A Diffusion Cloud Chamber for Viewing Alpha Tracks

James F. Burkhart
Physics Department
University of Colorado-Colorado Springs 80918

Although radon professionals are frequently asked to explain the health hazards caused by the inhalation of radon decay products and the subsequent impact of alpha particles on delicate lung tissues, very few radon testers and/or mitigators have actually "seen" an alpha particle. One of the time honored methods of viewing alpha particles in motion is to insert an alpha radiation source into a diffusion cloud chamber and to watch the tracks made by the alpha particles in real time as they traverse a cloud made by a supersaturated solution of methyl alcohol in air. Commercial cloud chambers are costly ($500.00 and up). Most home-built cloud chambers are not dependable in that they often do not work even when everything is done correctly (see inexpensive cloud chambers of this type in AAPT, 1972). What the author presents is a simplified diffusion cloud chamber that can be made for under $50.00 and is dependable. Also, inexpensive, non-licensable alpha sources are suggested.

Cloud Chamber Theory

First invented by C.T.R. Wilson[(1)] in 1911, the cloud chamber found a useful place in nuclear physics very soon after. Wilson himself photographed alpha particle tracks in 1912 and slow moving mixed with fast moving beta particles in 1923. These original photos can still be found in relatively modern textbooks (see, for example, Segre, 1977). Also, the positron (the first anti-particle ever found) was discovered by C. D. Anderson in 1932 in a Wilson cloud chamber (Hodgson, et al, 1997).

As useful as the Wilson-designed cloud chamber was, it was difficult to use and only allowed the viewing of the radiation tracks for a moment. Newer cloud chambers allow for continuous viewing although they do require a supply of dry ice in order to work.

What is presented here is the newer type of cloud chamber, called a diffusion cloud chamber. It allows for continuous viewing of radiation tracks for up to an hour, or until the dry ice all evaporates.

(1) Wilson had played around with a cloud chamber much earlier, in 1895. However, it was made for the purpose of reproducing atmospheric cloud formation, not for viewing radioactivity.

The heart of the diffusion cloud chamber is a small, clear, plastic or glass chamber that is at atmospheric pressure. Liquid methyl alcohol has been introduced into the chamber by saturating a sponge on the top interior of the chamber. The chamber is then sealed. The bottom of the chamber is maintained at a much cooler temperature by being in contact with dry ice. The temperature gradient that is set up by the difference in temperature allows for the continuous evaporation of the methyl alcohol off of the top interior of the chamber and the continuous production of a supersaturated methyl alcohol solution in air towards the bottom of the chamber as the alcohol diffuses downwards into the very cold air. (See figure 1.)

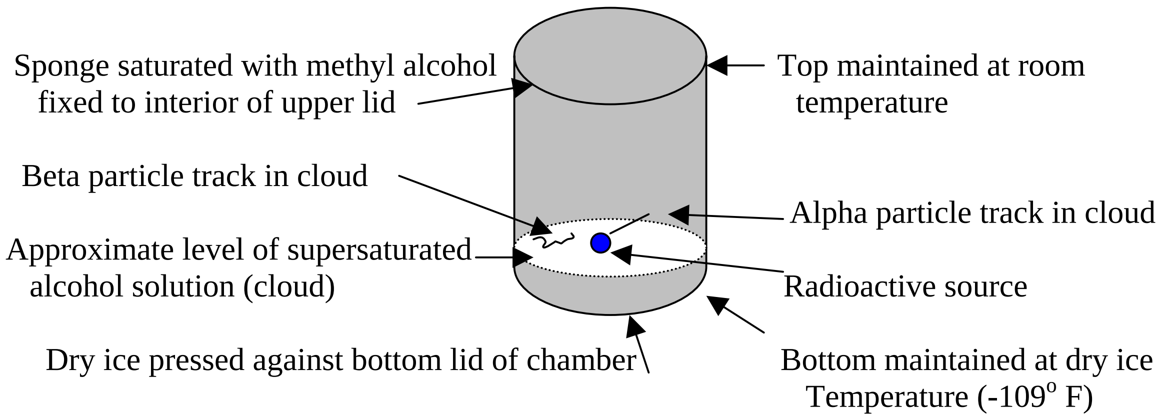

Figure 1: Basic ingredients of a diffusion cloud chamber.

A circular metal plate fits into the bottom of the chamber and is in excellent thermal contact with some dry ice. A cloud of methyl alcohol forms near the bottom of the chamber, approximately 1 to 4 millimeters above the cold metal plate. The cold plate keeps the bottom of the chamber cool enough for a supersaturated alcohol solution to be maintained there. When a radiation particle happens to traverse the cloud, it creates ion pairs out of the air atoms. The ion pairs act as condensation nuclei, allowing the alcohol to momentarily condense along the ion trail left by the passing particle, thus making the path of the particle momentarily visible as a brief track or "contrail". The track quickly dissipates, allowing newer tracks to be seen.

What Kind of Particles Can Be Seen in a Cloud Chamber?

Of the various types of radiation, alpha particles are of the most interest to radon professionals because it is the alpha particle that is emitted from the radon decay products (polonium-218 and polonium-214) that cause the ionization of lung cells. Alpha particles are made up of two neutrons and two protons tightly bound. They are emitted from the nucleus of an atom when the atom has too few neutrons to keep it stable. Fortunately, alpha particles cause tracks that are the easiest to see because these particles cause a great deal of ionization in a relatively short length. Their tracks are relatively thick and relatively short, usually only a couple of centimeters long. Alpha particles can ionize thousands of air atoms before the particles come to rest, picking up a couple of stray electrons and becoming helium atoms.

Beta particles can also be tracked in a cloud chamber. Beta particles are small, negatively charged particles emitted from a nucleus that has too many neutrons to keep it stable. Beta particles are identical to orbital electrons except that beta particles originate from within the nucleus. When viewed in a cloud chamber, a low energy beta particle makes a thin track that often has a tortuous path. The irregular shape of the path is caused by the beta particle bouncing off of atoms that it hits, causing it to change directions during its brief journey. High-energy betas are more rare but may be viewed as long, straight thin paths. The tracks can be many centimeters long.

Gamma rays are made up of high-energy photons coming from the radioactive nucleus. Since they have a very low probability of interacting with air inside the small chamber, you will probably never see a track made by a gamma ray. Gamma rays, when they do interact with matter, may produce low energy free electrons that have the same track as low energy betas. So, if you see a low energy beta track with a pure gamma source inside the cloud chamber, you are probably seeing the electron freed from an air atom by the passing gamma.

Cosmic rays do not come from within radioactive materials. That component of the cosmic rays which are typically protons or (much more rarely) are the bare nuclei of heavier atoms apparently are part of the solar wind and can also penetrate a cloud chamber leaving a track. However, this type of cosmic ray, called a primary ray, is usually stopped high in the atmosphere as it interacts with air atoms. Should you see the track of a primary cosmic ray you will be rewarded with an amazing show. You will see a shower of tracks, called an "evaporation star" (Oldenberg, 1961). More common are the so-called "secondary" cosmic rays. These are particles that come from the disintegration of the primary ray. These secondary particles are made up of a hodge-podge of electrons and gamma rays (the "soft" component) and more exotic particles. The most common exotic particle is the mu meson (the "hard" component). The mu meson makes up the majority of secondary cosmic rays found at sea level (Lapp and Andrews, 1963). A mu meson will make a straight track that has a thickness between that of an alpha particle and a beta particle. You should be able to see one track a minute, maybe more, even with no radiation source inside the chamber.

Radiation Sources

Although you will be using a radiation source provided by the instructor, you can easily procure your own source by purchasing a smoke detector and removing the radiation source from within. Ionizing-type smoke detectors (not photoelectric-type smoke detectors) have a small quantity of americium-241 housed in a small aluminum chamber (about 2 inches in diameter and 3/4 inch high) in the detector's interior. After disassembling the smoke detector, use a small soldering iron to unsolder the metal tabs holding the aluminum chamber in place. Once the chamber is removed, the source can be seen. The source is usually found on a small round table (about 1/4 inch in diameter). Unclip the source from its retaining straps.

The Firex smoke detector, model CC, which sells for $10.96 at Home Depot, is the easiest to take apart. The americium can be removed (once the aluminum chamber is unsoldered) by clipping two metal straps with a diagonal pliers. When you are not using the source in your cloud chamber, keep it inside a small glass or plastic bottle (like a medicine bottle) with the bottle capped to insure that no one receives unwanted alpha radiation. Americium-241 has a half-life of 432.2 years and so it will remain radioactive for many human lifetimes. It produces five different alphas with the most common one having an energy of 5.5 Mev (Kocher, 1981). However, this alpha will not be able to penetrate the glass or plastic bottle when the source is stored properly.

Older style Coleman lantern mantles are also great alpha producers. However, you will have to find one that was made 10 years ago, or more. More recent mantles no longer use the radioactive isotope (thorium) as a catalyst. An added benefit to using a mantle is that you will continue to have lots of tracks for about 5 minutes after you remove the mantle as the thoron (radon-220), which has been created by the thorium, and has a half-life of about one minute, decays inside of the chamber.

Of course, if you can still find an old radium watch dial, you will have a very good alpha source. For health reasons, radium dial watches are no longer produced and are, therefore, difficult to find.

Brazil nuts, when they are actually imported from Brazil, produce alpha particles that derive from the radioisotope out of the soil from which they are grown. Roughly speaking, the activity of a typical Brazil nut is 1800 times above the background radiation of other common foods[(2)] (Kastner, 1973).

Finally, when all else fails and you can not find a source, fire up your cloud chamber anyway. You should see about one secondary cosmic ray a minute (maybe more, depending upon your location) and an occasional random alpha particle from the radon decay products in your chamber.

Construction Details

The following instructions are for a cloud chamber that will be constructed by participants at a workshop given by the American Association of Radon Scientists and Technologists. Exact sizes of pieces of the cloud chamber represent those belonging to the cloud chamber that is being put together at that workshop. Since the size of the cloud

(2) Unfortunately, the author (Kastner) does not give any absolute radiation units, only the activity with respect to other foods like cereals, teas and peanut butter, all of which are below 100.

chamber is not critical, the reader may, at his or her discretion, substitute other sizes and/or pieces for the dimensions given here. On the other hand, when any part of the cloud chamber is critical, the directions will point this out so that the reader may follow that part of the instructions exactly.

1) The chamber for this cloud chamber is a purchased 0.6-quart storage canister. It is made of clear plastic with an airtight lid that can be easily removed. It has the brand name "Martha Stewart" and can currently be purchased at K-Mart for about $5.00. Although not critical, its dimensions are approximately 4 inches in diameter and 5 inches in height.

Remove the lid from the canister and hot glue a four-inch in diameter, one-half inch thick piece of foam rubber to act as a sponge onto the underside of the lid.

Drill a 1 1/8-inch hole in the center of the bottom of the canister. This hole will allow a 1-inch tube to be inserted through the bottom of the canister, conducting the cold from the dry ice, later. See figure 2.

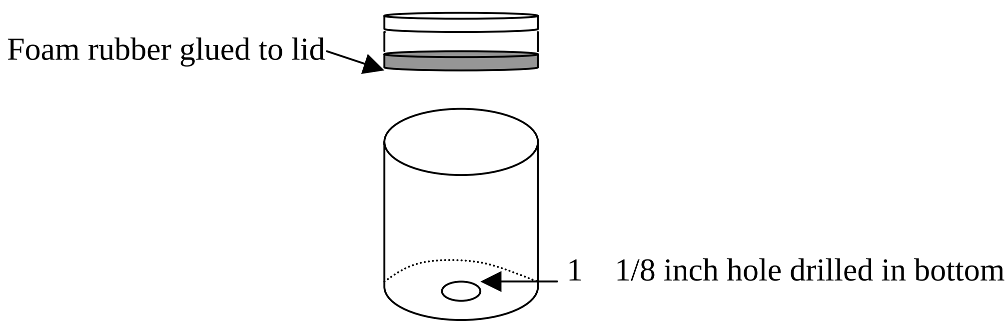

Figure 2: The canister with foam rubber hot glued to the inside of the lid and a hole drilled in its bottom.

2) The cold plate is used to conduct the cold temperature from the dry ice into the interior of the chamber. The cold plate is cut from a 1/8-inch thick piece of aluminum stock and is 3 3/4 inches in diameter. It is important that aluminum is used because stainless steel or other iron and steel products are not good thermal conductors. A 59/64-inch hole is drilled through the center of the round plate and tapped with a 1-14 thread (1-inch with 14 threads per inch tap). A 1 inch diameter, 4 inch long aluminum rod is threaded with the 1-14 die for only about 1/4 inch along one of its ends. The rod and the plate are then threaded together with the rod being screwed into the plate only until the end of the rod is flush with the plate. See figure 3.

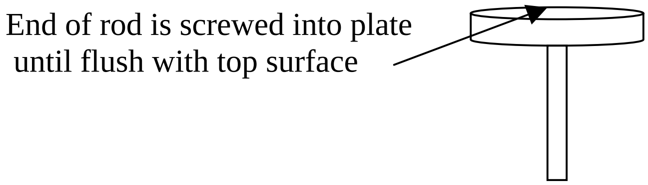

Figure 3: An aluminum rod is threaded to fit into a 1-14 thread tapped into aluminum plate.

3) Lightly sandpaper the plate/rod assembly and paint with a light coat of black metal primer. Once the primer is dry, paint with a light coat of flat black finishing metal paint.

4) The assembly of the cloud chamber requires the plate/rod to be inserted into the chamber from the top. It will be held in place with a 1/2 inch bead of Tub and Tile adhesive caulk (Dap Kwik Seal) which encircles the bottom of the plate about 1/2 inch in from its perimeter. The caulk must be applied to the bottom of the plate (the bottom of the plate is that side of the plate that has the rod extending out from it) prior to the plate/rod being inserted into the chamber, of course, as seen in figure 4.

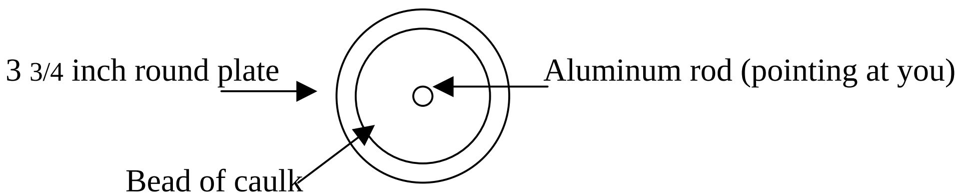

Figure 4: Bottom of metal plate with rod pointing out of the paper toward you. The caulk is applied as a 1/2-inch bead all around and near the perimeter of the plate.

As soon as the caulk is applied, gently drop the plate into the chamber, allowing the tube to penetrate the hole drilled in the bottom of the chamber. Seat the plate in the bottom of the chamber by gently rotating the plate, allowing the caulk to spread between the bottom of the plate and the chamber floor. You will be able to see the process by holding the

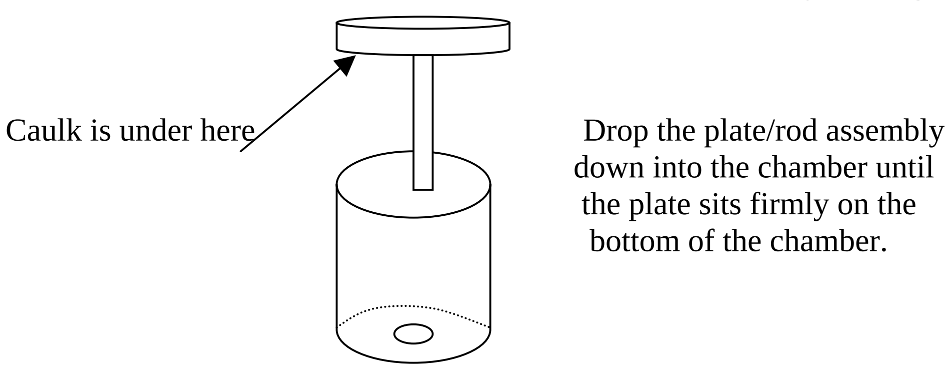

Figure 5: This shows the relative position of the caulked plate/rod assembly prior to insertion into the chamber.

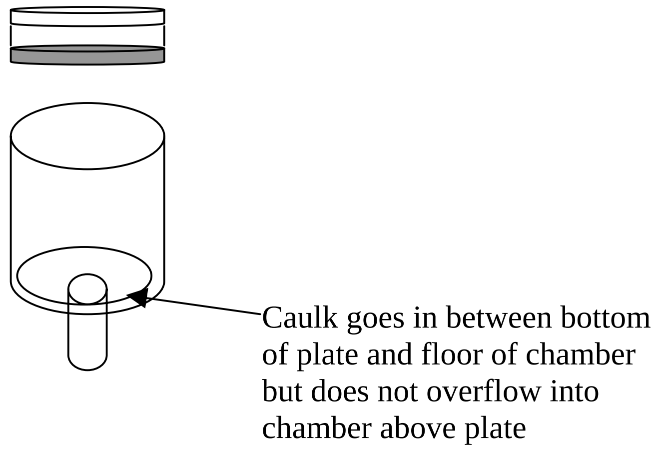

Figure 6: Completed cloud chamber with plate/rod assembly pressed into place by hand and held in place with caulk

chamber slightly above eye level where you can easily see the caulk through the transparent bottom of the chamber. Do not force the plate down so much that the caulk spreads around the plate and is forced up into the chamber. The caulk should spread no further than the perimeter of the plate, making an airtight seal around the plate. It is critical that there be no leaks at the bottom of the chamber or the diffusion of the alcohol will be disrupted by air currents and the cloud chamber will not work. See figure 5 and figure 6.

Operation of the Cloud Chamber

Using a hammer, break a pound or two of dry ice into very small pieces, approximately walnut size. Use gloves to protect your hand from freezing. Wear eye protection to guard against the flying dry ice chips. Place the assembled cloud chamber, without the lid on, into an insulated cup sufficiently large to accommodate the 4 inch length rod (workshop participants will be using a 20 ounce plastic cup, foam-insulated, made by Aladdin and sold at Wal-Mart for about $4.00. While holding a small gap between the bottom of the chamber and the top of the cup, place the pieces of dry ice into the cup. You need to have the chamber inside the cup as far as possible while you are doing this or else you will not be able to push the rod all the way into the cup once the cup is filled with dry ice.

When the cup is nearly full of dry ice, pour about one-half cup of rubbing alcohol (not methyl alcohol) into the cup. This will cause an immediate reaction with the dry ice and the dry ice/alcohol solution will start to "boil". This greatly aids the conduction of the cold from the dry ice to the aluminum rod and is critical.

By slightly shifting the cloud chamber back and forth and pushing down on it gently, you should be able to quickly seat the cloud chamber on top of the cup so that there is no gap between the cup and the bottom of the cloud chamber. Water vapor will escape from the cup through the slight gap beneath the chamber. That is not a problem and is expected.

When finished, the chamber and the cup will be as seen in figure 7.

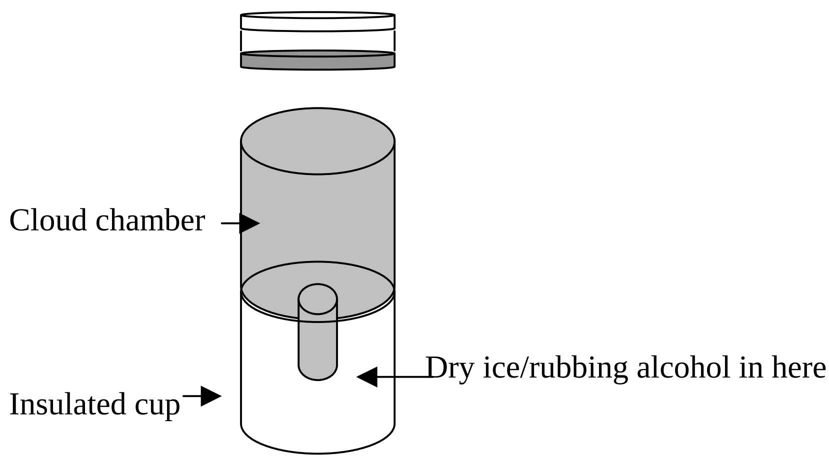

Figure 7: The cloud chamber is now resting on top of the insulated cup. The insulated cup is filled with small pieces of dry ice and about 1/2 cup of rubbing (isopropyl) alcohol.

Now, saturate the sponge on the inside of the lid with methyl alcohol. Some other alcohols will work, also. (See list of materials.) Do not use the rubbing alcohol for this or the cloud chamber will not work. Place the lid on the chamber and wait. In a few minutes, you should see a wispy fog forming in the bottom of the chamber just above the cold plate. Critical: viewing of this fog is greatly aided by being in a dark room and illuminating the cold plate from one side or the other with a strong flashlight.

Once the fog has formed, remove the lid temporarily and place the source in the center of the cold plate. Replace the lid as soon as possible. Again, in a few minutes you will see

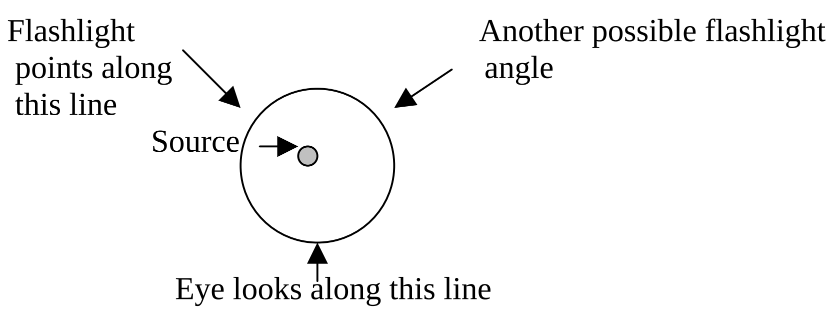

Figure 8: View from the top of two possible orientations for the flashlight.

the fog reform. Now, using the flashlight, illuminate the fog from various angles until you see the tracks from the radioactive source. See figure 8 for some suggested viewing angles.

Since alpha sources are often used in this experiment, don't be surprised if the alpha tracks disappear after a few minutes. This is because the source has become wetted by the alcohol and the alpha particles can not push through the alcohol film that covers the source. Simply remove the source and dry it off and replace it and the show will start over

.

Materials List

For those readers not attending the workshop, here is a review of the materials used.

Chamber

1. 0.6 quart airtight canister sold by K-Mart under the "Martha Stewart" brand, having a 1 1/8 hole drilled in its bottom center.
2. A 4 inch in diameter piece of foam rubber to be used as an alcohol sponge.
3. A glue gun for gluing foam rubber to inside of lid of canister.
4. Light sandpaper for sanding the plate and rod prior to painting.
5. One can of black primer and one can of flat black metal paint.
6. An 1/8-inch thick aluminum plate cut into a circle with a 3 3/4-inch diameter and a 1-14 thread tapped into its center.
7. A four-inch long, 1 inch in diameter, aluminum rod threaded on one end for about the first 1/4 inch using a 1-14 die.
8. A 5.5 fluid ounce tube of white Kwik Seal tub and tile adhesive caulk.

Dry Ice Cup

1. One 20 ounce insulated plastic cup made by Aladdin (PLO12203G). Any foam-insulated cup will work but it must have a diameter equal to the chamber (in this case, 4 inches) and a depth sufficient to accommodate the aluminum rod (in the case, a little more than 4 inches).
2. A small bottle, say 16 ounces, of rubbing alcohol (called isopropyl alcohol). This alcohol is mixed with the dry ice in the insulated cup in order to enhance the conduction of the dry ice temperature to the rod.
3. A small bottle, say 16 ounces, of methyl alcohol (also called methanol). This is the alcohol that is put into the chamber. It is poured onto the foam rubber sponge until the sponge is saturated. Ethyl alcohol works fine, also, if it is mostly free of water. For example, Everclear and Bacardi 151 rum, which can be purchased at most liquor stores, shows the tracks very nicely and the leftover makes a strong cocktail after the experiment is over. Finally, isopropyl alcohol will work if it is the high content (91 %) alcohol. In most drug stores, this is kept behind the pharmacy counter.
4. Two pounds, or so, of dry ice
5. Gloves and hammer to break the dry ice. Eye protection is not a bad idea, either, because the dry ice chips tend to fly when the cake of dry ice is struck

Viewing the Tracks

1. One dark room (inside) or direct, bright sunshine (outside)
2. One small, but bright, flashlight
3. One radioactive source
4. A lot of patience

Cleaning Up Afterwards

Wipe the interior of the chamber with a soft cloth or tissue paper until dry. Do not use a paper towel or scratchy cloth as it will permanently mark the interior of the chamber making it difficult to see through the chamber. Keep the cover off until the sponge dries completely.

Acknowledgement

Thanks to Mr. Scott Rehorst of the Physics department at the University of Colorado at Colorado Springs for his assistance in cutting the threads in the plate and the rod for those cloud chambers used in the AARST workshop. Dave Grammer, of RaData, Inc., came up with the idea of using Barcardi 151 rum. George Faggella, State of California radon coordinator, found out the chamber works fine with the 91 % isopropyl alcohol in the chamber.

References

AAPT, Apparatus for Teaching Physics: Reprints of Articles from the Physics Teacher, April 1963-December 1971, Committee on Apparatus for Educational Institutions of the American Association of Physics Teachers, January 1972, page 5 and page 66.

Emilio Segre, W.A., Nuclei and Particles, Second Edition, W. A. Benjamin Inc., 1977, pages 109-110.

Hodgson, P.E., Gadioli, E., and Gadioli Erba, E., Introductory Nuclear Physics, Clarendon Press-Oxford Science Publications, 1997, page 8 with photo on page 85.

Kastner, Jacob, Nature's Invisible Rays, U. S. Energy Research and Development Administration, Office of Public Affairs, Washington, D. C. 20545, 1973. See table on page 10.

Kocher, David C., Radioactive Decay Data Tables: A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments, Technical Information Center, U.S. Department of Energy, 1981.

Lapp, Ralph E. and Andrews, Howard L., Nuclear Radiation Physics, Third Edition, Prentice-Hall, Inc., 1963, page 257.

Oldenberg, Otto, Atomic and Nuclear Physics, Third Edition, McGraw-Hill Book Company, Inc., 1961, pages 340-347.