PLACES WITH HAZARDS

A TEACHER'S HANDBOOK ON NATURAL HAZARDS IN UTAH
for
SECONDARY EARTH SCIENCE CLASSES

GEOLOGIC HAZARDS LECTURE SET

The Radon Hazard in Utah

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This open-file release makes information available to the public during the lengthy review and production process required for a formal Utah Geological Survey (UGS) publication. This report is preliminary and has not been reviewed for conformity with UGS policy, or technical and editorial standards.

INTRODUCTION

The "Places with Hazards" curriculum was developed for secondary-level earth science teachers as a means of preparing students to live more safely in a world that can pose problems from natural hazards. Students should be able to make wise choices about where to live and work. The objectives are to learn about natural hazards, how they can be identified, what effects they have, and how they can be mitigated. Places in Utah are identified where natural hazards have occurred and can be expected to occur.

The curriculum contains ten sections: 1) overview, 2) earthquakes, 3) slope failures, 4) problem soil and rock, 5) radon, 6) volcanoes, 7) avalanches, 8) wildfires, 9) floods, and 10) dam safety. Each lecture is accompanied by a set of 35 mm slides for classroom use. Also included are activities, master sheets, glossaries, and resources.

The "Places with Hazards" curriculum was developed by two committees: 1) Lecture Preparation Committee consisting of technical staffs in several State government agencies and a Federal agency, and 2) Steering and Review Committee consisting of earth science teachers, a school administrator, and a college professor. Curriculum preparation was coordinated by the Utah Division of Comprehensive Emergency Management.

During the 1990-1991 school year, ten teachers in eight schools are participating in a pilot project using the curriculum materials. Feedback is anticipated to further improve the lecture set. Upon finalization, "Places with Hazards" will be available for distribution.

The Utah Geological Survey authored the five sections on geologic hazards: earthquakes, slope failures, problem soil and rock, radon, and volcanoes. Drafts of these five for the 1990-1991 pilot program are included in Open-File Report 211. Please note that although each section incorporates 35 mm slides into the module format, for this Open-File Report the slides are offered separately in each section's Part II.

The radon section of "Places with hazards" was prepared with a grant from the U.S. Environmental Protection Agency under the State Indoor Radon Grant Program.

Note to teachers
All figures and tables are provided in Appendix A.

Words in boldface in the text are important vocabulary; all are included in the glossary, Appendix B. A selected list of resources is provided in Appendix C for you and your students to use if you want to go beyond the information given.

CONTENTS

Figures and tables in the text are provided as master sheets in Appendix A.

I. OBJECTIVE

The student will be able to:

1. Identify the source of radon in soil and rock.

2. Describe geologic processes which contribute to the movement of radon from the source into buildings.

3. Identify areas in Utah where indoor radon levels are more likely to be excessive.

4. Identify the health effects of radon exposure.

5. Know methods to prevent radon contamination in new and existing buildings.

II. INQUIRY

In 1984, a worker at the Limerick Nuclear Power Plant in Pennsylvania repeatedly set off radiation alarms in the plant. After extensive testing it was determined that the worker, rather than being contaminated by a leak of radioactive material from within the power plant, was carrying in contamination from outside. The radiation source was found to be his radon-contaminated home in Boyertown, Pennsylvania; the home has one of the highest indoor radon levels recorded in the United States. This area of Pennsylvania is within the Reading Prong geologic province, which consists of rocks that have been subjected to intense heat and pressure, and have above-average uranium concentrations. These **metamorphic** rocks were the source of the radon found in the worker's home. This revelation established the relationship between geology and indoor radon levels, and prompted scientists to re-examine similar geologic areas elsewhere.

III. PROCESS

IIIa. The source of the radon hazard

Most geologic hazards are natural, dynamic, earth processes that tend to alter the landscape and adversely impact the works of society. During the past decade, Utah has been subjected to such geologic hazards as debris flows, debris floods, landslides, and the rapid rise of Great Salt Lake, which together cost the citizens of Utah hundreds of millions of dollars. These hazards are governed by geologic setting. The occurrence of high radon concentrations in buildings, although not a process of landscape alteration, is now recognized as another hazard controlled by geologic factors.

Radon is an odorless, tasteless, and colorless radioactive gas which forms as a product in three radioactive decay series. The most common of these is the uranium decay series where uranium (^{238}U) decays to form stable lead (^{206}Pb) (figure 1). New isotopes form through spontaneous disintegration and emit alpha, beta, and gamma radiation. Radon (^{222}Rn), one such isotope, forms directly from the disintegration of radium (^{226}Ra). As the radioactive decay process continues, a sequence of short-lived radon progeny form that emit mostly alpha and beta radiation (figure 1). Two other isotopes of radon (^{219}Rn and ^{220}Rn) also occur in nature and may contribute to the indoor radon problem, but ^{222}Rn is the most abundant of the radioactive radon isotopes, has the longest half-life (3.825 days), and is considered the most significant contributor to the indoor radon hazard. Subsequent references to radon imply ^{222}Rn derived from the ^{238}U decay chain.

Everyone receives some low-level radiation from naturally occurring radioactive isotopes present in nearly all rocks, soils, and water. We are also subjected to a certain amount of cosmic radiation that penetrates the earth's protective atmosphere. The amount and distribution of terrestrial and cosmic radiation varies with altitude and location, but daily doses of natural radiation pose a low health threat to the general population. However, terrestrial concentrations of radioactive isotopes are not uniformly distributed in rocks and soils. Some areas have elevated levels of radioactivity due to the geologic concentration of radioactive isotopes. Scientists have discovered elevated natural radiation levels in many parts of the world from measurements taken to monitor background radiation levels near nuclear power plants. Concern of the scientific community grew over the potential consequences of exposures to elevated levels of naturally occurring radioactive isotopes.

Radon concentrations in the atmosphere never reach dangerous levels because air movement dissipates the radon. People are subjected to a radon hazard in buildings or in natural enclosures with poor air circulation. There are four prerequisites to elevated indoor radon concentrations. The building must: (1) be built on ground that contains uranium, (2) have underlying soils that promote easy movement of radon, (3) have porous building materials or openings below grade, and (4) have a lower atmospheric pressure inside than outside. The ground must contain a certain amount of uranium from which radon emanates and the radon must travel easily through the soil to the structure before it decays. The structure must have foundation cracks or spaces in contact with the ground and have an atmospheric pressure lower inside than outside to allow radon to enter. Domestic water and home construction materials also contribute to indoor radon levels, but the major contributor in most cases is the geologic materials immediately underlying the home.

The first geologic consideration in evaluating a radon hazard is the distribution of rocks that may contain uranium in unusually high concentrations. Scientists recently discovered that certain rock types significantly contribute to elevated indoor radon levels. Areas underlain by rock such as **granite** (a crystalline rock formed from the solidification of molten magma within the earth), metamorphic rocks, some **volcanic** rocks (formed from the solidification of magma extruded onto the earth's surface), **black shales** (a sedimentary rock formed by the compaction of mud, with a black color imparted by included organic material), plus other **sedimentary** units (rock or soil formed from the settlement of solid material from a liquid or air suspension) derived from uranium-enriched source rocks are generally associated with an indoor radon hazard (figure 2).

If the radioactive source rock is present in the ground, there are several geologic considerations that enhance or impede radon emanation and movement. Rock and soil are composed of solid mineral grains, spaces between the grains (**pore space**), and fluid within the pore space (most often air or water). Once uranium is present in the mineral matter of the rock or soil, the radon formed must escape the crystal structure or surface film of the mineral grain. It does so during the spontaneous decay of radium, which emits **alpha particles**, positively charged subatomic particles which consist of two protons and two neutrons, and radon atoms. The radon atoms recoil in the opposite direction of the alpha particles. Radon atoms near the grain's surface may move into the pore space or burrow into an adjacent mineral grain (figure 3). Because the newly produced radon atom has a small recoil distance, grain size, pore size, **porosity** (the ratio of pore space within a rock or soil to its total volume), and moisture content are important components in radon **emanating power**. Emanating power is defined as the fraction of radon atoms that escape from the solid where they were formed.

Grain size and emanating power are inversely related. Grains larger than 1 micron (4×10^{-5} inches) can retard radon recoil because the recoil distance is less than the grain size and radon atoms produced deep in the grain's interior are unlikely to escape. Only radon atoms near the grain's surface have the opportunity to escape, thus reducing the amount of available radon atoms. Smaller grains also have a larger ratio of surface area to volume, which increases the relative amount of surface area available for the escape of radon atoms. Small pore size, though, can reduce emanating power because the recoiling radon can pass through the pore space and become embedded in the adjacent grain.

Another factor that influences radon production is the water that occupies the space between the grains. A water coating on the grains can increase radon emanation. When radon recoils from a grain in a dry environment it can pass through the dry pore space and become embedded in the adjoining grain. However, if the grain has a thin coating of water, the water absorbs the recoil energy of the radon atom and the radon will more likely be retained in the pore space. Water doesn't increase the rate of radon production, but allows a higher percentage of recoiling radon atoms to remain in the pore space.

Once free radon is present in the pore space of rock or soil, it can begin to move. Most sources of radiation are solids. However, radon is an inert gas that is very mobile. Therefore, radon can move with the air or, if dissolved in water, migrate through cracks and other open spaces in rocks and soils. Radon migration results from two mechanisms, **diffusion** and **mass transport**. Diffusion is the process of random movement of radon atoms by natural vibration. Mass transport is the process of convective flow of soil gas caused by air pressure differences within the soil, or between the soil and atmosphere, or between the soil and the foundation of a structure. Air pressure differences can be caused by barometric pressure changes in the atmosphere, wind blowing across a surface, or thermal convection generated by heating or cooling. These processes affect the release of radon from the soil, as well as the radon level within a structure. Home heating and wind conditions can create low atmospheric pressure inside a home, allowing it to act as a pump which draws in underlying radon-laden soil gas.

Radon was once thought to move through the rock or soil column by the process of diffusion. However the distance radon can travel by diffusion in about four days, the effective radon half-life, is negligible. Recent investigations suggest that both diffusion and convective flow are active in radon migration. Because high radon concentrations in some areas cannot be explained by diffusion alone, mass transport of radon by the convective flow of soil gas is thought to be the primary mechanism that moves large quantities of radon through the ground. Diffusion, however, may be the dominant mechanism of radon movement in soils with low average **permeability** (the capacity of a porous rock or soil to transmit a fluid; a rock may be porous, but if the pore spaces are not interconnected, the rock will not be permeable). Once soil gas reaches the backfill-and-subslab zone just outside the building foundation, pressure-driven convective flow of radon-bearing soil gas is commonly accepted as the dominant mechanism to move radon from outside foundations to inside the structure.

Water saturation of soil or rock columns can effectively inhibit radon migration. A small quantity of water increases radon emanation, but too much water restricts radon migration by reducing diffusion and blocking the flow of soil gas. Radon may move with the water, but the flow of water through soil and rocks is usually much slower, allowing time for the decay of included radon. Water does, though, provide an effective means to carry radon from its rock source. Where domestic water sources contain high levels of radon, they may contribute to indoor radon levels. Thermal waters from hot springs, and their deposits (tufa), are likely sources of radon.

The permeability and porosity of the rock or soil column also influences radon's ability to migrate to the surface. There is a correlation between areas that have permeable soils which contain open pathways enabling the migration of soil gas, and elevated indoor radon concentrations. Indices have been devised that attempt to predict indoor radon levels from soil permeability and soil gas radon concentrations. While such indices may work in relatively homogenous soils, spatial variations in most soils are large, as are temporal variations of soil gas radon concentration, making site characterization measurements difficult without an extensive sampling network.

Faults and fractures are zones of rock breakage which contain openings where air and water can move. Uranium in ground water is often deposited and concentrated in such zones. However, even if uranium mineralization does not significantly occur, fracture zones may enhance radon concentrations in soil gas adjacent to the fractures by providing permeable and porous pathways for radon-bearing gas to migrate toward the surface. Measuring radon concentrations over large areas can identify these zones. Monitoring changes in radon concentrations on active fault zones, such as the San Andreas fault zone in California, or in volcanically active areas may serve as a possible indicator of future geologic activity such as earthquakes or volcanic eruptions.

Ultimately, the exposure to the indoor radon hazard, in most cases, depends on non-geologic factors such as foundation condition, building ventilation, and life styles. Radon can find its way into buildings through small basement cracks or other foundation penetrations such as utility pipes (figure 4). Maximum radon concentrations are often found in basements or low crawl spaces because these parts of a house are in contact with the ground, which is the primary source of radon. Where private wells are used for household water, radon is released into the home during household activities such as showers and toilet flushing. Homes on municipal water systems are not subject to radon contamination since radon is released into the atmosphere while the water is being treated in the system, and radon decays into other substances when water is held in storage. In unusual situations. radon may be released from construction materials such as stone fireplaces, but building materials are not normally a major source of indoor radon.

Changes in building practices over the past 15 years have also contributed to the radon problem. Since the 1973 oil embargo, conservation of our non-renewable energy resources has been a national goal through energy-efficient practices. The building industry has made structures more energy efficient, but they have not improved ventilation systems to accommodate restricted natural air flow. Buildings, including single-family homes, constructed before 1973 often did not use energy-efficient measures, allowing indoor air to escape through above-grade joints and uninsulated walls and attics. Today, more energy-efficient homes and other buildings prevent the loss of indoor air to the outside. Studies have shown that newer, energy-efficient buildings with under-designed ventilation systems generally have higher indoor radon levels compared with older, conventional buildings.

IIIb. Measurement of indoor radon levels

Because non-geologic factors influence indoor radon concentrations, radon levels in buildings must be measured to determine if problems exist. Radon can be measured with both short-term and long-term passive detectors and electronic instruments. Some may be placed by the homeowner, while others require professional installation. Most people want information quickly, so they often select short-term monitoring methods which give quick, accurate results. A short-term measurement is one conducted for a period of less than three months. However, long-term monitoring, typically for a twelve-month period, provides more realistic information.

Measurements taken over a few days or on a single day will provide only a snapshot of indoor radon levels for that particular time. Radon emissions from the ground, and resultant indoor radon levels, fluctuate daily, weekly, and monthly because of atmospheric changes. In addition. concentrations fluctuate seasonally because building ventilation is less in winter than in summer, and indoor heating and air conditioning affect concentrations. A longer period of monitoring is recommended to smooth out short-term fluctuations. This will provide a more realistic picture of the yearly average indoor radon concentration. The

Utah Bureau of Radiation Control (UBRC) in Salt Lake City provides information on types of radon detectors available, their advantages and disadvantages, and comparative cost.

Radon measurement protocols suggested by the U.S. Environmental Protection Agency (EPA) attempt to assure accuracy and consistency of data. The protocols were developed to balance the need to obtain results quickly with the need to acquire measurements which best reflect long-term indoor radon levels. To accurately determine the indoor radon levels throughout the home, long-term monitoring is needed on each floor. However, a short-term screening measurement which follows EPA protocol (closed-house conditions) may be conducted in the lowest livable area of the house to determine if additional or follow-up testing is necessary. **Charcoal canisters** are commonly used for short-term measurements: **alpha track detectors** are commonly used for long-term monitoring.

Concentrations of radon gas are measured in **picocuries** per liter of air (pCi/L). A picocurie is the decay of about 2 radon atoms per minute. The Indoor Radon Abatement Act of 1988 states "The national long-term goal of the United States with respect to radon levels in buildings is that the air within buildings in the United States should be as free of radon as the ambient air outside of buildings." The average outdoor **ambient**, or background, radon level is about 0.2 pCi/L. The average radon level in the air of homes is about 1.5 pCi/L. The EPA, however, has proposed an **action level** of 4 pCi/L. Occupants of homes with radon levels above 4 pCi/L should take action to reduce radon concentrations; reduction of levels below 4 pCi/L may be difficult, and sometimes impossible, to achieve.

Additonal testing is not needed if the short-term screening measurement is less than 4 pCi/L and, although a small health risk is present, remediation is unnecessary. If a result is greater than 4 pCi/L and less than 20 pCi/L, a follow-up test of a 12-month measurement in two living areas of the house is recommended. If retesting confirms screening measurements, mitigation may be warranted in a few years. If a screening measurement is greater than 20 pCi/L and less than 200 pCi/L, retesting is recommended in two living areas of the house for no more than three months. If a screening measurement is confirmed, remediation should take place within the next several months. If a screening measurement is over 200 pCi/L, retest immediately in at least two living areas of the house. If confirmed, remedial action should commence within several weeks. Thus, current EPA measurement protocols emphasize immediate, short-term, follow-up testing in two living areas of homes with screening measurements greater than 20 pCi/L. The UBRC follows these guidelines but emphasizes the value in long-term monitoring.

IIIc. Potential radon-hazard areas in Utah

Two separate strategies guide investigators in their attempt to determine the magnitude of the potential radon hazard in Utah. One is to determine the distribution and magnitude of elevated indoor radon levels through testing in existing buildings. The other is to make geologic observations and develop methods to assess the likelihood of radon hazards at sites prior to construction.

The geologic basis for radon-hazard areas

Until recently, little was known about indoor radon in Utah. Indoor radon measurements made over the past few years in limited areas of the state suggested that certain locations in Utah may be susceptible to elevated radon levels. Other studies have addressed Utah's outdoor radon occurrences in soil and water. A coordinated statewide effort was initiated by the Utah Geological Survey (UGS) to identify and map rock types that are believed to produce radon in elevated quantities. The results of this work guided a year-long indoor radon study conducted by the UBRC in 1988.

The potential for elevated levels of indoor radon is now associated with rock types having average uranium concentrations less than 15 ppm (parts per million). Many areas of the country, including much of Utah, are underlain by rock which could produce elevated indoor radon levels. Radon-hazard areas within Utah were identified by known uranium occurrences (possible point sources for radon); uranium-enriched rocks (generalized sources) at the surface or beneath well-drained, porous, and permeable soils; anomalous surficial uranium concentrations; and the surface trace of the Wasatch fault zone. Included are uranium mines, uranium mill sites, and geothermal areas, as well as apparent surface concentrations of uranium determined by airborne surveys which outline the distribution of uraniferous rocks not otherwise shown by geologic mapping.

Areas in Utah with a greater potential for elevated indoor radon levels, based on geologic data, are shown on figure 5. The map is only a guide to help state health officials, interested decision-makers, developers, and the public determine areas for indoor radon surveys. The stippled areas primarily represent generalized outcrop patterns of radon-producing geologic formations. The boundaries are approximate and may be revised with future, more detailed study. Areas of low radon potential may occur within stippled areas. It is important to remember that this map only addresses some of the factors that influence the indoor radon hazard. Other factors such as radon movement through soil, permeability, building foundation condition, and indoor atmospheric pressure are not considered.

The Utah indoor radon study

Although small concentrations of radon occur virtually everywhere, parts of Utah have all of the necessary geologic conditions to identify them as potential radon-hazard areas. Elevated levels of radon in any one building, and the resultant risk posed to its occupants, is largely controlled by building construction and occupant life styles. However, indoor radon levels are consistently higher in areas where favorable geologic conditions exist. The UBRC conducted a survey to assess indoor radon levels statewide. The information derived from this study provided the first indication of the extent of Utah's indoor radon problem, and provided the UGS with valuable information required to examine the relation between geology and indoor radon levels.

The indoor radon study commenced in late 1987, and 631 homes were ultimately tested. The volunteers were solicited from cities or towns within radon-hazard areas (figure 5). The homes selected to participate in the study were owner-occupied, single-family dwellings. The volunteers were instructed to place alpha track detectors in the lowest livable area in their homes, and were asked to monitor their homes for at least twelve months. The distribution of the monitors was based on population density. Thus, the Wasatch Front (the metropolitan area from Provo to Brigham City) received about 80 percent of the monitors. Throughout the study, volunteers were regularly contacted to insure proper testing protocol. The monitoring period ended in the final quarter of 1988, and nearly every monitor was returned for analysis.

Geographic distribution of the radon data was analyzed by compiling summary statistics of radon values by zip code. Radon values between 4 to 10 pCi/L, 10.1 to 20 pCi/L, and greater than 20 pCi/L were plotted on the Potential Radon Hazard Map (figure 5) for comparison of indoor values and the mapped hazard areas. A geologic basis for clustering of high radon values was then determined.

Results of the Utah indoor radon survey show a lognormal distribution with a geometric mean of 1.8 pCi/L and a maximum concentration of 68 pCi/L (table 1). Nearly 86 percent of the homes tested had concentrations less than 4 pCi/L and about 14 percent of the homes were found to have concentrations greater than 4 pCi/L (table 2). The 1980 census for Utah indicates about 288,000 single-family homes statewide. The survey results, therefore, show that there may be 41,100 homes with elevated indoor radon concentrations (33,400 between 4 and 10 pCi/L; 5,400 between 10 and 20; and 2,300 greater than 20). This is likely a maximum estimate of the potential hazard, because most participants were solicited from suspected radon-hazard areas delineated on the basis of geologic parameters. Within the identified hazard areas, clusters of high indoor radon values (greater than 10 pCi/L) were apparent. The clusters occurred in Monroe, Sevier County and in Wasatch Front communities in and near Provo and Sandy. Isolated high indoor radon values were recorded elsewhere in Utah.

There appears to be a geologic basis for the clusters of high indoor radon values. Homes in the Monroe area of Sevier County are located on permeable, alluvial sediments (permeability provides a pathway for radon gas) derived from a known bedrock radon source, have ground-water depths greater than 10 ft (3 meters) (there is no water in shallow soils to impede the flow of soil gas), and are near the Sevier fault zone (a zone of increased permeability and a possible source of uranium and its decay products) and a large thermal spring (an additional source of radon gas). In Sandy and Provo, homes near the mountain front are more likely to have elevated indoor radon levels than homes in valley areas. These mountain-front homes are located on highly permeable shoreline deposits of Pleistocene Lake Bonneville derived from a known bedrock radon source, have ground-water depths greater than 10 ft (3 m), and are near the Wasatch fault zone.

IV. IMPACT

IVa. Recognizing indoor radon as a health problem

Radon, a radioactive gas of geologic origin, has now been found in many buildings throughout the United States in sufficient concentrations to represent a health hazard to building occupants. The greater your exposure to radon, the greater your risk of developing lung cancer. The EPA estimates that from 8,000 to 40,000 Americans will die each year from lung cancer caused by long-term radon inhalation. If you regularly drink household water containing radon. it is not considered a health risk. Waterborne radon is a problem only when the radon is released from the water and enters household air. Estimates of the contribution of radon in water to airborne radon range from 1 to 2.5 pCi/L in air for every 10,000 pCi/L in water.

Inhalation of radon and radon decay progeny was suspected as a health problem in the late 1950s and early 1960s when investigations were conducted on miners who worked in underground uranium mines. The studies concluded that high concentrations of radon found in the mines contributed to an increased incidence of lung cancer among miners. Indoor radon problems were also believed to have been associated with homes built on uranium mill tailings or uraniferous phosphate processing waste. The lower concentrations of uranium found in most rocks were assumed not to contribute to significant levels of radon indoors. Increased awareness of a potential health risk from exposure to elevated indoor radon levels began in the mid-1970s as a result of research conducted in Sweden. Still, most health concerns for the general population were focused on the potential exposure to radiation generated from nuclear power plants. The demonstration, in 1984, of an association between elevated indoor radon levels and lower concentrations of uranium found in various rocks near Boyertown, Pennsylvania, was therefore surprising.

IVb. The health effects of radon exposure

Radon and other sources of natural radiation are ubiquitous in small concentrations, but most natural background radiation is of a low-level dosage not considered to be a general health threat. Most buildings throughout the United States contain some radon, but concentrations are usually less than 3 pCi/L. Long-term exposure to these levels is generally considered a small health risk to the general population. However, health officials believe breathing elevated levels of radon over time increases a person's risk of lung cancer because of internal radiation damage to the lungs from decaying radon and radon progeny (figure 6).

Inhalation of radon is not thought to be the primary source of internal radiation because radon does not attach itself to the lining of the lungs. In addition, most radon atoms are exhaled before they decay and emit dangerous alpha particles to lung tissue. The radioactive isotopes formed from radon decay are of more concern because they are not inert and most readily attach themselves to the first charged surface they come in contact with, typically, dust or smoke in the air. People who smoke place the occupants of the building at greater risk because the smoke places a greater percentage of particles in the air, to which radon progeny become attached and are then inhaled into the lungs.

The dust or smoke particles with radon progeny attached become lodged in the lining of the lungs. Once lodged, the resident time in the lungs for these particles is greater than the cumulative half-life of the radon progeny. This allows tissue to be directly bombarded by a series of energetic alpha particles as the radon progeny decay (table 3).

V. MITIGATION

Va. Radon reduction techniques in the home

If elevated radon levels are discovered in the home, a number of methods can be considered for reducing indoor radon levels. These methods fall into two categories: 1) methods aimed at preventing the radon from entering the house, and 2) methods aimed at removing radon or its decay products after entry. The specific method chosen will depend upon the initial radon concentration, house design, and construction details.

Some actions may be taken immediately, and can be done quickly and with minimum expense. Discourage smoking in your home - this will not only reduce your risk from radon exposure, but will also reduce your family's overall chance of developing lung cancer. If practical, spend less time in areas with higher radon concentrations - radon tends to collect in the basement and other low areas of the home. Ventilate by opening windows and turning on fans to increase fresh air flow - this is not always possible during cold Utah winters.

Such immediate actions are effective, but do not offer long-term solutions. The selection of permanent radon reduction methods requires the identification of radon entry routes and driving forces, and the performance of diagnostic testing to aid in selection of the most effective radon reduction measure. The assistance of a professional is often required.

There are five classes of permanent radon reduction techniques: 1) **ventilation** may be natural as with open windows, in which case energy may be wasted and comfort sacrificed, or a heat recovery ventilator may be used, which reduces the energy and comfort penalties; 2) **sealing** may totally prevent the movement of radon from the soil into the house, or may prevent most gas flow through an entry route, but is not truly gastight (known as "closure"); 3) **soil ventilation** withdraws radon-contaminated soil gas and diverts it outdoors; 4) **house pressure adjustments** prevents the flow of soil gas into the house by altering pressure differentials between the house and soil; and 5) **air cleaning** removes radon decay products, which are solid particles, from the air after the entry of radon gas into the house.

Once the appropriate radon reduction technique has been chosen and implemented, post-mitigation diagnostic tests should be conducted to ensure that the reduction system is operating properly.

Vb. Radon reduction in new construction

Rather than expend time and effort removing radon from a house once contaminated, a more effective technique would be to prevent the radon from ever entering the structure. Prevention is difficult in existing buildings, but is advisable in new construction.

New construction may incorporate two techniques for prevention of radon entry: 1) homes should be designed and constructed to minimize pathways for soil gas to enter, and 2) homes should be designed and built to minimize the difference in pressure between indoors and outdoors. since pressure differences are the driving force for soil gas to enter the home. Features can also be incorporated during construction that will facilitate radon removal after completion of the home if prevention techniques prove to be inadequate. Specific construction techniques are technical in nature and will not be discussed here, but information is available from the EPA.

Vc. Removal of radon from household water

If there is no measured problem with airborne radon in a home, there generally is no need to test for radon in household water. If indoor radon levels are high, low-cost test kits are available from commercial laboratories for testing of water. Testing of water from municipal water supplies is generally not necessary; radon contamination usually occurs only from well water, and even there is not common.

If water tests indicate you have a radon problem, you may either remove the radon from the air after it has left the water, or you may remove the radon from the water before it reaches the indoor air. In many cases good ventilation of bathrooms, the laundry, and the kitchen, particularly during periods of water use, may be adequate, though impractical during cold weather. Water may be stored before use for several days to allow the radon to decay, but a very large storage tank is needed. Home aeration systems spray the water through an air-filled chamber and use a fan to move the contaminated air out of the house, but these devices are not readily available or widely used. Devices which use granular activated charcoal to remove radon from water are presently the least costly for a single home using its own well and, to date, are the most extensively tested and used.

VI. CONCLUSION

Radon is an environmental concern throughout the country because of its suspected link to lung cancer. Radon is an odorless, tasteless, and colorless radioactive gas that occurs in nearly all rocks and soils. It is found in most buildings in small concentrations that do not constitute a health threat. However, scientists have recently discovered that geologic conditions can influence the likelihood of having elevated indoor radon levels.

In Utah, excessive levels of indoor radon have been found in a higher proportion of homes along the mountain fronts of Provo and Sandy, and in the Monroe area of Sevier County. Each of these areas are affected by several geologic factors which served to predict the increased potential for an indoor radon hazard. Each area was adjacent to bedrock with higher-than-average uranium concentrations and was underlain by soil derived from the adjacent bedrock. Moreover, the soil provided a permeable pathway for the radon-laden soil gas to travel to the overlying houses. In addition, the soils are well-drained, which permitted the soil gas to travel rapidly, unimpeded by ground water, allowing soil gas to enter homes prior to the decay of radon. Nearby fault zones in both areas, and hot springs in the Monroe area, provided an additional possible source of radon.

Because of the complex relationships between geologic and non-geologic factors that control radon levels, predicting radon concentrations from building to building is difficult even in areas with a high geologic potential for radon production. The current understanding of radon behavior prohibits extrapolating radon values over any distance. But with additional indoor radon surveys and geologic characterization of sites, discovering critical combinations of components will lead to an easier and more reliable method of radon assessment. It is important to determine the critical factors that contribute to the potential radon hazard for areas prior to construction so that mitigation techniques can be incorporated into building design. There are, however, low-cost effective techniques for the removal of radon gas in existing homes.

APPENDIX A

FIGURES

TABLES

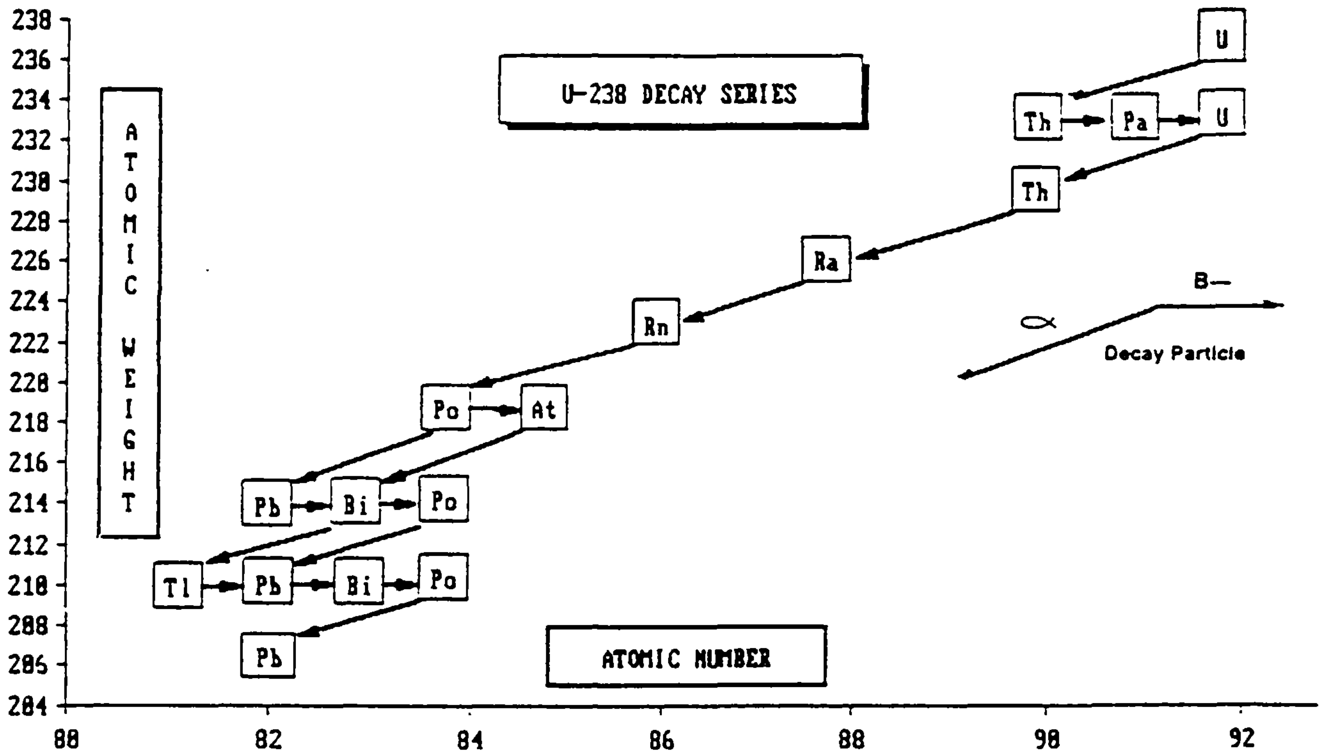

Figure 1. Uranium (^{238}U) decay series. Radon (^{222}Rn) is derived from radium (^{226}Ra) and is the only isotope in the series that is a gas. Because it is also inert, radon has the ability to move with air or water without participating in chemical reactions (modified from Durrance, 1986).

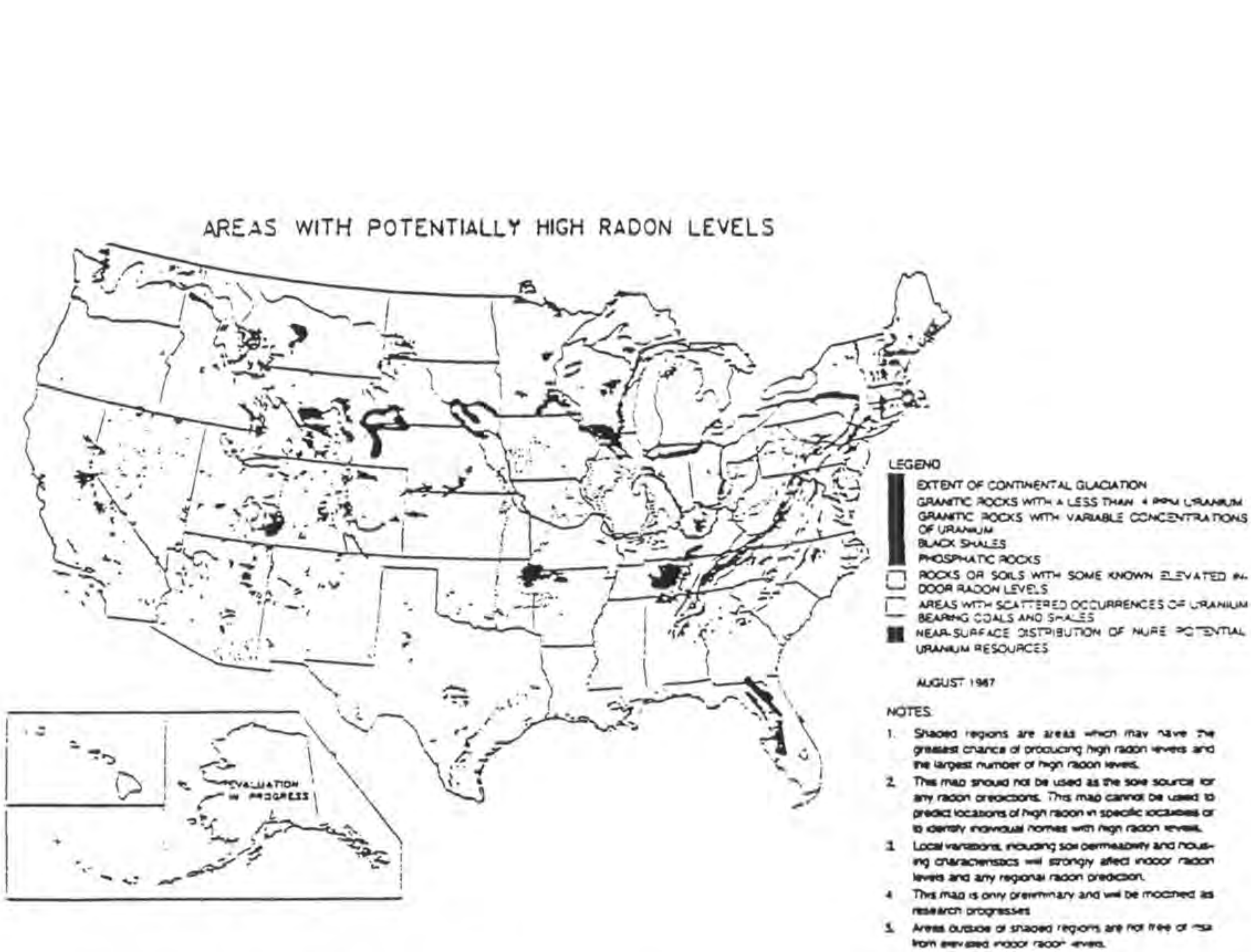

Figure 2. Areas in the United States the U.S. Environmental Protection Agency identifies with potential high radon levels. These areas delineate certain rock types found throughout the U.S. that have the capability of producing greater than average amounts of radon (EPA, press release August, 1986, and August, 1987).

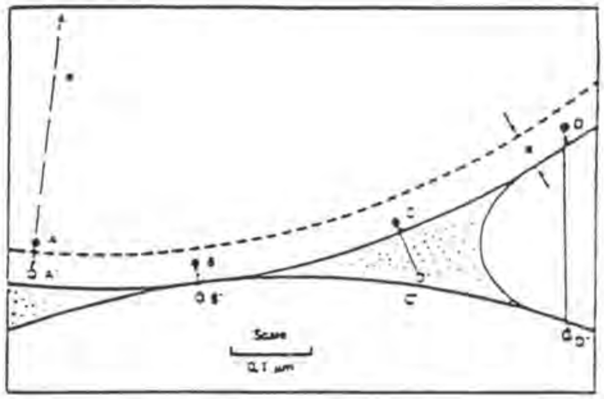

Figure 3. Idealized cross section of two mineral grains showing how radon can escape (the emanation process). The two grains are in contact near B. The stippled pattern represents a meniscus film of water between grains. The white area to the right of the water is air. ^{226}Ra atoms are represented by the solid dots and ^{222}Rn atoms are the open circles. R is the recoil distance of the newly formed radon atom. Because of the small recoil distance of radon within the grain, only radium atoms found near the grain's surface would contribute to radon emanation. Recoiling radon atoms passing through a film of water are more likely to remain in the pore space, while radon atoms that pass only through air may become embedded in the adjoining grain and rendered harmless (from Tanner, 1980).

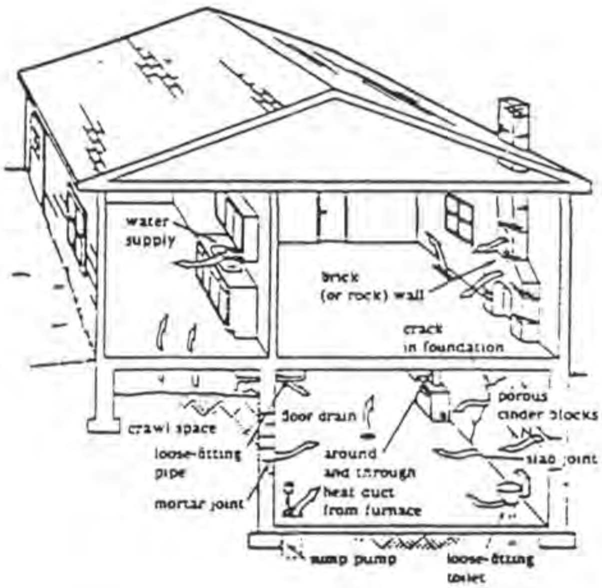

Figure 4. Various pathways for radon to enter a home. Most of the routes are in the basement, because that is the part of the house with the greatest surface area exposed to the surrounding soil (reprinted from <u>Radon: The Invisible Threat</u>, c1987, by Michael Lafavore. Permission granted by Rodale Press, Inc., Emmaus, Pennsylvania 18098).

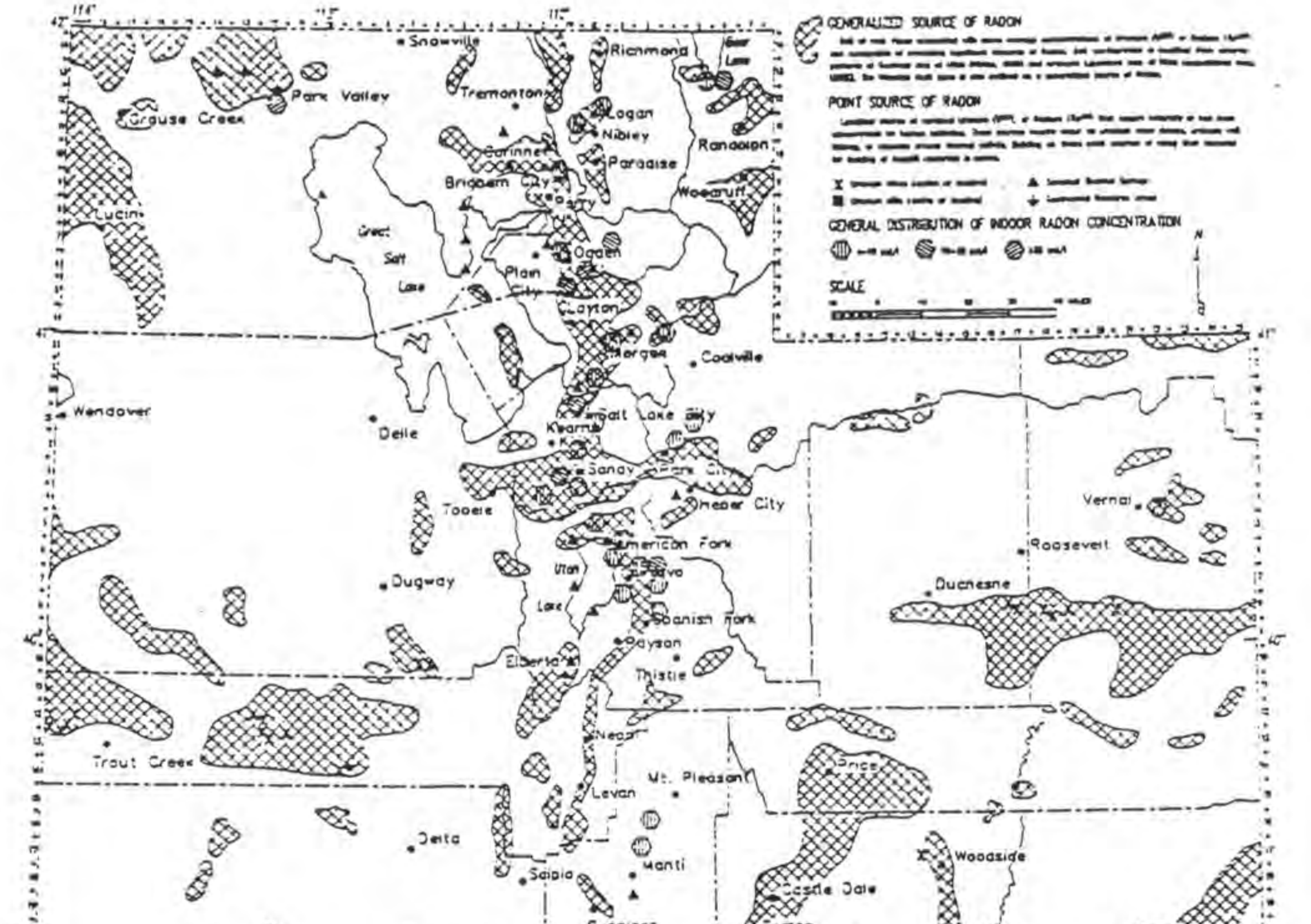

Figure 5. Generalized radon potential map of Utah (modified from Sprinkel, 1987) showing the general distribution of indoor radon concentrations determined in the survey of 1988.

RADON RISK EVALUATION CHART

pCi/l	WL	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels	Comparable risk
200	1	440—770	1000 times average outdoor level	More than 60 times non-smoker risk
100	0.5	270—630		4 pack-a-day smoker
40	0.2	120—380	100 times average indoor level	2,000 chest x-rays per year
20	0.1	60—120	100 times average outdoor level	2 pack-a-day smoker
10	0.05	30—120		1 pack-a-day smoker
4	0.02	13—50	10 times average indoor level	5 times non-smoker risk
2	0.01	7—30	10 times average outdoor level	200 chest x-rays per year
1	0.005	3—13	Average indoor level	Non-smoker risk of dying from lung cancer
0.2		1—3	Average outdoor level	20 chest x-rays per year

Figure 6. Radon risk evaluation chart. The EPA (1986) has developed this chart to provide comparable risks for people to evaluate their personal risk to the radon hazard. Units of measurement often used to report radon decay product concentrations are working levels (WL), noted in the second column. One working level (WL) is defined as the quantity of short-lived radon decay products that will result in 1.3 x 10^{-5} Mev (million electron volts) of potential alpha energy per liter of air (EPA, 1987a).

	UTAH	OGDEN	OREM	PROVO	SANDY	EAST SLV	WEST SLV
Sample Size	631	49	44	43	42	181	40
Average	2.73	3.42	2.12	3.10	3.52	2.24	1.68
Median	1.80	1.30	1.90	2.10	2.10	1.70	1.40
Mode	1.00	0.80	2.20	0.70	0.90	0.70	1.70
Geometric mean	1.80	1.50	1.80	2.03	2.28	1.63	1.37
Variance	18.14	96.06	1.22	9.68	20.27	3.82	1.56
Standard deviation	4.26	9.80	1.11	3.11	4.50	1.95	1.25
Standard error	0.17	1.40	0.17	0.47	0.69	0.15	0.20
Minimum	0.01	0.30	0.20	0.30	0.50	0.01	0.30
Maximum	68.20	68.20	4.60	13.60	26.20	15.70	6.50
Range	68.19	67.90	4.40	13.30	25.70	15.69	6.20
Lower quartile	1.00	0.80	1.30	0.90	1.30	1.00	0.90
Upper quartile	3.10	2.10	3.10	3.70	3.40	2.80	1.85
Interquartile range	2.10	1.30	1.80	2.80	2.10	1.80	0.95
Skewness	9.19	6.31	0.40	1.71	3.58	2.85	2.25
Standardized skewness	94.21	18.03	1.08	4.58	9.46	15.67	5.83
Kurtosis	118.98	41.94	-0.80	2.47	15.70	13.67	5.88
Standardized kurtosis	610.07	59.92	-1.09	3.31	20.76	37.55	7.58

Table 1. Statistical analysis of indoor radon concentrations measured in the 1988 radon study conducted by the Utah Bureau of Radiation Control. The Ogden area includes Ogden, North Ogden, South Ogden, Pleasant View, Washington Terrace, and Uintah; the East Salt Lake Valley (East SLV) includes most cities east of the Jordan River such as Salt Lake City, South Salt Lake City, Holladay, Murray, Midvale, and Draper; the West Salt Lake Valley (West SLV) includes most cities west of the Jordan River such as West Valley City, Kearns, Bennion, Taylorsville, West Jordan, South Jordan, and Riverton.

LOCATION	TOTAL HOMES	NO. HOMES	<4 pCi/l	NO. HOMES	4<10 pCi/l	NO. HOMES	10<20 pCi/l	NO. HOMES	≥20 pCi/l
Utah	631	541	85.74%	73	11.57%	12	1.90%	5	0.79%
Ogden	49	44	89.80%	2	4.08%	2	4.08%	1	2.04%
Orem	44	43	97.73%	1	2.27%	0	0.00%	0	0.00%
Provo	43	34	79.07%	7	16.28%	2	4.65%	0	0.00%
Sandy	42	34	80.95%	6	14.29%	1	2.38%	1	2.38%
East SLV	181	159	87.85%	20	11.05%	2	1.10%	0	0.00%
West SLV	40	37	92.50%	3	7.50%	0	0.00%	0	0.00%
Sevier Co.	14	8	57.14%	3	21.43%	1	7.14%	2	14.29%

Table 2. Distribution of indoor radon concentrations measured in the 1988 UBRC radon study. The Ogden area includes Ogden, North Ogden, South Ogden, Pleasant View, Washington Terrace, and Uintah; the East Salt Lake Valley (East SLV) includes most cities east of the Jordan River such as Salt Lake City, South Salt Lake City, Holladay, Murray, Midvale, and Draper; the West Salt Lake Valley (West SLV) includes most cities west of the Jordan River such as West Valley City, Kearns, Bennion, Taylorsville, West Jordan, South Jordan, and Riverton.

Isotope	Symbol	Half-Life	Decay Particle	Energy (MeV)
Uranium	U-238	4.468 billion years	a	4.195 4.14
Thorium	Th-234	24.1 days	b	0.192 0.10
Protactinium	Pa-234m Pa-234	1.18 minutes 6.7 hours	b b	2.31 2.3
Uranium	U-234	248,000 years	a	4.768 4.717
Thorium	Th-230	80,000 years	a	4.682 4.615
Radium	Ra-226	1602 years	a	4.78 4.59
Radon	Rn-222	3.825 days	a	4.586
Polonium	Po-218	3.05 seconds	a, b	6.0
Astatine	At-218	2 seconds	a	6.7 6.65
Lead	Pb-214	26.8 minutes	b	0.7 1.03
Bismuth	Bi-214	19.7 minutes	a, b	a=5.5 b=3.2
Polonium	Po-214	0.000164 seconds	a	7.68
Thallium	Tl-210	1.32 minutes	b	5.43
Lead	Pb-210	22.3 years	b	0.015 0.061
Bismuth	Bi-210	5.02 days	a, b	a=4.7 b=1.16
Polonium	Po-210	138.3 days	a	5.3
Lead	Pb-206			

Table 3. The uranium (^{238}U) decay series showing the half-lives of isotopes. Radon's (^{222}Rn) half-life is less than four days and the combined half-life of radon progeny is about 90 minutes. a=alpha; b=beta

APPENDIX B

GLOSSARY

Action level - The level of indoor radon above which action should be taken by occupants of homes to reduce radon concentrations. The action level is defined as 4 pCi/L by the U.S. Environmental Protection Agency. Reduction of indoor radon to levels below 4 pCi/L may be difficult, and sometimes impossible, to achieve.

Air cleaning - A method to remove radon decay products, which are solid particles, from indoor air. The air is continuously circulated through a device which removes the particles.

Alpha particle - A positively charged subatomic particle emitted during the decay of certain radioactive elements, including radon. An alpha particle is indistinguishable from a helium atom nucleus and consists of two protons and two neutrons.

Alpha track detectors - A device for measurement of indoor radon levels. Radon enters the device and decays, emitting alpha particles. The alpha particles strike the detector and produce submicroscopic damage called alpha tracks. Alpha tracks are counted in a laboratory to determine the amount of indoor radon.

Ambient level - The level of radon, or any other component, in outdoor air. The Indoor Radon Abatement Act of 1988 states "The national long-term goal of the United States with respect to radon levels in buildings is that the air within buildings in the United States should be as free of radon as the ambient air outside of buildings."

Black shale - A dark, thinly layered sedimentary rock whose dark color is the result of high levels of organic matter. Black shale is formed when material is deposited in quiet-water, reducing environments.

Charcoal canister - A device for measurement of indoor radon levels. Radon enters the device and decays, depositing decay products on a charcoal bed. The decay products are measured in a laboratory to determine the amount of indoor radon.

Diffusion - The random movement of individual atoms or molecules, in the absence of mass transport. Atoms of radon can diffuse through tiny openings in house foundations.

Emanating power - The fraction of radon atoms that escape from the solid where they were formed. In rock and soil, emanating power depends upon grain size, porosity, and the nature of material (gaseous or liquid) that fills the pore space between grains.

Granite - A light-colored, coarse-grained igneous rock formed at considerable depth by crystallization of molten or partly molten material.

House pressure adjustment - A method to reduce the driving force for movement of radon in soil gas into a house. Pressures at the lower levels inside a house are commonly lower than the pressures in the surrounding soil, drawing soil gas into the house by mass transport. If the degree of house depressurization is reduced, the rate of soil gas influx might be reduced.

Igneous - A rock or mineral that has solidified from molten or partly molten material.

Mass transport - The process of bulk flow in which radon-bearing soil gas moves into a house as the result of pressure differences between the house and the soil. Synonymous with convective movement.

Metamorphic - A rock or mineral that has formed from the mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions which have generally been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks originated.

Permeability - The capacity of a porous rock or soil for transmitting a fluid. A measure of the ease with which radon-bearing soil gas can flow.

Picocurie - A unit of measurement of radioactivity. A curie is the amount of any radionuclide that undergoes exactly 3.7×10^{10} radioactive disintegrations per second. A picocurie is one trillionth (10^{-12}) of a curie, 0.037 disintegrations per second, or the decay of about 2 radon atoms per minute. Picocuries per liter (pCi/L) is a common unit of measurement of the concentration of radon in air, and corresponds to 0.037 radioactive disintegrations per second in every liter of air.

Pore space - The open spaces in a rock or soil, in between solid grains. The spaces may be filled with gas (usually air) or liquid (usually water). The type of material within the pore space affects the emanating power of the rock or soil.

Porosity - The ratio of the volume of pore space in rock or soil to the volume of its mass, expressed as percentage.

Radioactive - The property posessed by some elements, including radon, of spontaneously releasing subatomic particles accompanied by the release of energy. This process of radioactive decay results in the transformation of the original element into another element or isotope.

Radionuclide - Any radioactive element or isotope.

Radon - The only radioactive element which is a gas. Radon refers to any of a number of radioactive isotopes having atomic number 86. Radon-222 is the most abundant of the radioactive radon isotopes, has the longest half-life (3.825 days), and is considered the most significant contributor to the indoor radon hazard. Radon-222 forms directly from the disintegration of radium-226, within the uranium-238 decay series.

Sealing - A method to prevent the movement of radon from soil into a house. Soil gas entry routes (such as foundation cracks, porous building material, and openings for plumbing) are treated to provide a physical barrier between the soil and the house interior.

Sedimentary - A rock composed of solid, fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice, or that accumulates by other natural agents, such as chemical precipitation from solution or secretion by organisms. Sedimentary rocks initially form in layers on the Earth's surface at ordinary temperatures in a loose, unconsolidated form.

Soil ventilation - A method to prevent the movement of radon from soil into a house. Soil gas is drawn or blown away from the house before it can enter.

Ventilation - A method to reduce indoor radon levels by displacing house air with outdoor air. This may be achieved without attempting to recover heat lost from inside the house (by opening doors, windows, or vents, or by using a fan), or by recovering the heat (with heat recovery ventilators or air-to-air heat exchangers).

Volcanic - A finely crystalline or glassy igneous rock resulting from molten or partly molten material and associated gases which rise into the Earth's crust and are extruded onto the surface and into the atmosphere.

APPENDIX C

RESOURCES

Video

"Revising a Citizen's Guide to Radon" is a 37-minute video on the indoor radon hazard. The video was produced by the U.S. Environmental Protection Agency and describes the origin of the hazard, effects on human health, and measurement and mitigation techniques. The video is available through the Utah Department of Health, Bureau of Radiation Control.

Maps

A radon-hazard potential map is available for the state of Utah, at a scale of 1:1,000,000, from the Utah Geological Survey (Sprinkel, 1987), and a description of the radon hazard in Utah is also available which summarizes the results of the statewide sampling of indoor radon levels conducted by the Bureau of Radiation Control (Sprinkel and Solomon, 1990). More detailed studies of specific areas throughout Utah are being conducted and, when complete, study results will be available from the Utah Geological Survey.

The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the American Association of State Geologists, is compiling a national radon atlas. The atlas will contain a chapter on the radon potential of Utah, and will be available from the U.S. Geological Survey upon completion.

Booklets

Booklets on various aspects of the radon hazard are published by the U.S. Environmental Protection Agency. These booklets are distributed in Utah by the Bureau of Radiation Control.

Speakers

Individuals are available to speak on various aspects of the radon hazard in Utah. For information on the geologic aspects of the radon hazard, contact the Utah Geological Survey. For other aspects of the hazard, contact the Utah Bureau of Radiation Control.

Additional information

For additional radon information, you may want to contact the following:

For questions about geology and radon in Utah:

Utah Geological Survey
606 Black Hawk Way
Salt Lake City, Utah 84108
(801) 581-6831

For questions about health, testing, and mitigation:

Utah Division of Environmental Health
Bureau of Radiation Control
288 North 1460 West
P.O. Box 16700
Salt Lake City, Utah 84116
(801) 538-6734

For general radon information:

U.S. Environmental Protection Agency
8HWM-RP
999 18th Street, Suite 500
Denver, Colorado 80202
(303) 293-1709

For general information on geology and radon:

U.S. Geological Survey
Earth Science Information Center
125 South State Street
8th Floor, Federal Building
Salt Lake City, Utah 84138
(801) 524-5652

APPENDIX D

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