Radon and Radon Daughters: Characteristics, Health Effects and Occurrences in Dwellings in Chadron, Nebraska

Arthur W. Struempler
Chadron State College

Steven E. Johnson
University of Nebraska - Lincoln

1987. *Transactions of the Nebraska Academy of Sciences,* XV: 69-74.

RADON AND RADON DAUGHTERS: CHARACTERISTICS, HEALTH EFFECTS AND OCCURRENCE IN DWELLINGS IN CHADRON, NEBRASKA

Arthur W. Struempler and Steven E. Johnson*

Chemistry Department
Chadron State College
Chadron, Nebraska 69337

*Present address: Computer Sciences
Nebraska Hall, Room 225
University of Nebraska–Lincoln
Lincoln, Nebraska 68588-0521

Radon and radon progeny were sampled biweekly from January through June, 1984 in outside air and five representative buildings at Chadron in northwestern Nebraska. The buildings were constructed of a variety of materials. Radon averaged from a low of 0.2 pCi/L in outside air to a high of 5.3 pCi/L in an energy–efficient home. Radon daughters ranged from 0.001 WL in outside air to a high of 0.014 WL, again in the energy–efficient home. A strong positive correlation existed between radon and radon progeny. Health risks associated with elevated levels of radon and radon progeny are discussed and assessed.

† † †

INTRODUCTION

Increasing attention is being placed on the health risks of low levels of natural radiation. Uranium is ubiquitous in soil and rock and is one source of natural radiation. One of the decay products of uranium is radon, and it, too, is radioactive. Since 1950, uranium mill-tailings were inadvertently incorporated into home-building materals or into homes built on uranium mill tailings at several locations in the United States, which has led to unacceptable levels of radon gas in indoor air. Higher than average uranium concentrations are found in Oligocene soil and rock in northwestern Nebraska, where Chadron is located (Smolen, 1984). Recently, a major uranium ore body was discovered near Crawford, also in northwestern Nebraska (Gigot, 1981). Radon's health implications are appearing in a number of public news articles (Chandler, 1984; Harvey, 1984; Inman, 1984; Murphy, 1985). This study was undertaken to evaluate radon characteristics, health aspects of elevated levels of radon, and radon concentrations in residential buildings in Chadron, Nebraska.

LITERATURE REVIEW

Radon Chemistry

The uranium–238 (U–238) decay series gives rise to a number of radionuclides, including radium–226 (Ra–226) and radon–222 (Ra–222). Each radionuclide has different chemical and physical properties. Three different radiation species are emitted in the U–238 decay process, namely, alpha and beta particles, and gamma radiation. A chart showing the U–238 decay scheme is shown in Figure 1. It shows the members of the series, halflives, types of disintegrations, and maximum energies of the emitted species.

Radon is the heaviest of the noble gases and has 12 short–lived isotopes. Of these, Rn–222 is the most abundant, consisting of 99 percent of the radon present (hereafter Rn–222 is referred to as radon). Radon is odorless, invisible, tasteless, quite soluble in water, and has a half–life of 3.82 days. Being

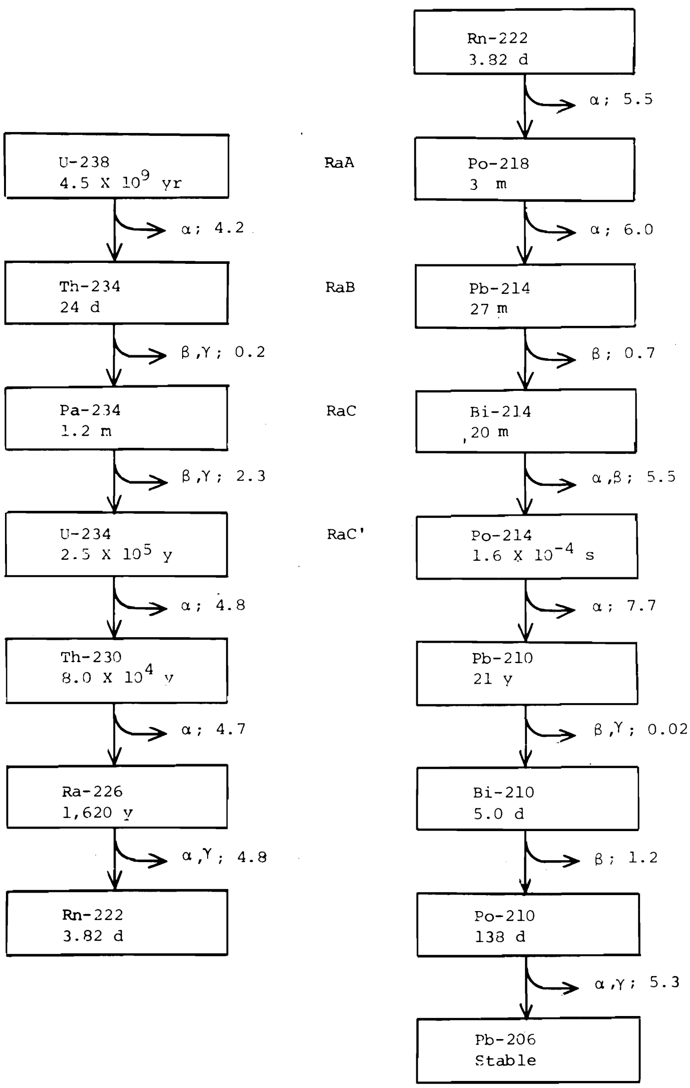

FIGURE 1. The uranium decay series. The left column indicates the decay sequence from U–238 to Rn–222. The right column continues the decay sequence and depicts Rn–222 to stable Pb–206. Only major branches are shown. Alpha particles are indicated by α; Beta particles by β; and gamma radiation by γ. Particle energies are given in MeV (after Lapp and Andrews, 1963).

gaseous, it continuously leaks from its rock sources into the air. Radon's distribution in nature is linked to its immediate parent Ra–226, must be renewed constantly to maintain a constant concentration. The earth's crust contains less than 100 tons of radon.

Radon gas, when inhaled, does not pose a health threat because of its chemical and physiological inertness. However, the four nuclides following Rn–222 in the uranium decay series pose a health threat because they are solid charged heavy metallic particles, not gases. They are daughter products or progeny of Rn–222 and are referred to as RaA(Po–218), RaB(Pb–214), RaC(Bi–214), and RaC′(Po–214). The daughter progeny have high activities as characterized by their halflives of 27 minutes or less. Polonium–218 and Po–214 are alpha particle emitters, although effectively RaC is the source of RaC′ since it emits a particle almost instantly. If not inhaled, alpha particles are not generally regarded as a health threat in the environment because the particles are stopped within a few centimeters in the atmosphere. When inhaled, radon daughter products are a health threat because of their size and charged aspects, and tend to collect on aerosols and airborne particles and become lodged in the respiratory tract. It is estimated that between 25 and 50 percent of the daughters are retained in the lung (Rock and Beckman, 1979).

Units of Measurement for Radon and Radon Daughters

Radon gas concentrations in air are generally expressed in terms of its radioactivity as picocuries per liter (pCi/L). One picocurie of any radioactive material produces 2.2 decay transformations per minute.

For radon decay products the United States public health officials have adopted the concept of the "working level" (WL) as a measure of radon progeny. One WL is the concentration of any combination of the four short–lived Ra–222 daughters in one liter of air without regard to degree of equilibrium, which will deliver 1.3×10^5 MeV of alpha radiation energy (Anonymous, 1983). One pCi/L radon is assumed to correspond to 0.005 WL radon daughters (Anonymous, 1985). Both pCi/L and WL are a measure of the concentration of radioactivity in the air, not how much a person actually receives.

Concentration of Radon and Radon Daughters

In air, the background radon content near the uranium mineralized ore deposit near Crawford, Nebraska, averaged 0.19 pCi/L for an eight–month period (Wyoming Fuels Company, 1983) and 0.20 pCi/L for a 12–month period (Struempler, 1985). A somewhat lower level of 0.1 pCi/L was reported in New Mexico (Wilkening, 1964), and 0.13 pCi/L in New Jersey, whereas a high of 0.73 pCi/L was reported in Grand Junction, Colorado (Spitz et al., 1978). This high value at Grand Junction may be associated with nearby uranium surface-mining activities and related building materials high in uranium. It appears, however, that a mean radon value of about 0.15 to 0.20 pCi/L would represent radon background in the midwestern states. Average worldwide values of 150 pCi/m³ (0.15 pCi/L) (Anonymous, 1975) and 100 pCi/m³ (0.10 pCi/L) have been reported (Anonymous, 1977). Any increase in indoor radon concentrations over background would most likely originate from uranium in building materials, water, and local soils.

Researchers have shown that meteorological conditions, such as pressure, temperature, wind velocity, wind direction, relative humidity, precipitation, and soil moisture, can influence atmospheric radon concentrations, but these factors tend to be minimized if integrated over long periods (Fleischer and Mogro–Campero, 1978; Kisieleski, 1980). For this reason a number of continuous measurements over a long period of time should be performed to yield a statistically significant mean.

Indoor radon concentrations, too, can vary widely. Various reports indicate that indoor radon ranged from 0.2 to 4.0 pCi/L (Nero, 1983) and from 0.2 to 3.0 pCi/L in another report (Pohl and Pohl–Ruling, 1976). More extreme ranges have been reported from 0.1 to 27 pCi/L (Nero et al., 1983). In Grand Junction, Colorado, radon concentrations in a basement of a "control" house averaged 0.92 pCi/L for a six–day period. Where 30 cm of uranium tailings were below the foundation, the mean concentration averaged 56.5 pCi/L, with a range of 16.4 to 236.8 pCi/L (Spitz et al., 1978). However, an average concentration for many types of buildings in various countries and different buildings was reported as 1.0 pCi/L (Cohen, 1979). An estimate for indoor radon exposure in the midwestern area is about 0.8 pCi/L. This value is based on a radon concentration of 1.0 pCi/L indoors and 0.2 pCi/L outdoors and 75 percent occupancy.

Likewise, background WLs concentrations are variable. In northwestern Nebraska, an average background of 0.002 WL was found (Struempler, 1985). A higher reading was found in Grand Junction, Colorado, which indicated an average background of 0.007 WL (Anonymous, 1980).

Health Aspects

In the 15th century, mine dust was recognized among German miners to cause "lung disease." It is now known that this "lung disease" is cancer. The relationship of lung cancer deaths among the early European miners who received large doses of radiation to lung cancer deaths among the non–occupational groups was as high as 48:1. Another study showed that when radon daughters exceeded 0.3 WLs, lung-cancer deaths among miners in Sweden were about three times greater than lung-cancer deaths among those in the non–occupational exposed groups (Rock and Beckman, 1979). Today, radon daughter concentrations greater than 0.1 WL for the occupational group suggests the need for further sampling to assess the potential hazard (Rock and Beckman, 1979).

The question, however, of health risks from inhaling radon daughters is controversial and complex for a number of reasons (Harley and Pasternack, 1981). The quantitative approach to radon-daughter concentrations to induced lung cancer risks rests heavily on uranium-mining data, because miners exposed to higher levels of radon had a greater incidence of lung cancer than the general population. This relationship is usually treated by the linear dose–effect hypothesis that assumes that lung cancer deaths are proportional to dose (or a linear relationship to exposure). This basis of health risk is open to argument, but it is the best measure of obtaining risk estimates of induced cancer.

One risk estimate for lung–induced cancer from background environmental radon based on the linear dose effect hypothesis, is 35×10^{-6} deaths per year (Cohen, 1979). Assuming a lifetime of 60 years, this risk estimate equates to 150 induced cancer deaths per 100,000 population, or 0.15 percent. The Environmental Protection Agency (EPA) estimates that approximately 5,000 to 15,000 deaths per year in the United States are caused from radon decay progeny in homes (Anonymous, 1985). This is a death risk from 0.22 to 0.65 percent based on 2,300,000 deaths each year in the United States (assuming one death per year per 100 persons).

In August, 1986, EPA set a health guideline for the amount of radon gas in homes that is considered safe. This is the first time that EPA has acted concerning a naturally occurring problem. EPA has established a limit of 4 pCi/L as a level of radon gas that poses the risk equivalent of smoking half a pack of cigarettes a day. Furthermore, 8 pCi/L level of radon gas projects a two percent lifetime risk of developing lung cancer.

Still another risk estimate might be based on the mortality rate of lung cancers associated with "pristine–radon" conditions before industrialization. In 1930, the mortality rate from lung cancer per year in the United States was approximately 0.003 percent for females and 0.005 percent for males. This rate has now increased to approximately 0.02 percent in females and 0.08 percent in males (del Regato et al., 1985). The slope of this curve between the two time periods exhibits exponential form, especially for the female population. The lag in the exponential form among females is probably due to their later smoking habits and the associated latent effects from smoking. The curve suggests, however, that prior to 1930, and before smoking was popular in the female population, the death rate was about 3 in 100,000 females and might be considered baseline in the United States. This value before 1930 projects to 180 deaths per 100,000 or 0.18 percent for a 60–year life span. Radon, however, would not have been responsible for all these induced lung cancers as other contributors would add to base–line values.

Other risk estimates range lower and higher (Nero, 1983; Harley and Pasternack, 1981; Stranden, 1980), but it appears that a general life risk estimate from environmental radon might be about 0.15%, or 150 in 100,000. This is a small value compared to the lifetime risks of lung cancer today nearing 4% (120,000 per year in the United States) from all causes, most of it attributed to cigarette smoking (Anonymous, 1985).

METHODS

Air was collected biweekly (twice monthly) at six sites in Chadron from late January until June 1984. The sampling sites included the basement of the Chadron City Hall (brick construction, built about 1900); the men's restroom on the ground floor of the Dawes County Court House (brick, 1932); the custodial room on the ground floor at the Chadron Community Hospital (brick, 1940); the basement of a residence at 402 West 8th Street (wood, 1966); the shower room on the ground floor of the Chadron State College Science Building (brick, 1970) until May 4, and lecture room 008 in the Science Building after May 4; and outside air. All these buildings have concrete floors. For checking radon daughter concentrations 100 liters of air were passed through a Type AA 0.80 micron Millipore filter and measured by the modified Kusnetz Method. For radon, simultaneously samples of air were obtained in a flow–through ZnS cell of the Lucas type. An EDA–200 Radon/Radon Daughter Detector was used for the counting instrument and analytical procedures followed the manufacturer's recommendations (EDA Instruments, Inc., 1 Thorncliffe Park Drive, Toronto, Canada M4H 1O9).

RESULTS AND DISCUSSION

The concentration of radon and radon daughters measured during the sampling period is shown in Table I. Radon concentrations are expressed in pCi/L and radon daughters in WLs. The arithmetic mean ($\overline{X}$) of radon and radon daughters for each sampling site is shown along with the correlation coefficient (*r*) between radon and radon daughters. The limits of detection are 0.1 pCi/L for radon and 0.001 WL for radon daughters. Radon in outside air in Chadron averaged 0.2 pCi/L and should constitute background content. This concentration is the same as that found in previous studies near the uranium-ore deposit at Crawford, Nebraska (Wyoming Fuels Company, 1983; Struempler, 1985). Chadron is 40 km northeast of Crawford. Based on a limited number of samples of this study, no indication exists that the underground uranium ore body near Crawford increases ambient radon concentrations. This conclusion is consistent with studies that indicate radon is dispersed within a short distance (one km) from open uranium mill tailings (Anonymous, 1983).

Radon in the courthouse was similar to background probably because an open window prevailed in the restroom during the sampling periods. This level should also constitute background levels.

TABLE I. Biweekly radon (Ra) and radon daughter (Ra-dau) concentrations at Chadron, Nebraska, 1984.*

	City Hall		Court House		Hospital		402 W. 8th		Sci. Bldg.		Outside Air	
Date 1984	Ra	Ra-dau	Ra	Ra-dau	Ra	Ra-dau	Ra	Ra-dau	Ra	Ra-dau	Ra	Ra-dau
Jan. 30	2.4	0.013	0.1	0.001	3.0	0.010						
Feb. 10							9.8	0.030	0.2	0.001	0.2	0.001
Feb. 15	3.0	0.013	0.2	0.001	5.8	0.020						
Feb. 24							0.8	0.004	0.2	0.001	0.1	0.001
Feb. 29	0.9	0.008	0.1	0.001	3.0	0.008						
March 9							2.9	0.011	0.5	0.002	0.2	0.002
March 14	3.7	0.018	0.1	0.001	4.7	0.018						
March 21							12.0	0.021	0.4	0.002	0.3	0.001
March 28	0.8	0.006	0.1	0.001	5.4	0.015						
April 3							8.8	0.022	0.7	0.002	0.1	0.001
April 11	3.2	0.013	0.2	0.001	2.8	0.010						
April 18							7.4	0.017	0.2	0.001	0.3	0.002
April 27	1.7	0.007	0.1	0.001	1.8	0.005						
May 4							5.4	0.020	0.1	0.001	0.1	0.001
May 10	2.3	0.006	0.2	0.001	0.3	0.002						
May 17							0.8	0.002	3.2	0.019	0.2	0.001
May 22	2.1	0.003	0.1	0.001	1.3	0.003						
May 30							3.6	0.014	1.7	0.008	0.2	0.001
June 5	1.5	0.004	0.3	0.002	0.7	0.002						
June 12							1.6	0.004	0.7	0.003	0.2	0.001
June 19	2.7	0.010	0.2	0.001	1.0	0.004						
$\overline{X}$	2.2	0.009	0.2	0.001	2.7	0.009	5.3	0.014	0.8	0.004	0.2	0.001
r	+0.75		+0.70		+0.97		+0.89		+0.99		+0.43	

*Radon concentrations in pCi/L; radon daughter concentrations in WLs.

On the other hand, where uncirculated air generally prevailed, radon concentrations increased considerably. Radon averaged 5.3 pCi/L in the basement of 402 W. 8th Street. All collections at this location were made with closed windows except on May 17 when a window was open. The home is regarded as energy–efficient, which reduces outside air interchange. The basements in the custodial storage area in the Hospital and in the City Hall, both with limited circulation, averaged about 2.5 pCi/L. Collections through May 4 in the Science Building were made in the shower room on the ground floor with the air circulation system in operation. This system cycles outside air, of varying proportions, depending on the outside air temperature. The remainder of the collections were made in lecture room 008 located on the ground floor. On May 17 and 30, the circulation system was not in operation and higher readings were noted. On June 12, the air conditioning system was in operation and a lower radon level was again reflected.

Radon daughter concentrations at 402 West 8th Street averaged 0.014 WLs, followed by the city hall and hospital with a 0.009 WL. A 0.014 WL in the energy–efficient home is considerably below the 0.1 WL generally assessed as the level for further sampling in occupational sites, such as underground mines. For a public occupied structure a 0.015 WL (which is proportional to 3 pCi/L radon) has been proposed by the EPA as a remedial action level (Anonymous, 1980).

Although the study is not extensive, with only a limited number of grab samples analyzed, the question now is what extent the higher radon content in the energy–efficient home will increase the risk of lung cancer.

Evidence developed from the literature indicates that 0.8 pCi/L radon will produce a lifetime cancer-risk of about 0.15 percent. Then proportionally, 4.0 pCi/L radon in the energy–efficient home (75 percent occupancy factor) will increase the risk to 0.75 percent.

One aspect of interest and significance is the strong correlation exhibited between radon and radon daughters at all collection sites, especially where detection limits were not approached. Within the limits of the data and of the study, it would appear that sampling only for radon might provide a reasonable profile of radon-daughter concentrations. Sampling for radon only would simplify analytical techniques and reduce the cost of related equipment. Under these conditions, radon daughters would need to be analyzed only if high radon was detected.

CONCLUSIONS

The literature suggests that elevated levels of radon increase the risk of lung cancer. The implications of elevated radon in the energy–efficient dwelling in northwestern Nebraska merit attention. As more energy–efficient homes are being built, monitoring for elevated levels of radon is needed, and corrective actions must be taken if the health risks become too large.

SUMMARY

Based on biweekly sampling from January into June, 1984, at six collection sites at Chadron, Nebraska, radon ranged from 0.2 in outside air to 5.3 pCi/L in a residential basement area. The average WL of radon daughters ranged from 0.001 in outside air to 0.014 in a basement area of an energy–efficient home. A strong positive correlation existed between the concentrations of radon and radon daughters. Uncirculated air enhanced the concentration of these nuclides. The health risk associated with the highest levels merits concern, and corrective actions to remove radon should be undertaken.

ACKNOWLEDGMENTS

We acknowledge our appreciation to officials of the City Hall, Court House, and Hospital for permitting their buildings to be sampled.

Any correspondence should be directed to the senior author.

REFERENCES

Anonymous, 1975. *Reactor safety study. Report WASH-1400.* Washington, D.C., United States Nuclear Regulatory Commission: 472p.

__________, 1977. *Sources and effects of ionizing radiation.* United Nations Scientific Committee on Effects of Atomic Radiation. New York, United Nations: 725p.

__________, 1980. *Draft environmental impact statement for remedial action standards for inactive uranium processing sites. 40 CFR 192 (EPA 520/4-80-011).* Washington, D.C., EPA Office of Radiation Programs. Environmental Protection Office of Radiation Program: 8–27.

__________, 1983. *Standards for remedial actions at inactive uranium processing sites. Rules and regulations. Federal Register. Part II, January 5, 1983.* Environmental Protection Agency: 48, 584–606.

———, 1985. *Information sheet on indoor radon*. Washington, D.C. United States Environmental Protection Agency: 5p.

Chandler, D. L. 1984. Worries mounting over indoor air quality. In *Boston Globe* as reported by the Omaha World–Herald, 26 August: 3-F.

Cohen, B. L. 1979. Radon: characteristics, natural occurrence, technological enhancement, and health effects. *Progress in Nuclear Energy,* 4:1–24.

del Regato, J. A., H. J. Spjut, and J. D. Cox. 1985. *Cancer: diagnosis, treatment, and prognosis*. St. Louis, Missouri, C. V. Mosby Company: 1079p.

Fleischer, R. L., and A. Mogro–Campero. 1978. Techniques and principles for mapping of integrated radon emanating within the earth, *(in) The natural radiation environment III, book of summaries*. Houston, Texas: 5.

Gigot, P. A. 1981. Kansas–Nebraska Natural Gas says unit found a significant uranium deposit. *Wall Street Journal,* 13 January: 14.

Harley, N. H., and B. S. Pasternack. 1981. A model for predicting long career risks induced by environmental levels of radon daughters. *Health Physics,* 40: 307–316.

Harvey, P. 1984. *American Broadcasting Company network news report, 17 March.*

Inman, V. 1984. Risk of cancer from radon gas increases with growth of energy–efficient homes. *Wall Street Journal,* 23 February: 29.

Kisieleski, W. E. 1980. *Radon release and dispersion from an open pit uranium mine. NUREG/CR–1583*. Argonne National Laboratory, Argonne, Illinois: 68p.

Lapp, R. E., and H. L. Andrews. 1963. *Nuclear Radiation Physics*. Englewood Cliffs, New Jersey, Prentice–Hall: 413p.

Murphy, J. 1985. The colorless, odorless killer. *Time,* 22 July: 72.

Nero, A. J. 1983. Indoor radiation exposure from Rn–222 and its daughters: A view of the issues. *Health Physics,* 45: 277–288.

Nero, A. V., M. L. Boegel, C. D. Hollowell, J. C. Ingersoll, and W. W. Nazaroff. 1983. Radon concentrations and infiltration rates measured in conventional and energy–efficient homes. *Health Physics,* 45: 401–405.

Pohl, E., and J. Pohl–Ruling. 1976. Determination of environmental or occupational Rn–222 in air and water and Ra–226 in water with feasible and rapid methods of sampling and measurement. *Health Physics,* 31: 343-348.

Rock, R. L., and R. T. Beckman. 1979. *Radiation monitoring*. Washington, D.C., United States Government Printing Office, 1980–603–102/12: 75p.

Smolen, M. 1984. Radon remedies. *New Shelter,* June. Rodale Press: 32.

Spitz, H. B., N. Cohen, and M. E. Wrenn. 1978. Diurnal variation of radon indoors and outdoors and its depending upon natural and artificially enhanced source material in the environment, *(in) The natural radiation environment III, book of summaries*. Houston, Texas: 200–201.

Stranden, E. 1980. Radon in dwellings and lung cancer — a discussion. *Health Physics,* 38: 301–306.

Struempler, A. W. 1985. Chemical and radiological composition of air and ground water near the mineralized uranium ore deposit at Crawford, Nebraska. *Transactions of the Nebraska Academy of Sciences,* 13: 96–106.

Wilkening, M. H. 1964. Radon–daughter ions in the atmosphere, *(in) The natural radiation environment*. Chicago, University of Chicago Press: 359–367.

Wyoming Fuels Company. 1983. Crow Butte Uranium Project, Dawes County, Nebraska. *Application and supporting report for research and development source material license. Volume II*. Submitted to the United States Nuclear Regulatory Commission, Washington, D.C., February 11: 2.10. 13–14.