A History of Radon- 1470 to 1984

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We will explore two separate pathways of radon history over time, an occupational history and a residential history. The occupational history goes much farther back in time and is where we will start the story. The residential history is much more recent in time but possibly more widespread than many would have thought.

The occupational story starts in a region known as the Erzgebirge, the Ore Mountains. These mountains separate present day Germany from Czechoslovakia. The two principle towns of interest are Schneeberg on the German side of the mountains, about 50 miles due south of Leipzig and Jachymov in Czechoslovakia, about 60 miles northwest of Prague. Mining first started in Schneeberg in the early 1400's and in Jachymov in 1516 after the discovery of rich veins of silver. It seems as though the dawn of the Renaissance (1450-1600) was a real driving force for mining in these two districts due to the increased demand for metals for military purposes and gold and silver to fund trade, expeditions of discovery, and building projects.

Mining in these very early years was for silver, copper, and iron, and later for cobalt and arsenic containing ores. After the discovery of uranium in 1789 by Martin Klaproth, pitchblende was then mined, primarily at Jachymov. This pitchblende may have contained about 1% uranium. The uranium was at that time used for coloring wood, leather, pottery glazes and glass.

The miners of these very early years paid a heavy price for their labors. A quote from Agricola's publication De Re Metallica gives us a feel for the conditions in the mines and the miners fate, "the dust has corrosive qualities, it eats away the lungs and implants consumption in the body… Women are found who have married seven husbands, all of whom have this terrible consumption has carried off to a premature death." The miners themselves called this disease "Bergsucht" or "Mountain Sickness." The miners attributed it to sub-terranean dwarfs. Others attributed it to metallic vapors. It would not be until 1879 that malignant tumors of the lung were found to be the cause of death, and it would be into the 1920's and 30's when radioactivity in the mines was believed to be the cause of the tumors.

We should return to Agricola for a moment. Georgius Agricola was born Georg Bauer in Saxony in 1494. Though Georgius was known as the father of mineralogy he also explored the areas of metallurgy, philosophy, natural sciences, and medicine. In fact, in 1527 he was chosen as the town physician at Jachymov. Georgius was a key figure in helping to advance numerous safety factors in mines, some useful and some not so useful. Georgius introduced various forms of mine ventilation, masks worn over the mouth and face, and other types of protective apparatus

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for hands and feet. This information was published in his landmark publication De Re Metallica (On the Subject of Metals), in 1556. Interestingly this publication was translated into English by our 31st President Herbert Hoover, and his wife Lou.

There is a fairly quiet period in the English literature from these very early years until the early to middle 1800's. However, there is information in the European publications regarding both the mining and the lung damage that it caused. Obviously, these publications were written in German and unreadable by this author. It was at this time due to the 1789 discovery of uranium that this black ore (pitchblende) was mined at Jachymov. Records indicate three pits were mined in 1853 and remarkably this mining continued, at various locations in the Erzgebirge until the unification of Germany in 1990. Obviously the purpose for the mining of the uranium was not always the same. We already mentioned that initially the uranium was used as a coloring agent; then later, starting in 1946, it was used to supply the Soviet Union for weapons production and nuclear power. A recent Health Physics (March 2006) article by Irene Bruske-Hohlfeld, et al details the lung cancer risk amongst these uranium miners.

As part of this interesting history on radon, Dr. Victor Archer has estimated that the miners at Schneeberg were exposed to an average cumulative exposure of 6,480 WLM and that the miners at Jachymov received 3,840 WLM.

Causation

We must follow a long and winding road to go from the "Mountain Sickness" of the Erzgebirge to the progeny induced lung cancer of today.

Malicious "sub-terranean dwarfs" were thought to pervade the mines and be the cause of this terrible malady. This was the belief, at least, of the miners. Paracelsus (1493-1541) a contemporary of Agricola, and a physician himself, postulated the inhalation of metallic vapors ', which settle on the lung… in different ways' as a cause for the "Mountain Sickness." It seems also that Agricola thought the problem to be some type of inhalation problem because he devised horse and water-powered bellows for mine shaft ventilation and protective veils of fine netting to wear over mouth and nose. He also forbid miners from going into the mines while the veins and rocks were being heated and giving forth a 'foetid vapour and the shaft or tunnels are emitting fumes… lest the stench affect their health or actually kill them.' Other plausible explanations include tubercular disease and the presence of arsenic in the dust.

We would never really get to the root cause of the problem had it not been for four very significant discoveries; first was the discovery of x-rays in 1895 by W.C. Roentgen, then radioactivity in 1896 by Henri Becquerel, third the discovery of radium in 1898 by M. and P. Curie, and finally the discovery of radon by Friedrich Ernst Dorn in 1900, initially called "radium emanation" and not to be called radon until 1923. From these four discoveries we can now move on with the rest of the story.

In 1879 Harting and Hesse by use of clinical and anatomical research proved that the "Mountain Sickness" of the Schneeberg miners was actually a malignant tumor of the lung. These authors

even wrote a letter to the mining and health authorities at Jachymov inquiring as to any occurrences of cancer of the lungs of this group of miners. The Jachymov authorities wrote back in the negative. It would not be until 1926 that the lung cancer prevalence in the Jachymov miners was found to be similar to that at Schneeberg. These authors stated that from the period 1869 to 1877 about 75% of all deaths among miners of Schneeberg were due to lung cancer. Though this number is probably unreliable, it can be contrasted with the autopsy findings in 1878 from the Institute of Pathology at the University of Dresden where malignant tumors of the lung only accounted for 1% of all cancers. Lung cancer was a very rare disease 150 years ago. After 1900 there began a gradual increase in the lung cancer frequency and then in the 30's there was a much more rapid incidence of this disease. We find ourselves today with lung cancer being the most common type of cancer in the world.

Radon measurements in the various mines were finally starting to be made in the early 20th century. These measurements made in the 1920's and 30's showed values from the hundreds to many thousands of pCi/L. Actually, the results were evaluated in terms of Mache Units. This unit of measure had been in use in the 20's and 30's, whereby 1 Mache unit was equal to 3.64 Eman, which was equal to 364 pCi/L. The unit was named after H. Mache (1876-1954). These measurements started to give the scientists the "magic bullet." Yes, there was a radioactive substance in the mines that also happened to be a gas. This started to give a cause and effect that the malignant tumors of the lung may be due to the radon content of the mines. However, new ideas don't always take hold immediately. Others thought that the "Mountain Sickness" might be due to toxic ore dusts. Others thought arsenic or other mine contaminants, or just the overall poor health of the miners. Another complicating factor was the occurrence of silicosis. There was also the problem of misdiagnosis; whereby tuberculosis, a common disease of that day, was diagnosed when lung cancer was in fact the problem.

The landmark work by Dr's Pirchan and Sikl in 1932 published in The Ameircan Journal of Cancer links the miner's lung tumors with the radon in the mines at Jachymov. Dr. Pirchan was the head Physician at the State Radium Institute, Jachymov, and Dr. Sikl was Professor of Pathology at the Czech University, Pargue. They conclude their paper with "the most probable cause of the tumors, radium emanation, which is contained in the air of Jachymov pits up to 50 mache units, might be considered. A cumulative effect of small quantities of emanation inhaled for a period of many years may be assumed. This question, however, requires further investigation." The other interesting fact about these two doctors is that they were from Czechoslovakia yet they publish their work in an American publication. It seems as though the authorities of Jachymov and the National Health authorities continued to deny that there was any problem in the mines.

The research on radium and radon exposure and its effect on humans were now gearing up on the other side of the Atlantic. This work was being done on factory workers, medical patients, radium dial painters, and members of the armed forces. Though more and more were being convinced that radon indeed was the causative agent there were still problems. The calculated dose to the lung due to radon was too small to produce the effects seen in comparison to radium doses and to external radiation doses associated with carcinogenesis. The answer to this problem will be obvious to most of us in this audience. The decay scheme for radium had already been worked out and people knew that there were "daughters." However, very few workers made

measurements to characterize the decay products. In 1944 Lorenz even pointed out that radon only contributed a few percent of the dose from an equilibrium mixture. In the early 1950's William Bale from the University of Rochester hit the nail on the head. "In these and other past evaluations of the hazard associated with radon the vital fact seems to have been almost entirely neglected that the radiation dosage due to the disintegration products (daughters) of radon present in the air under most conditions where radon itself is present conceivably and likely far exceed the radiation dosage due to radon itself and to disintegration products formed while the radon is in the bronchi." Dr. John Harley may also be given credit for his identical ideas in his Ph.D work. Thus, it is really the radon decay products that deliver the significant dose to the lungs, far more so than the radon gas. This fact had been overlooked in all past studies.

It seems as though the "sub-terranean dwarfs" and "foetid vapors" have been given a new name, radon daughters, and that the target has now been spotted, the tracheo-bronchial tree, and that the end result can be cancer of the lung.

The U.S. Experience

News had spread quickly from Europe to the U.S. regarding the discovery of and uses for radium and uranium. Beginning in the late 1890's exploration and mining had begun in the Four Corners Area (Utah, Colorado, Arizona, New Mexico). During these early years the uranium was mined for the extraction of radium. In fact, much of this uranium was shipped to Pennsylvania by Standard Chemical Company for radium production from 1912 to 1920. Radium was thought to be a new wonder substance for the treatment of many maladies. Uranium was still being used as a coloring agent in glass, and vanadium, which was often found with uranium, was used to harden steel. This mining continued into the1940's. Obviously, the war efforts and the Manhattan Project caused a shift in what the uranium was used for. In 1948 uranium was the prize with the ultimate goal of the production of uranium-235 and plutonium. However, U.S. mines were not able to meet the demands of the U.S. Government for uranium, so the Government turned to Canada and the Belgian Congo.

It seems as though the Federal Government, the States, and many mining companies had not learned the lessons from the "European Experience." In 1950 there were about 500 miners working in a number of different uranium mines in the western United States. By the early 1980's there was a drastic decrease in uranium mining from 300 underground uranium mines in 1980 to 16 in 1984, with a commensurate decrease in miners from 9,076 in 1979 to 1,405 in 1984, and to 448 in 1986.

Radon concentrations were similar to many of the European mines with values reported from as low as 37 pCi/L to 22,000 pCi/L or higher. Duncan Holiday of the U.S. Public Health Service (PHS) had made measurements and reported that radon concentrations in the mines measured were much too high. He recommended that control measures be instituted. This was 1950. However, the Federal Government was in competition with the Soviet Union to build up atomic arsenals, the mining industry appears to have lacked the commitment, and the States did not have authority to institute safety controls in the mines. This lack of attention to mine safety ultimately resulted in unnecessary lung cancer deaths in many miners. Lung cancer and lung cancer deaths

were starting to appear in uranium miners, however, as late as 1958 the numbers were still considered too small to draw a conclusion that the deaths were excessive for the miners. In 1959 the Public Health Service published a pamphlet that warned about the hazards of radon exposure and distributed this to the miners. This seems to be the first time that the Federal Government tried to warn the miners. In 1960 the PHS presented more conclusive evidence on the correlation between lung cancer and uranium mining. Finally, in 1967 the Federal Government set the first standard for radon and its daughters in uranium mines at 0.3 working levels (WL). Various workplace practices primarily ventilation and dust control were able to help mining operations meet this new standard.

Outside of the U.S. various other groups of miners were also being exposed to radon/radon progeny. Some areas being Joachimsthal and Schneeberg as already discussed. Newfoundland fluorspar miners received on the average 1,700 WL-months (WLM), and their lung cancer rates were starting to well exceed the expected rates. British underground iron miners received on average about 260 WLM. They also showed a significant difference between observed verse expected lung cancer death rates. Conversely, the British underground coal miners, where the radon concentration averaged about 2 pCi/L saw no difference in lung cancer rates than those expected in the general population. Reports are also available for French iron miners, South African gold miners, and Russian manganese miners.

Residential

We now turn our sight to the human residence. The place where now about 6 billion of us live. The place that often has four sides, a roof, and a part in contact with the ground. The place where many of us spend about 70% of our time. The place we call "home."

I think that we are all aware of the radon issue really gaining national attention in December of 1984 with the Watras house; however, there is evidence that there was an increasing awareness to the issue prior to 1984. The August 28, 1980, Federal Register shows the formation of a Federal task force to examine radon in structures. This group worked under the title of the United States Radiation Policy Council and was a collaboration between the U.S. EPA and the Department of Energy. This was likely the first governmental group to appraise the national indoor radon problem as a whole. The Task Force concluded that attention to this issue was warranted because of the "possible prevalence of relatively large exposures, a trend toward even higher exposures due to improved energy efficiency in inhabited structures, the risk from such exposures, and the potential large population at risk." The Task Force also realized that many of these exposures were not associated with contamination events, but also found with considerable frequency in natural surroundings. The Task Force went on to say that a "national radon program" should not be undertaken until more is known about the prevalence of high exposures and the ways of controlling them.

In 1982 the Conference of Radiation Control Program Directors (CRCPD) performed a survey of all the states concerning the radon issue. The survey found that 17 states were making radon measurements. However, the majority of these measurements were for the mineral wastes, and the mineral exploration, mining, and milling processes. Four states listed making measurements

in "Indoor, Solar and Energy efficient buildings." Six states stated they were making routine measurements in indoor air; however, eight states were performing routine radon in water measurements. All of this would suggest that the states had some ideas about indoor radon but would never have imagined the extent of the problem as we find today. A second survey by EPA and CRCPD published August 28, 1987 found that all 50 states were now involved to greater or lesser extent with radon programs. Some states were just providing information (7), some were being formed (24), some were being developed (14), and a final group was operational, including Florida, Maine, New Jersey, New York, and Pennsylvania. About 20 million dollars had been appropriated for funding radon programs, with about 89% of this in the three Reading Prong States (NJ, NY, PA).

Montana may have been one of the first states to investigate radon occurrences in the indoor, residential environment. Montana was receiving phosphate slag from Idaho and using this for residential construction. They suspected that because of this slag they may have elevated radon concentrations in those homes where the slag was used. The state undertook an investigation in Butte, MT and found that radon values often above 20, some in the 100's and a high value of 350 pCi/L. Interestingly, these indoor values were not due to the phosphate slag, but naturally occurring from the soil gas the houses were located on. The state went on to do some remedial demonstration projects and to evaluate some of the limited radon instrumentation available at the time. They also advised other state radiation programs to look for similar radon problems.

Researchers from Argonne National Laboratory in 1978 "were very surprised to observe a value of 26 pCi/L in the bedroom air of a house" in the Chicago area. They looked for all types of sources to try and explain this "high" reading, from a large source of radon in the house, to the smoke detector, to ceramic tile on the floor, until they finally concluded that the source was the unpaved crawl space. This goes to show how unusual it was to find a radon value of 26 pCi/L back in the late 70's. The authors even mention the scarceness of radon data within the country. The high value plus the scarceness of data may have led them to the conclusion that "there is clearly scope for a comprehensive survey of the levels of radon in houses in the U.S.A., …"

Sweden

At least during "modern" times Sweden is the site of possibly the earliest known radon survey for residential structures. In 1956 Hultqvist studied naturally occurring radioactivity in buildings. A large fraction of Swedish homes built from 1930 to 1975 used aerated concrete incorporating alum shale and having radium-226 concentrations in the range of 40 pCi/g. This was the primary reason for these surveys. A secondary reason was to assess the radiation doses by the population from natural background radiation. The author finally notes that this type of survey could now be conducted due to the appropriate measuring instruments recently developed.

Radon measurements in 26 cellars showed average concentrations of 16, 9.6, and 25 pCi/L, for wood, brick, and concrete containing alum shale, respectively. Two apartments constructed of concrete containing alum shale measured 470 and 350 pCi/L.

Austria

In 1973 F. Steinhausler measured radon concentrations in public and private buildings in Innsbruck. About 750 measurements were performed. The dependence of meteorological variables on indoor concentrations was also investigated. Measured mean radon concentrations were from 0.75 to 3.11 pCi/L, with maximum values up to 7.5 pCi/L. This author advised measuring radon over a period of several weeks during the different seasons to gain a significant yearly mean.

In order to help assess the radiation induced risk of lung cancer in a given population a radon survey was carried out in Salzburg. Somewhat more than 1000 radon grab samples were made in 1982, with a low mean radon concentration of 0.4 pCi/L and a maximum value of 5.1 pCi/L. The authors attributed building materials as being the major source of the indoor radon. They even go so far as to attribute most indoor radon problems in European structures to be due to building materials rather than soil.

United Kingdom

Some of the earliest measurements in the UK were carried out in 1965 by Haque, Collinson, and Blyth-Brooke. There maximum result was 5 pCi/L. A later radon survey in the major population centers was performed in 1974. This survey found a median of 0.3 pCi/L, with an arithmetic mean of 0.6 pCi/L. Later surveys looked at areas of predominantly igneous geology and found higher results than the "National Survey" above.

Grand Junction, CO

In 1950 the Climax Uranium Company started to produce a high-grade uranium product (U_3O_8). The uranium was sold to the Atomic Energy Agency for the production of nuclear weapons. The site was located on a 200-acre tract on the north bank of the Colorado River. The mill closed in March 1970. During the production of the uranium product, millions of tons of rock containing the raw uranium are crushed to fine sand like consistency. The uranium is extracted and the product that is left is known as uranium mill tailings. These tailings contain thorium-230, radium-226, radon and its progeny, and polonium-230. About 300,000 tons of this material was made available to the public in the Grand Junction area in the 50's and 60's. This material was used in construction as a sand substitute and for backfill. As one can imagine and was found to be the case many homes built with or on top of this material were subsequently found to have indoor radon problems. In 1970 under a federally sponsored program, the Colorado Department of Health made radon progeny measurements in many hundreds of homes containing tailings contamination. Other homes in the non-contaminated parts of Grand Junction were also measured to determine background levels. Remediation has since taken care of these homes under the Uranium Mill Tailings Remediation and Control Act.

Elliot Lake, Ontario

Located about 75 miles due east of Sault Ste. Marie and north of Lake Huron this region was once accounting for 82% of all of the uranium production in Canada. Uranium was initially discovered in 1953 and at peak production in 1983 with 11 mines in operation, thereafter there was a decline in the mining operations until the last mine ceased operation in 1996. Most of the homes in this area were naturally "contaminated" with radon and not due to mine operations. Many of the homes in the area were actually owned by miners working the uranium mines. There were some active sub-slab depressurization systems installed in homes for radon remedial measures.

Port Hope, Ontario

Port Hope is located on the northern shore of Lake Huron about 275 miles southeast of Elliot Lake. It is near the former site a radium refinery, which opened in 1932 and stopped radium work in 1954. However, due to the needs of the Manhattan Project the radium production switched over to uranium production in 1941. The tons of uranium bearing rock was shipped all the way from the Port Radium Mine site near Great Bear Lake, in the Northwest Territories, just below the Arctic Circle to Port Hope, Ontario, where the refining took place. It was all of the tailings from the radium and uranium production that was then dumped in various parts of the Port Hope area that contributed to the radon problems that subsequently arose. The tailings were also used for backfill around foundations. Contraband was even taken from some of the processing plants and used in homes for one purpose or another. The contraband was often contaminated.

In 1975 the Atomic Energy Control Board (AECB) started a survey of homes in the Port Hope area, and also the three other areas of Canada contaminated from uranium production activities: Elliot Lake, Bancroft, and Uranium City. In Port Hope both gamma radiation and radon problems were discovered. Teams came into the Port Hope area from 1976 to 1981 and tested 3500 homes, did extensive follow-up measurements in 750 of the 3500, and then finally performed remedial work in 450 homes. Most of the homes had "marginal" radon values ranging up to 0.1 working levels, with a few extremes of 50-100 pCi/L.

Around the World

Numerous other occurrences of radon have been reported from many parts of the world over the past decades. These investigations have usually been due to mining impacts, mine product incorporation into building materials, or structures located on top of mine residue. Some of the studies have been due to indoor air quality concerns often brought on by the weatherization of buildings. Finally there is an interest in determining the background radiation exposure to the general population.

In 1978 Stranden et al. measured 120 dwellings around Oslo, Norway. They found very low levels, with mean radon concentrations for wood, concrete, and brick dwellings of 1.3, 2.0, and 1.0 pCi/L, respectively. Fleischer et. al. in 1983 measured 10 non-energy efficient homes and 14 energy efficient homes in New York State. The energy efficient homes averaged 6 pCi/L and the non-energy efficient homes averaged 1.3 pCi/L. A. C. George and J. Eng from the

Environmental Measurements Laboratory (EML) performed radon measurements in New Jersey, New York, and Pennsylvania as part of clean-up efforts from the Manhattan Project. These measurements from 1978 to 1980 in 33 buildings showed very low values ranging from 0.5 to 10 pCi/L. The EML team also made numerous measurements in New York City to determine "normal" environmental levels indoors. Trying to determine radiation dose contributions from man-made sources, Arpad Toth in Hungary in 1970 also made 841 indoor radon measurements in 14 different towns. He wanted to be able to add natural radiation dose to man-made dose to derive risk estimates for the population at large. We could go on with other studies like these in Maine, Florida, Montana, Poland, and the Soviet Union.

I go to the trouble of mentioning these studies to point out the early awareness and worldwide distribution of radon measurements well before December 1984. Many investigators were aware that there were indoor radon occurrences in homes and buildings solely due to natural causes; however, I do not believe that any of those investigators would have imagined neither the extent of the radon problem today nor the magnitude of the concentrations.

Boyertown, PA

Boyertown is about 36 miles northwest of Philadelphia. It is a fairly quiet and rural town located in a rural part of the state. However, there is an unseen ominous presence located below the buildings of this area: a mass of Precambrian granite and granitic gneisses generally enriched in uranium more often than other common rocks. Some of these rocks containing up to 80 ppm uranium. More typical uranium contents in granitic rocks are on the order of 3-4 ppm.

It was December 1984, Stan Watras a Boyertown resident and an employee of the nearby Limerick Nuclear Generating Station was getting ready to leave work for the day. As he was leaving the plant through the portal radiation monitor, it alarmed. This would not be so unusual had it not been for the fact that there was not yet any nuclear fuel on site and thus no major source of radiation contamination at the plant. This one time incident did not really raise any concern, however, this went on for about two weeks. This was also quite a nuisance to Mr. Watras since he often had to remove his clothes, have them washed, and then shower himself. By this time Mr. Watras had enough, he decided to try an experiment. Upon arrival at work one day he immediately walked through the plant entrance, turned around, walked right back out through the portal monitor, and set off the alarm. This was now proof that he was bringing something in on his person or clothes to set off the alarms, with the most logical source being something at home. He asked some of the health physics (HP) staff if they would come out to his home and do some surveys, they would not. He then proceeded further up the chain of command until he finally got the approval to have someone come out to his home.

Three HP techs came out to the house with various types of survey instruments and some grab sampling equipment. The survey instruments "went off" immediately once in the house. These instruments did not show any specific "hot spots", but rather a uniform diffuse cloud of activity throughout the entire house. They did see more activity in the basement than on upper floors. Upon analysis the grab samples showed radon progeny. At this point the utility called Tom Gerusky and Maggie Reilly at the state Bureau of Radiation Protection (BRP) in Harrisburg.

The BRP staff went to the house and confirmed the utility findings, reporting 2600 pCi/L in the basement. The Watras family was advised to move out of the house, which they did.

Now there was the problem of fixing the home. No one around the area knew how to deal with the problem. Stan went to numerous local government officials and finally ended up at Congressmen Gus Yatron's office. The Congressmen was able to track down some research that the EPA had done on radon remediation of 18 homes. Now they had something to go on. At this point Philadelphia Electric Company (PECO), the plant owner, decided to fund the remedial work at the house and the BRP would fund the engineering. This was not your typical sub-slab system!

There was basically four phases to the work. Phase One consisted of excavation around three walls with installation of a radon/waterproofing system with drain to daylight. Replace fill and landscape. Phase Two consists of work in basement to deal with venting and sealing stem wall and running vent stack through structure to roof. Phase Three seals all floor/wall joints; floor cracks, and fills sump hole and seals. Phase Four was to install the sub-slab vent system with routes to roof. The floor slab was completely removed and re-poured due to the poor quality of the concrete and its variable thickness of 1 to 3 inches. Phase one work started on April 23, 1985 and Phase four work was completed on June 3, 1985, for a 41-day project. The final remedial action costs were $32,670. Post-mitigation radon concentrations were well below 4 pCi/L.

Fortunately, the Watras family was only in the house for about one year prior to the discovery. A quick calculation can show the absorbed dose due to this exposure. Assume 10.4 WL at 40% equilibrium factor, 6136 hours spent in home per year, radiation-weighting factor for alpha's of 20, and tissue weighting factor for bronchial tree of 0.08. This calculation shows that for those staying at home their whole body dose equivalence was 786 rem for that year. This is obviously a very significant dose, however, this is a worst-case scenario assuming a basement exposure. This dose received during an acute exposure would most probably be fatal. However, as of this writing all of the Watras family is doing fine. We do not have any information on the homeowner prior to the Watras family. The home was built in 1977, which could have resulted in an exposure of about six years to a previous owner.

The Watras family was finally able to move back into a successfully mitigated home in July 1985, about seven months after the initial discovery. They are still in that home to this day.

There were several universities interested in the Watras family and home after this incident. New York University Medical Center performed radiation scans looking for Pb-210 accumulation in bone. They did these scans on the skull. They found that the highest accumulation of Pb-210 was in the baby, then Mrs. Watras, then their other son Mike, and finally Mr. Watras. The University of Minnesota also called the Watras family and wanted to get samples of basement windows and eyeglasses to do retrospective dose calculations. I don't know whether they obtained the samples or not.

As an interesting footnote to the Watras incident and to the credit of the Bureau of Radiation Protection, there were actually plans in place to start a pilot project to measure radon in the late 1970's. Information had come to the Bureau from the Pennsylvania Power and Light Company

of a radon survey they had conducted in employee homes to determine if weatherization programs were effective. The study found some homes with elevated radon, but with no correlation to construction. This pilot program would have been started based on this information had it not been for an event on March 28, 1979. The Three Mile Island accident threw the radon pilot project well on the back burner. Plans were again made in 1984 to begin a modest survey during fiscal year 1985-1986. This time the survey would not be put off; in fact, Stanley Watras would accelerate it.

Radon Spas

Actually, the history of radon spas goes back much further than the history of exposure, causation, and mining. It is believed that 2500 years ago warm radon sources were used therapeutically on the island of Ischia in the volcanic area around Naples. Archeological finds around the thermal springs of Bad Gastein, Austria suggest even earlier use of the springs, possibly as much as 5, 000 to 6,000 years ago. The Romans also seemed to use the "healing" effects of the springs in the Gasteiner Valley. During the Middle Ages the baths at Bad Gastein took on a more public appearance. The water was directed into wooden bathtubs and enclosures were built to contain the tubs. The "communal bath" seems to be a part of life at that time. Paracelsus (1493-1541) investigated the healing effect of the thermal waters, but could not come to any conclusions as to their effect. He therefore declared that the effect of the waters were "God's own work."

Many other areas of the world also have been noted for these radon spas including Japan, Germany, Austria, France, Russia, Finland, and New Zealand, and even the U.S. It does seem as though the radon spas are more accepted in Europe than the U.S. The Europeans may have a more open approach to the "alternative therapies." Two "Radon Spas" of note in the U.S. are the Merry Widow Mine and the Free Enterprise Mine, both in Montana. The Hot Springs, Saratoga Springs, NY, and Hot Springs, AR are also of interest, and back in the 1920's were promoted because the mineral waters had a high content of radioactivity, including radon. The radon concentration in the mines varies significantly. Measurements in the air of the Montana mines by the Montana Department of Health have ranged from 233 to 1300 pCi/L. Private laboratory measurements in the Free Enterprise Mine show values ranging from 1100 to 1600 pCi/L. In some of the thermal spas of Europe concentrations up to 5,000,000 pCi/L (water) have been reported, more typical concentrations are much lower around 2,000 to 30,000 pCi/L.

Painful inflammatory diseases such as Osetoarthritis, Rheumatoid Arthritis, and Ankylosing Spondylitis seem to be the major reason for individuals seeking treatment in the radon spas. However, the Free Enterprise Mine literature also claim this therapy to have long term beneficial effects for Asthma, Gout, Hayfever, High Blood Pressure, and a host of other ailments. The therapies can be both inhalation and immersion.

The mechanisms for the beneficial effect of the radon spas covers a wide range of theories: from stimulation of the immune system, influences on homoeostasis, reduction in free radicals, and adaptive effects at the sub-cellular level on the genes, and DNA. Many of these effects are tied to the hormesis phenomenon. Hormesis is a concept that describes the nature of dose-response

relationships in biological systems as displaying a stimulatory response at low doses, and an inhibitory response at higher doses. Proponents of the beneficial effects of the radon spas would claim that the relatively small radiation exposures received in the spas would stimulate this hormetic effect, and lead to certain improvements in health. Even though concentrations are high, exposure times are relatively short. A therapy session may run for a week to 10 days with up to three hours per day in the spa. With some general assumptions (10 WL, 21 hrs, 1.31 rad/WLM, QF 20, W_t 0.08), this would work out to be a dose of about 0.8 rem whole body. For spas around the world the 10 WL may be high, and whole body doses may be closer to a range of about 0.01 to 0.3 rem. The number of people who use these spas is small. The Free Enterprise Mine quotes about 500 people per year. However, some estimates from Russia may be much higher at about 1 million annually. As one can imagine, for those who are suffering and mainstream medicine has not provided relief, any alluring alternative may be tempting.

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