactors, hot cells, and other DOE facilities. Spinoff applications may include continuous removal of radon gas from homes and office buildings. This paper presents the results of extensive parametric experiments conducted with prototype packed-column absorption devices to establish the feasibility and operational efficiencies attainable. Performance parameters evaluated include breakthrough times, saturation capacities, Henry's law constants for a range of candidate organic fluids, absorption and degassing rates measured at different temperatures, and the effects of radon concentration on attainable removal efficiencies.

II. TECHNICAL APPROACH

The studies conducted for this project were based upon the recent serendipitous discovery at ANL that common corn oil adsorbs radon quite effectively at room temperature and release the radon when heated slightly (50-60 °C). This allows the oil to be regenerated either in a batch or continuously operating mode by absorbing radon in the cool stage and venting the radon to the atmosphere in the heated stage. · Subsequent experiments showed that a range of hydrocarbon oils exhibit this same property not only for radon, but also for xenon and krypton. This discovery has led to the design of simple and inexpensive devices for continuous separation and concentration of heavy noble gases from air or from a mixture of lighter noble gases. Such devices offer numerous substantial advantages over costly and complex cryogenic charcoal systems for the removal of radon, xenon, or krypton during D&D of reactors, hot cells, and other DOE nuclear facilities. Initial proof-of-principle experiments have demonstrated that

the process works well with eighteen oils, including four that are low cost and biologically benign. Experiments have also demonstrated that the process is quite scalable. Small units can be designed for an individual room; intermediate units for homes; and larger, packed-column configurations can be designed for schools, offices, mining applications, or facility and site D&D applications.

On a molecular level, the mechanism responsible for the strongly temperature-dependent absorption/desorption phenomenon is not currently known. It is postulated that there may be a clathrate effect, wherein the heavy, monatomic noble-gas atoms are being trapped in the interstitial spaces in the much larger fluid molecules. This would be consistent with ANL's findings that the mechanism works only with the heavy noble gases Rn, Xe, and Kr, and not with the lighter gases He, Ne, or Ar. Clathrates are known to work only with a range of sizes that "fit snugly" in the host's interstices. An alternative hypothesis is that there is a temperature-dependent solubility phenomenon that fortuitously absorbs and releases the noble gases between the "convenient" temperatures of 20 and 60 °C.

The technical approach for absorption investigations has been to use controlled sources of radon in ANL's Radon Research Laboratory to quantitatively assess the performance of a selected class of oils over a range of Rn concentrations, and to select and evaluate various system performance parameters. Experiments conducted to date have demonstrated the ability to concentrate radon at room temperature (20-22 °C). In tests of gas concentration, prototype units have been tested that use a simple bubbling mechanism (by forcing the air through a diffuser at the bottom of the absorption chamber). Or, for surface contact enhancement while minimizing the pressure drop, packed-column units have been designed and tested wherein the air is passed through a vertical plastic tube containing various sizes of glass beads, raschig rings, or structured packing materials. Laboratory experiments conducted with ambient radon have demonstrated the ability to continuously remove and concentrate radon gas from the air when it is present at a concentration of only 10^6 atoms per liter.

For degassing of the fluid, a sequence of experiments has been conducted which demonstrate that the working fluid can be purged effectively by several methods. We have demonstrated that warming of the fluid immediately releases > 99% of the absorbed noble gas. This makes possible construction of a simple apparatus for continuous concentration where the carrier gas passes through an absorption chamber at room temperature, and the working fluid is continuously circulated through a degassing chamber for warming. The desorbed noble gas is drawn into an evacuated steel storage cylinder that is replaced periodically (for radioactive-gas remediation), or into an appropriate counting chamber (for high-sensitivity alpha, beta, or gamma detection), or simply to an outside exhaust line (for home Rn mitigation). The working fluid is passed through a coil in a finned radiator as it is returned to the absorption chamber. Alternatively, for large-scale remediation applications where energy minimization is not a constraint, water chilling or mechanical cooling may be employed. In addition to warming, we have found that continuous degassing may be achieved with mechanical agitation, ultrasound, microwaves, and by passing the working fluid over a surface as a thin film. These degassing methods may be used alone or in combination (depending upon energy utilization constraints for

a given application) and may be enhanced by introduction of a partial vacuum in the degassing chamber.

Spinoff applications of this system include: Reduction of DOE hot cell emissions and personnel exposures; remediation of DOE site Rn problems; recovery and isolation of radioactive Xe & Kr fission gases (DOE, DOD facilities, NRC licensees); low cost Rn mitigation in subsurface mines; commercial production of noble gases from air (avoiding the costly cryogenic distillation methods currently in use); gas tagging for commercial nuclear fuel rods; improved integrating Rn detector for earthquake prediction; and ultrahigh sensitivity Xe and Kr detectors. [1,2]

The major objective of this research was to demonstrate the feasibility of using an oil-based apparatus to remove radon from indoor air. Another objective of the project was to sufficiently understand the physical mechanisms responsible for radon absorption in order to predict the effectiveness of particular solvents. Knowledge of the absorption mechanism may help optimize the performance of the best oils or perhaps engineer more effective materials for the purpose of fluid-based radon mitigation

III. STATIC EXPERIMENTS

Target Problem, Experimental Apparatus and Procedure

During absorption testing small volumes of oil (50-200 ml) are saturated with air (~0.6 ft^3) containing a input radon concentrations between 170 and 268 pCi/l. The uptake of radon by the oil is then measured: radon free air is bubbled through the oil for a period of ~30 minutes, at a rate of 1 l/min. The air is passed through a dry-ice chilled charcoal trap, which removes radon quantitatively. The radon from the charcoal is transferred to a Lucas cell scintillation chamber and counted.

All of the experiments were performed using a standard experimental setup and methodology. These experiments have been designed to measure concentration factors while varying a number of parameters. The general procedure followed is based upon years of experience with a documented methodology [3]. The general procedure may be described briefly as follows:

Radon gas is accumulated in a radon generator for a test sample. A test sample of known radon concentration is then created. For experiments wherein high concentrations of radon were needed, Pylon radon generators were used. For these experiments the radon is first flushed from the generator with air into a Saran bag (Saran has a low affinity for radon). Two bag sizes were used for the experiments reported herein: 16-in X 16-in (20 l) and 16-in X 24-in (48 l). Radon-rich air from the Saran bags would then be used for the experiments. For experiments in which lower concentrations of radon were required, we employed a large (300-cu. ft.) compressed air cylinder that was prepared many years ago with 0.11 μCi of Ra-226 on its inner wall. The

amount of air placed into the cylinder, as reflected in the cylinder's measured pressure, determines the radon concentration. The concentration achievable is typically in the 100-300 pCi/l range, and must be measured before each experiment.

Next, a fluid sample is saturated with radon from the appropriate sample bag. A pump is used to pull approximately 20 l of the sample gas out of the Saran bag, and the gas is then bubbled through a small (50 cc) sample of fluid (when utilizing the gas cylinder generator, the tank's pressure is used as the driving force). Previous experiments have shown that 0.2-0.4 cu. ft. (6-11 l) of sample gas is sufficient to assure that the 50 cc fluid sample has been saturated. As long as the concentration factor remains approximately the same over the range of concentrations studied, a single 20 l sample bag is sufficient to saturate the sample fluid.

The radon is removed from the fluid for counting by passing approximately 20 l of dry, radon-free air through the fluid. The volume required to completely degas the fluid was verified over the range of radon concentrations used in these experiments. This gas is then passed through drying tube traps, cooled by a freon/dry ice slurry, which freezes any water vapor out of the sample air. Finally, the radon is selectively absorbed from the sample air in a charcoal trap, which is also cooled by a freon/dry ice slurry (see cited reference for details involving this setup).

A rough vacuum is pulled on the charcoal trap to remove all of the air. The charcoal trap is then removed from the freon slurry and is allowed to heat up to room temperature. It is then heated to 500 °C (heated vacuum) to release the radon from the charcoal. A small amount (10-20cc) of helium is then purged into the charcoal trap to serve as a carrier gas for removal of the radon. A positive displacement pump is used to move the He/Rn mixture into a Lucas cell, with an integral ZnS scintillation window, and simultaneously pull a vacuum within the charcoal trap. This purge-pump process is repeated another 4 times (5 times total) to raise the pressure within the Lucas cell to 1 atmosphere (the volume of a Lucas cell is 100 cc). Note that the He carrier gas increases the counting efficiency approximately 10% over that when using air.

The radon is then counted and the saturation concentration factor calculated. The Lucas cell is placed into counting equipment designed specifically for operation with these cells. The counting equipment automatically accounts for radon daughter build-up and decay. If the gas cylinder generator was utilized, a second Lucas cell is filled with sample gas emanating from the tank. The radon concentration in pCi/l within the fluid is then calculated as the ratio of the radon activity detected within the Lucas cell, after accounting for radon decay during the experimental process, to the volume of the fluid sample (nominally 50 cc). The saturation concentration factor is then calculated simply as the ratio of the fluid's concentration to the sample bag's concentration.

The static absorption experiments included the following systematic parameter variations:

- Volume required for reaching saturated Rn equilibrium

- The effect of oil temperature on Rn concentration factor

- Effect of different oils on concentration factor

Degassing was found to be effective using heat, agitation, microwaves, and ultrasound. For degassing via sonication, previously used reaction vessels were modified and adapted from an earlier inverted conical design. Adapters were manufactured for the vessels in order to introduce radon-free air as a purge (in most tests) for the oil being degassed. Ultrasonic removal of radon occurred by extending a sonication probe into oil.

The oils in each of the degassing tests were analyzed to determine any residual Rn present. Quality Assurance/Quality Control testing has also been done in conjunction with all experiments as follows: (1) blank oil samples were analyzed for Rn, (2) unexposed oil samples were checked to determine foreign Rn introduction, (3) exposed oil samples were checked for Rn absorption (without degassing) to verify Rn presence in the oil, and (4) a measurement was made of Rn/air concentration in the supply tank at the start of the tests.

Static Saturation Test Results

To determine the saturation times for a given volume of oil, different volumes of radon rich air were passed through 50 ml Mazola® at a flowrate of 1 l/min. The concentration of radon in the oil was then compared with the concentration of fully saturated oil. Table 1 indicates that 100% of the equilibrium concentration for Mazola® was reached when 0.4 ft^3 of radon rich air passed through the oil. All subsequent tests used at least 0.4 ft^3 of radon rich air to assure saturation.

Temperature effects on the concentration factor of corn oil were also tested. The concentration factor was found to be strongly dependent on temperature. The concentration factor consistently decreased with a rise in temperature. At 2 °C, the concentration factor of corn oil was 12.676; at 60 °C, it decreased to 4.04.

For eleven trials, the mean concentration factor of corn oil was 7.77 ± 0.71. Replicated trials were performed only for corn oil. In addition to testing Mazola® corn oil, other vegetable and hydrocarbon-based oils were tested. Static tests performed for this investigation are summarized in Table 2. The vegetable oils had concentration factors ranging from 4.45 to 8.85. 3-in-One oil had the highest concentration factor of all oils tested, 9.70. Mineral oil had a factor of 8.69. Engine and lubricating oil factors ranged from 3.72 to 9.70. There appears to be a trend with hydrocarbon content and with viscosity. Viscous fluids had a lower concentration factor: 5W-30 motor oil had a concentration factor of 9.40; 10W-30 oil had a 8.70 concentration factor; 50W oil was 6.08. The hydrocarbon oils had the highest concentration factor values: low weight motor oils and 3-in-One oil were higher than vegetable oils, which are triglycerides and not pure hydrocarbons.

Oxidation of Oil

One experiment with used corn oil (aged approximately two months) was conducted and showed a significant degradation in radon absorption capacity (reduction in concentration factor from 7.79 to 2.79). The oxidation/degradation of oil is therefore a potential concern for long-term deployment of mitigation technology. Auto-oxidation is the direct chemical attack by oxygen from the air via a free radical mechanism that results in the deterioration of the oil [4]. The primary products of oxidation are hydroperoxides which decompose into hydroxyl group containing compounds, including ketones, aldehydes, and mixed structures like oxirane and epoxy groups. The first period of oxidation, induction, is characterized by relatively slow oxidation. A rapidly accelerating rate of oxidation occurs during the second period and is marked by a rancid smell. Extensive chemical changes occur during this period, marked by decrease in iodine value, saponification equivalent, and percent normal unsaturation. Polymerization occurs during more advanced stages of autoxidation, which affects viscosity. The induction period is definite in saturated fatty acids, and more gradual in unsaturated ones. The rate of oxidation is affected by the distribution, geometry, and number of double bonds in glyceride chains (rate increases with unsaturation), presence of antioxidants and metal pro-oxidants, light, and temperature. There are many methods of determining the extent of oxidation, such as evaluation of iodine and peroxide values [Reference 5, p. 173]. Chemical antioxidants may be added to corn oil to substantially retard the auto-oxidation mechanisms. It is recommended that a followon project include a sequence of experiments to quantify the degradation rate of the radon absorption properties of corn oil for virgin corn oil, and for corn oil treated with one or more antioxidants.

IV. RADON REMOVAL PROTOTYPE

Findings from the static tests formed the basis for a prototype apparatus for dynamic radon removal testing at ANL. The test apparatus is a basic packed column scrubber (Figure 1), in which air containing radon is in continuous contact with oil. The setup does not include an integrated degassing unit: initial tests focused on absorption capabilities. [Degassing experiments are being conducted separately and shall be reported in a future paper.] Also included in the setup are a variable speed pump for the oil and a compressor to moderate the air flowrate.

A laboratory-scale absorption tower was constructed to obtain data on mass transfer rates and flow characteristics. The tower, which was constructed of Plexiglas®, has a 76-mm (3-in.) I.D. and either a short (0.406 m high) or tall (1.07 m high) packed-bed test section plus flow meters, a differential pressure gauge, and air/oil pumps. A peristaltic pump with a 500-ml/min capacity circulated the absorbing liquid (corn oil in the initial tests). Gas and liquid flow rates were monitored with rotometers. Glass balls (4 and 6-mm diameter) and 6.4-mm (1/4 in.) and 9.5-mm (3/8-in.) plastic Raschig rings were available for tower packing. Flooding can result from

either a high liquid flow or a high gas flow and was observed for 6.4-mm (1/4-in.) Raschig rings during absorption measurements.

Measurements of radon removal were made with this apparatus in the Argonne Radon Research Facility. The oil-based absorption column can remove the majority of radon gas in the air stream, up to 98.7%, with a 1.07-m (42-in.) packing column under certain flow conditions.

V. INVESTIGATIONS INTO RADON ABSORPTION CHEMISTRY

The gas solubility in a liquid refers to the amount of gas solute that will dissolve in a liquid solvent at a given temperature and pressure to form a solution. The solubility of a gas at a given temperature depends upon the partial pressure of the gas, the vapor pressure of the pure liquefied gas, and the interaction between molecules in the liquid phase [6]. In general, an increase in the partial pressure of a gas will increase the gas solubility; an increase in temperature will decrease solubility; solvents having similar structure will behave similarly.

The fundamental rule of solubility states that "like dissolves like." When intermolecular forces of solute and solute are alike, the solute will be soluble in the solvent. Radon, a nonpolar, monatomic noble gas, has an even distribution of charge, and is most soluble in nonpolar solvents. Radon is known to be soluble in nonpolar organic liquids, particularly in hydrocarbons. Theory attributes solubility of inert gases to interaction between induced dipoles if the solvent is somewhat nonpolar [Reference 7, p. 50]; the most soluble gases will be the ones most easily polarized. As the heaviest of the noble gases, radon is most easily polarized. Outer shell electrons, which are further from the nucleus, are more loosely held than those of the lighter gases. Radon solubility in somewhat nonpolar solvents will be greater than xenon, krypton, argon, neon, and helium solubilities.

The solubility of a gas in a liquid can be expressed in a variety of ways. Henry's law constant is often used at low pressures. Henry's law states that the concentration of gas dissolved in the liquid phase is proportional to the partial pressure of the gas. Another typical measure of solubility is the Ostwald coefficient: the ratio of the volume of gas absorbed to the volume of absorbing liquid at the same temperature. The Ostwald coefficient is numerically equivalent to the concentration factor, the ratio of the concentration of gas in the liquid phase to the concentration of gas in the gas phase, provided there is no change in volume on mixing [8]. The concentration factor has been used in test results and discussions that follow. Radon solubility, in terms of the concentration factor can be determined by measuring the comparative radioactivity in the gas and liquid phases, which reflects the comparative concentrations

A variety of vegetable oils were tested for absorptive capacity. Concentration factors were measured for peanut, corn, soybean, olive, walnut, and safflower oils. The highest mean concentration factor among the vegetable oils is for peanut 8.45; the lowest is safflower, 4.45.

In general, all vegetable oils are similarly structured. They are mostly triglycerides, or glycerol esters of fatty acids, which are the combination of three fatty acid molecules and one molecule of glycerol. Among fats and oils, the proportions of the component fatty acids and of individual triglycerides vary. Based on the fact that different fatty acids had different concentration factors, as calculated by Nussbaum, it is expected that different oils will have different absorptive capacities. The majority of component fatty acids in vegetable oils are oleic and linoleic acids, which both contain eighteen carbon atoms. Oleic acid contains a single double bond. Linoleic has two. Nussbaum determined the solubility of linoleic and oleic acid to be 7.93 and 8.23, respectively [Reference 9, p. 62]. Vegetable oils having substantially different amounts of linoleic and oleic acids should have a slight difference in absorptive capacity.

Table 3 summarizes solubility data for vegetable oils tested at Argonne during the course of this investigation. Included are measured concentration factor, component fatty acids, and physical properties such as iodine number, specific gravity, viscosity, and saponification number [4, 5]. The iodine number is defined as the number of centigrams of iodine absorbed by one gram of fat. Double bonds absorb iodine and thus the iodine number is a measure of unsaturation. The saponification value is the weight in milligrams of potassium hydroxide needed to completely saponify one gram of fat and is related to the average molecular weight of fatty materials. Physical data are literature values. The variation in literature values, which is a result of the variation in the oil samples, limits the ability to predict solubility behavior with high accuracy. Of the oils tested, olive oil has a noticeably lower iodine number, a reflection of its relatively lower percentage of polyunsaturated acids. Walnut and safflower oil has higher iodine values than most of the oils tested. Both walnut and safflower oils have a lower than average measured concentration factor. This is consistent with Nussbaum's observation that unsaturation results in lower solubilities.

The variation in solubility results among the different oils is within a few standard deviations of the concentration factor results for corn oil. The mean concentration factor for corn oil was 7.77± 0.71. It is believed that the relatively small variations in concentration factors between the oils tested reflect the similarity in molecular makeup of the oils. Nussbaum [9] demonstrated that solubility increases as the carbon chain length increased in fatty acids--yet levelled off after six carbon atoms. The difference in solubility between fatty acids above eight carbon atoms is not systematic. The vast majority of fatty acids present in oils have over fourteen carbon atoms. Likewise, the degree of unsaturation present--a difference of one or at most two double bonds in a triglyceride--has only a slight impact on the measured solubility. The effect of unsaturation, however small, may become significant when dealing with related factors such as viscosity, melting point and reactions (oxidation). For example, double bonds put kinks in the hydrocarbon chain, making it difficult for a crystal structure to form; unsaturation will lower the melting point of oils.

The most noted distinction in measured solubilities of all substances tested is between squalene and squalane. These two substances are hydrocarbons, not triglycerides, which differ only by the presence of double bonds; squalene has six double bonds, squalane has none. This makes a strong argument for unsaturation's effect upon increasing radon solubility for hydrocarbons.

This effect was not observed in vegetable oils. However, since the structure of vegetable oils is not a single hydrocarbon chain, the conclusion that unsaturation will increase solubility does not necessarily follow.

Knowledge of all components within the oil is important when making theoretical predictions. As fatty acids are the major component of oils and fats, their chemistry will be the determining factor for oil and fat chemistry.

However, minor deviations from theoretical predictions may be attributed to the minor components. Any compound that is soluble in oil may alter radon solubility. Oils and fats are not merely composed of fatty acids and glycerides. Sterols, vitamins, pigments, phospholipides, and antioxidants are also present [Reference 5, p. 19]. However, the lack of distinction in concentration factor among different vegetable oils and with partially refined corn oil suggests that minor component composition may not have a great impact on absorption.

VL CONCLUSIONS

Static test results showed that the radon concentration factor, defined as the radon concentration attained in oil divided by the radon concentration of the input air-stream, for a range of hydrocarbon and vegetable oils was in a range between 2.0 and 9.7. The results of degassing tests conducted using heat, agitation, microwaves, and ultrasonic sonication have shown that heat and agitation can remove essentially all radon from the oil. One recommendation emerging from the set of ultrasonic degassing experiments conducted is that the ultrasound transducer should be configured in the form of a horizontal flat plate with the oil flowing over its surface in a relatively thin horizontal layer. This configuration would minimize reabsorption of radon gas, and should require no sweep gas.

The lab-scale test apparatus having a 76-mm (3-in.) diameter and 0.406 and 1.07-m (16 and 42-in.) high packed beds has been designed, constructed, and tested successfully. The packing materials tested were 4 and 6-mm glass balls and 6.4-mm and 9.5-mm (1/4-in. and 3/8-in.) size Raschig rings. Initial work was directed toward determining the characteristics such as pressure drop and flooding in countercurrent flow of corn oil and air through the packing in this system. A series of dynamic radon-absorption tests was conducted using a 6.3-mm (1/4-in.) size Raschig ring packing material in the 76-mm (3-in.) diameter and 1.07-m (42-in.) packed tower. A radon concentration of 180-290 pCi/l of air flowed through the absorption tower while the fresh corn oil was introduced at the top of the tower. The preliminary test results showed that the radon absorption rate is 77-81% for 1 l/min air and 259 ml/min oil. The removal rate increased to the 82-86% range when the oil rate increased to 442 ml/min. For the lower air flowrate case, 0.5 l/min, the absorption rate increased to the 97-98.7% range for a 259 ml/min oil flowrate. The absorption rate showed a surprisingly smaller value (89-94% range) when the oil rate was increased to 442 ml/min. Further study is planned to examine the effect of fluid flow and packing material on the absorption rate and attainable pressure drops.

Literature sources and experimentation show that vegetable oils composed mainly of oleic and linoleic acids have approximately the same solubility characteristics. Low-viscosity hydrocarbon solvents have the highest degree of radon solubility of the oils tested. Estimates of radon solubility in all types of oils can be made by comparing solubility parameter values given composition or energy of vaporization information.

Empirical determination of absorption and degassing rates, where economically feasible, are perhaps more important than theoretical predications of solubilities in developing a system of maximum efficiency. Viscosity may be the rate-determining characteristic, which may not necessarily be related to solubility. Therefore, it would also be advantageous to study the effects of viscosity on the radon absorption/degassing phenomena. By testing different flowrates, for a given volume of air, the rate of absorption and desorption can be further understood. Likewise, testing the equilibrium characteristics of lighter noble gases, such as xenon and krypton, are expected to give insight to the sensitivity of the effect of polarizability and size of gas molecules on diffusivity. Such experiments are being conducted in a separate collaboration (funded by the Environmental Management branch of the US Dept. of Energy) between ANL and the Georgia Institute of Technology [See e.g. Refs. 1 and 2].

Corn oil favorably absorbs heavy noble gases and is nonvolatile, nontoxic, and inexpensive. Corn oil also has the added advantage that it absorbs noble gas radionuclides at temperatures just under room temperature and releases the gases when heated above this temperature range. The other chemistry aspects cannot be ignored, however. Corn oil is known to undergo oxidation and polymerization, which will necessitate the addition of antioxidants for long-term field deployment of oil-based radon mitigation systems.

VII. REFERENCES

1. W. R. Russ, J. D. Valentine, B. D. Rooney and K. C. Gross, "Fluid Transfer Concentration of Airborne Radioxenon to Enhance Monitoring Capabilities," *Nucl. Instruments & Methods in Physics Research*, A 422, pp. 820-825 (Feb 1999).

2. W. R. Russ, D. O. Stuenkel, J. D. Valentine, and K. C. Gross, "Improved Radioxenon Detection Techniques for use with Fluid-Based Concentration," *Proc. 1999 IEEE Nuclear Science Symposium*,, Seattle, Wa. (Oct 26-28, 1999).

3. H. F. Lucas, H. F., F. Markun, "Radon in Air Calibration Procedure: A Primary Method," Technical Note, *Nuclear Science and Engineering*, 99, 82-87 (1988).

4. Swern, D., "Bailey's Industrial Oil and Fat Products", Volume 1, John Wiley &Sons, New York (1979).

5.   Eckey, E. W. "Vegetable Fats and Oils", Reinhold Publishing, New York (1954).

6.   Fogg, P. G. T. and W. Gerrard, "Solubility of Gases in Liquids", John Wiley & Sons, New York (1991).

7.   Hildebrand, J. and Scott, R., "Solubility of Nonelectrolytes", Reinhold Publishing,New York (1950).

8.   Clever, H. L., "Solubility Data Series", Volume 2, Pergamon Press, Oxford (1979).

9.   Nussbaum, E. "Radon Solubility in Body Tissues and in Fatty Acids."   Ph.D. Thesis,University of Rochester (1957).

Table 1.
Determination of Equilibration Air-Sample Volumes for Mazola® Corn Oil

Volume Radon Rich Air (ft^3)	Fraction Saturation
0 .1	0 .836
0 .2	0 .953
0 .4	1 .001
0 .6	0 .987

Table 2.
Static Absorption Test Summary

Test Number	Oil Type	Concentration Factor	Radon Concentration pCi/l	Oil Volume ml	Air Volume ft³	°C
1	mazola	8.105	172.917	200	1.20	22
2	mazola	8.35	191.86	200		0
3	halovac	3.72	201.62	200	0.626	21
4	squalane	5.257	201.62	200	0.603	21
5	squalene	8.68	204.15	200		21
6	halovac	1.83	204.15	200		21
7	mazola	8.85	16.63	200		21
8	squalene	9.576	213.83	200	0.473	21
9	halovac	4.166	220.39	200	0.605	21
10	mazola	8.166	220.39	200	0.782	21
11	amoco LD 10W-30	8.696	228.42	200		21
12	valvoline SAE 50	6.08	242.85	200		21
13	trak HD SAE 30	7.969	242.85	200	0.772	21
14	chevron SAE 5W-30	9.240	90.63	200		21
15	valvoline super HPO 10W	9.235	90.63	200		21
16	3-in-One	9.688	90.63	200	0.953	21
17	mazola	7.07	108.32	100		21
18	mazola	7.28	118.59	100		21
19	mazola	7.28	122.45	50		21
20	mazola	6.67	133.86	50		21
21	mazola	8.1345	133.63	50		21

Test Number	Oil Type	Concentration Factor	Radon Concentration pCi/l	Oil Volume ml	Air Volume ft³	°C
22	mazola	8.49	135.78	50		21
23	soybean	7.427	157.768	50	0.600	21
24	canola	6.694	157.768	50	0.625	21
25	safflower	4.4549	157.768	50	0.600	21
26	peanut	8.451	157.768	50	0.600	21
27	olive	7.1278	157.768	50	0.621	21
28	walnut	6.3989	157.768	50	1.0	21
29	mineral	8.686	250.39	50	0.60	21
30	refined corn	7.179	250.39	50	0.60	21
31	used mazola	2.789	250.39	50	0.60	21
32	mineral	9.051	268.06	50	0.60	21
33	mazola	7.10	268.06	50	0.60	21

Table 3. Summary of Tested Vegetable Oil Characteristics

Property	Peanut Oil	Corn Oil	Soybean Oil	Olive Oil	Canola Oil	Walnut Oil	Safflowe rOil
Concentratio nFactor	8.45	8.85	7.43	7.13	6.69	6.40	4.45
Iodine Number	84-100	103-128	120-141	80-88	110-126	135-162	140-150
Saponificatio n Number	188-195	187-193	189-195	188-196		190-197	186-197
Specific Gravity	0.910-0.915	0.915-0.920	0.917-0.921	0.909-0.915		0.9113-0.9235	0.919-0.
Viscosity (cP)	77 (20 °C)	30.80 (40 °C)	50.9 (25 °C)	77 (20 °C)			
ComponentF atty Acids							
Myristic		0.2-1.5	0.1-0.4	trace-1	0.1		

Palmitic	6-10	8-13	7-11	7-20	3.5		
Stearic	3-6	1-4	2.4-6	0-3	1.5		
Oleic	40-71	24-46	22-34	65-85	60.1		
Linoleic	13-38	34-61	50-60	5-15	20.1		
Linolenic		0.6	2-10		9.6		

Figure 1. Radon Removal Prototype