This Health Hazard Evaluation (HHE) report and any recommendations made herein are for the specific facility evaluated and may not be universally applicable. Any recommendations made are not to be considered as final statements of NIOSH policy or of any agency or individual involved. Additional HHE reports are available at http://www.cdc.gov/niosh/hhe/reports

NIOSH HEALTH HAZARD EVALUATION REPORT

HETA #2004-0094-2978
National Park Service
Hot Springs, Arkansas

September 2005

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluation and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employers or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by John Cardarelli II of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Amanda Bryson, DSHEFS, and Timothy Radtke, Department of the Interior (DOI). Analytical support was provided by Dr. Henry Spitz, Health-Related Energy Research Branch (HERB), DSHEFS. Mr. James R. Budahn, U.S. Geological Service (USGS), conducted the gamma spectrometry analyses, Mr. James D. Cathcart, USGS, conducted the X-ray diffraction analyses, and Mr. Robert A. Zielinski, USGS, conducted the scanning electron microscope and energy dispersive X-ray analyses. Desktop publishing was performed by Robin Smith and Shawna Watts. Editorial assistance was provided by Ellen Galloway.

Copies of this report have been sent to employee and management representatives at Hot Springs National Park and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed from the following internet address: http://www.cdc.gov/niosh/hhe. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your written request to:

NIOSH Publications Office
4676 Columbia Parkway
Cincinnati, Ohio 45226
800-356-4674

After this time, copies may be purchased from the National Technical Information Service (NTIS) at 5825 Port Royal Road, Springfield, Virginia 22161. Information regarding the NTIS stock number may be obtained from the NIOSH Publications Office at the Cincinnati address.

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Radiation Exposures at Hot Springs National Park

The National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation (HHE) request from Hot Springs National Park in January 2004 concerning radioactive mineral deposits in piping that were was removed from a bath house being renovated. In a site visit, investigators from NIOSH and the Department of the Interior (DOI) identified RradiumRadium-226 in the mineral deposits within the piping and provided recommendations regarding the safe handling of that material. NIOSH investigators returned to the park to conduct radon progeny measurements and collect water samples to evaluate potential exposures to radiation in air and water.

What NIOSH and DOI Did

- Analyzed the drainage pipe removed from the Hale Bathhouse for radiation.
- Took radiation measurements in several bath houses and the Administrative Building in the park.
- Made radiation measurements in the Hale Bathhouse and the Administration Building to find the ratio between radon and its decay products.
- Collected water samples from the Hale spring and the fountain just outside the Administration Building for radium and radon.
- Collected soil and rock samples from the Hale Bathhouse basement to check for radioactive materials.

What NIOSH and DOI Found

- High radiation levels were found in some areas in the basement of the Hale Bathhouse. However, these areas were not routinely occupied.
- Two buildings (Hale Bathhouse and the Administration Building) had radon concentration levels above the EPA action limit.
- Park officials had successfully reduced radon concentrations below the EPA action limit in the Hale Bathhouse basement.
- The radon equilibrium factors estimated in the park buildings were lower than those typically found in indoor residential environments.
- Radium concentration in the water samples from the Hale spring and the fountain were below the EPA maximum concentration limit.
- The radon concentration in the water sample from the Hale Bathhouse spring (but not the public drinking fountain) was above the EPA maximum concentration limit.

What Hot Springs National Park Managers Can Do

- Continue to check the radon concentrations in park buildings.
- Complete radon remediation plans for the “Tower Room” in the basement of the administration building.
- Start a routine water monitoring program to assure that radium and radon levels in publicly accessible fountains are below the EPA limits.

What the Hot Springs National Park Employees Can Do

- Learn more about the health effects associated with radon and radium exposures by visiting the EPA website www.epa.gov.

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for
HETA Report #2004-0094-2978

Health Hazard Evaluation Report 2004-0094-2978
National Park Service
Hot Springs, Arkansas
September 2005

John Cardarelli II, PhD, CHP, CIH, PE
Timothy Radtke, MSEH, CIH (Dept of the Interior)
Henry Spitz, PhD
Amanda Bryson

SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation (HHE) request for technical assistance from the Department of the Interior (DOI) on January 13, 2004. The request described concerns about potential exposures to national park employees from naturally occurring radioactive mineral deposits in piping removed from renovated bathhouses at Hot Springs National Park (HSNP), Hot Springs, Arkansas.

On January 26, 2004, NIOSH and DOI investigators made on-site radiation measurements and identified radium-226 (^{226}Ra) in mineral deposits in water pipes. NIOSH investigators made recommendations regarding safe handling of the water pipes and also recommended conducting radon concentration measurements throughout HSNP. Gamma-radiation levels measured by NIOSH, the DOI, and the State of Arkansas in six bathhouses were low and similar to previously reported values, except for a few localized areas in the Hale Bathhouse basement. These areas of higher gamma-radiation were associated with rock in the bathhouse foundation which was rich in naturally occurring radioactive material (NORM), particularly ^{226}Ra. On July 1, 2004, additional radon-progeny measurements and water samples were collected to assess radioactive constituents in the air and spring water. Radon-progeny measurements determine the amount of alpha activity in the air that could be inhaled. The alpha activity measurement is called a "Working Level" (WL) and determines if a respirator is recommended based on NIOSH criteria. These WL measurements are used with radon concentration measurements to calculate the equilibrium factor (EF). The EF is an important site-specific parameter because it is used to convert radon concentrations (picoCuries [pCi/L]) to WL estimates. The site-specific EF results indicated that the radon concentration and WL relationship in HSNP buildings behaved more like thermal spa environments than the typical indoor residential environment.

Following the NIOSH recommendation, indoor radon measurements were made by park officials in every HSNP bathhouse and the park's Administration Building between May 2004 and February 2005. Only the Hale Bathhouse and the Administration Building Tower Room had airborne radon concentrations above the U.S. Environmental Protection Agency (EPA) recommended remedial action level of 4 pCi/L. The Tower Room, not routinely occupied or accessible to building occupants, was posted with a warning sign. Water sampling showed that ^{226}Ra concentrations in the Hale spring water were below the proposed EPA maximum concentration limit (MCL = 5 pCi/L), but above the proposed EPA MCL (300 pCi/L) for ^{222}Rn (the Administration Building public water fountain source did not exceed either proposed limit).

NIOSH investigators conclude that a potential health hazard exists for some workers at the HSNP due to the elevated radon concentrations in the Hale Bathhouse basement and the Administration Building Tower Room. Remedial actions and ongoing radiation monitoring by HSNP officials have reduced exposure potentials to levels as low as reasonably achievable. NIOSH investigators recommend continued routine radon monitoring and starting a water monitoring program for radium and radon in public drinking water.

Keywords: NAICS 712190, Nature Parks and Other Similar Institutions, HSNP, NORM, radiation, Radium, radon, working level, equilibrium factor, natural springs, bathhouse

Table of Contents

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation (HHE) request from the Department of the Interior (DOI) on January 13, 2004. The request concerned potential radiation exposures to park employees from radioactive mineral deposits in piping that was removed from Hot Springs National Park (HSNP) bathhouses undergoing renovation. Radioactive contamination was detected at a salvage yard/landfill that refused to accept the pipes.[1] On January 26, 2004, a site visit was conducted at HSNP. Investigators from NIOSH and DOI performed radiation measurements that identified radium-226, (^{226}Ra) in the mineral deposits within the piping. Recommendations were provided by NIOSH regarding the safe handling of the material. On July 1, 2004, NIOSH investigators returned to HSNP to conduct radon progeny measurements and collect water samples to evaluate exposure to radiation and radioactive materials in the air and water.

BACKGROUND

Hot Springs National Park (HSNP)

In 1803, HSNP became a U.S. territory as part of the Louisiana Purchase. By 1807, the first permanent settlers to reach the Hot Springs area realized the springs' potential as a health resort. In 1832 Hot Springs was set aside as a U.S. Government reservation by act of Congress. In its earlier conception, Hot Springs could not be considered a national park because the sole purpose of its establishment was as a national reservation to alleviate human ills. The waters, believed to possess medicinal value, were available to all and their commercial exploitation was prevented.[2] By the 1830s, log cabins and a store had been built to accommodate visitors to the springs. In 1877 the U.S. courts formally established government control.

In 1884 the government enclosed Hot Springs creek in an underground arch for flood and sewage control. By 1901 all of the springs had been walled up and covered for protection. Between 1912 and 1922 the wooden bathhouses built in the 1880s were replaced by fire-resistant brick and stucco structures (Figure 1; Superior, Hale, Maurice, Fordyce, Quapaw, Ozark, Buckstaff, and Lamar). A more complete chronology of events from 1803 to 1993 is available on the HSNP website.[3]

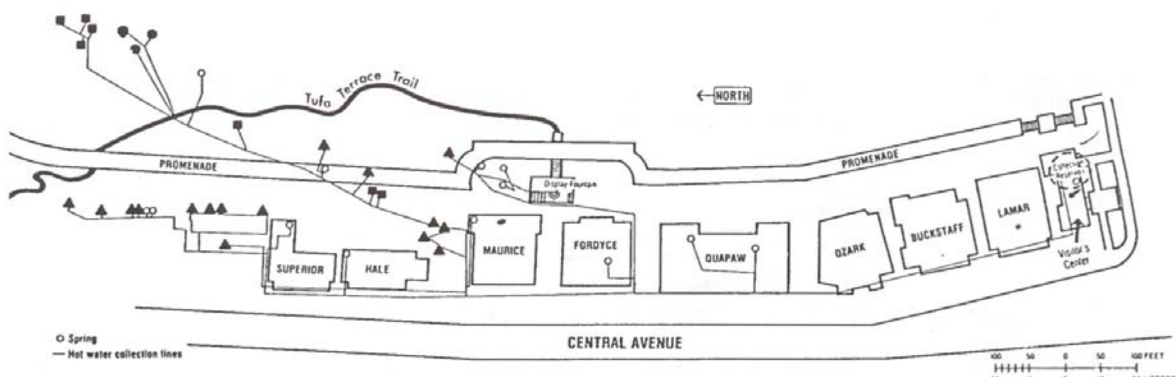


Figure 1: Distribution of springs and bathhouses at HSNP. (Source: Epperson and Rhodes, 1990)

In 1905, a professor from Yale University showed that the hot spring waters contained a measurable level of radioactivity, due primarily to the presence of dissolved radon gas, a natural decay product of radium. These two elements come from the radioactive decay of uranium and thorium found in the rock through which the thermal waters flowed. Both radon and radium were considered historically to have curative properties.

Following the creation of the National Park Service (NPS) in 1916, the Hot Springs Reservation became the 18th national park on March 4, 1921. Its designation as a national park accompanied the final phase of remodeling or construction of the current eight bathhouses on Bathhouse Row. However, by the 1960s the bathing industry in the park and in the city had declined considerably. The Fordyce Bathhouse was the first to close in 1962, followed by the Maurice, the Ozark, and the Hale in the 1970s. Between 1984–1885, the Quapaw, Superior, and Lamar closed, leaving the Buckstaff as the only bathhouse still operating on Bathhouse Row.[4]

In its current configuration, most of the springs are covered, with their water running through underground pipes rather than filtering down over the hillside. The Hot Springs Creek flows through a tunnel beneath Central Avenue, and the valley floor has been flattened to make it wider.

Bathhouse Row and its environs were placed on the National Register of Historic Places on November 13, 1974. The desire to revitalize Bathhouse Row also led citizens to campaign for adaptive uses of the vacant buildings. The most elegant bathhouse, the Fordyce, has been adapted for use as a visitor center and museum. Today, nearly all the empty bathhouses are under consideration for adaptive renovation.[4]

Creation of Hot Springs

Thermal springs occur throughout the United States, particularly where there has been recent volcanic activity, although they are rare in the central part of the continent. An unusual set of geologic conditions has created and maintained the flow of hot waters in central Arkansas.

Although some believe the hot springs at HSNP originate from waters rising from hot magmas deep in the earth, their origin has been determined by USGS geochemists to be the result of rainwater that fell into the valley some 4,000 years ago. This rainwater percolated into the earth's crust about 6,000 to 8,000 feet where cracks and fractures then provided a quick route to the surface. This water is heated by the energy released from natural radioactive decay of potassium, uranium, and thorium in the earth's crust as well as from heat generated from compression of the planet's interior by gravity. Carbon-14 dating suggests that the spring water is about 4,000 years old.

The springs emerge in a compact belt along the southwestern slope of Hot Springs Mountain. During the past century, excavation and covering of springs have reduced the number of spring openings from 72 to fewer than 40. The purpose of this work was to increase and concentrate spring water flow to a central reservoir from which the water can be redistributed to individual bathhouses and public drinking fountains (Figure 1). While individual springs vary in the amount of water they discharge (some are mere seeps), each opening is completely encased in metal and concrete and capped with a gas-tight metal hatch.[5] The amount of water discharged by all the hot springs ranges from about 750,000 to 950,000 gallons per day. USGS studies have shown that the discharge is highest in winter.

Discovery of the Radiation Problem

In January 2004, the NPS Midwest Regional Office contacted the DOI concerning the bathhouse drainage pipes rejected by a salvage yard/landfill because of radioactive contamination. This initiated a series of actions by DOI to assess the potential radiological hazards to contractors and NPS employees performing renovation work at HSNP, including a technical assistance request to NIOSH to help evaluate the potential radiological hazards.

Photo 1: Drainage pipe with radioactive scale.

The pipe (Photo 1) rejected by the landfill was stored in a hazardous waste locker in the maintenance area of the park. A NIOSH investigator measured an exposure rate near the surface of about 50 micro Roentgens per hour (μR/hr). Although the pipe was wrapped in plastic, the State of Arkansas recommended treating and disposed of it as naturally occurring radioactive material (NORM) waste material.

METHODS

Site visits were conducted by NIOSH investigators in January and July 2004. The purpose of the initial evaluation was to positively determine if the radium, radon, and other radionuclides were natural or from an external contaminant. Previous DOI measurements at HSNP had identified the following NORM: Radium-226 (^{226}Ra), radon-222 (^{222}Rn), and the short-lived radioactive decay products of radon.[5]

A portable gamma spectrometer (Exploranium GR-135) was used to verify that radiation emitted from the piping was NORM. The spectrometer enables the user to locate contamination, estimate dose (measure and determine the hazard level), and analyze (identify) nuclides for risk assessment. The spectrometer has four detectors (sodium iodide [NaI], Geiger-Müller [GM], neutron, and cadmium-zinc-tellurium [CZT]) to measure and analyze multiple radiation fields. The 4.0 cubic inch NaI(Tl) detector is used to detect and analyze gamma radiation to identify gamma emitting radionuclides. The GM detector is used to detect the presence of gamma radiation while the solid state neutron detector is coupled with a miniature photomultiplier tube. The CZT detector's resolution is approximately twice that of NaI and is used in special applications to improve the nuclide identification capability.

On January 26, 2004, DOI and NIOSH investigators measured radiation in the basement of the Hale Bathhouse from which the piping was removed (Photo 2). Sampling locations were identified using an Exploranium GR-135 (Photo 3) which identified higher radiation intensities in the rock and soil. A piece of the rock foundation and several basement soil samples were collected and sent to a USGS laboratory for mineral analyses by X-ray diffraction and gamma spectrometry. Additional gamma-radiation measurements were made throughout the basements of the remaining seven bathhouses by DOI and State of Arkansas investigators.

Photo 2: Hale Bathhouse. Hot Springs National Park, Hot Springs, Arkansas.

Photo 3: NIOSH investigator making radiation measurements in the Hale Bathhouse basement. This area's elevated natural background radiation level from radium-226 was identified via gamma spectrometry.

During the second site visit in July 2004, NIOSH investigators collected water samples and measured radon and short-lived radon decay products in the basement and on the first floor of the Hale Bathhouse. The water samples were collected from the spring located in the basement of the Hale Bathhouse and from the public fountain in front of the HSNP Administration Building (Photo 4). These samples were sent to a NIOSH contract laboratory for analyses of ^{226}Ra and ^{222}Rn concentrations.

Photo 4: NIOSH investigator collecting a water sample from a public fountain.

Measurements of radon progeny concentrations in air were performed using the method described by Thomas[6] which involves collecting radon progeny on an air filter and measuring the alpha activity of the radon decay products after sampling is ended (Photo 5). The radon progeny are RaA: ^{218}Po, RaB: ^{214}Pb, and RaC: ^{214}Bi. The sensitivity of the Thomas method is approximately 1 pCi/L[a]. A 5-minute air sample was collected on 37 mm diameter Teflon® (polytetrafluoroethylene) filters (0.5 µm pore size). The total alpha disintegrations were measured in three successive time intervals and the radon progeny concentration was determined in units of Working Level. The activity equilibrium between radon and its short-lived progeny in air is inversely related to the ventilation of air in the space being measured. The appropriate level of respiratory protection is determined by the WL exposure and is based on the NIOSH Recommended Standard for Occupational Exposures to Radon Progeny in Underground Mines.[7] Although these bathhouses are not underground mines, the radon concentration and radon sources, spring water, and radium deposits are similar to those found in underground mines. Therefore the NIOSH recommendations for mines are applicable to this environment.

Photo 5: Upper left corner shows a Pylon® radon monitor. Center shows a SKC Airchek HV30 Air Sampler and filter cassette, which is used to capture radon progeny. The filter is removed and the alpha disintegrations are recorded by a scaler counter.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff use environmental evaluation criteria to assess a number of chemical and physical agents. For chemical agents, the primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[7] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[8] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[9] For physical agents such as ionizing radiation, the primary sources of environmental evaluation criteria for the workplace are: (1) the National Council on Radiation Protection and Measurements (NCRP) limits of exposure to ionizing radiation,[10] (2) the International Commission on Radiological Protection (ICRP) limits of exposure to ionizing radiation,[11] (3) the U.S. Department of Labor, OSHA PELs,[9] (4) the U.S. Department of Energy (DOE) standards for external and internal exposure,[12] (5) the U.S. Nuclear Regulatory Commission (NRC) occupational dose limits,[13] (6) the U.S. Environmental Protection Agency (EPA) federal radiation protection guidance for occupational exposure,[14] (6) the Food and Drug Administration (FDA) performance standards for ionizing radiation emitting products,[15] (7) the U.S. Department of Transportation (DOT) radiation limits for transportation of radioactive materials,[16] (8) the International Air Transportation Association (IATA) radiation protection and quality assurance programs,[17] and (9) the International Atomic Energy Agency (IAEA) occupational radiation protection safety standards.[18] Employers are encouraged to follow the limits most applicable to their specific agency. In this work environment the OSHA PELs are the most appropriate criterion.

Ionizing Radiation

Natural radiation background exposure varies around the world from less than 0.005 mR/hr to more than 2.5 mR/hr[19], producing an annual dose of about 40 millirem (mrem) to 22,000 mrem[b], respectively. The greatest dose is due to anomalous, localized deposits of NORM. Variations in the natural radiation

[a] 1 pCi/L = 37 Becquerel per cubic meters (Bq/m^3)

[b] A millirem is a unit of measure of ionizing radiation exposure of living tissues that takes into account the differences in biological harm (Relative Biological Effectiveness [RBE factor]) caused by different types of ionizing radiation.

background also occur with altitude and living conditions. The average annual background dose in the United States has been reported to be about 360 mrem. Radon exposure is responsible for about 55% of background dose (about 200 mrem) and is greater where the presence of NORM material (uranium and thorium) is elevated. Cosmic radiation produces an annual dose of 27 mrem (8%) and terrestrial radiation from NORM in the crust of the earth accounts for 28 mrem (8%). Radiation exposure from internally deposited radioactive material, mainly potassium-40, delivers about 39 mrem (11%) to each person. Medical and other manmade sources of radiation exposure (including consumer products) account for about 63 mrem (18%). Other industrial sources of radiation exposure account for only 3 mrem (0.3%) and include the nuclear fuel cycle, fallout, and artificial sources.

Important forms of ionizing radiation include the alpha and beta particles and gamma rays emitted from radioactive materials. These are called ionizing radiation because they can remove (knock) electrons out of atoms and molecules, creating electrically charged particles called ions. This ionization process transfers energy from the radiation to the irradiated material, and can cause chemical and physical changes in human tissue. The various types of ionizing radiation differ widely in their abilities to penetrate tissue and deposit energy. Alpha particles travel only a very short distance (less than 1 mm) in living tissue and thus cannot penetrate the skin. These particles are present with radon and two of the radon decay products. Beta particles are identical to electrons, are thousands of times smaller than alpha particles, and can penetrate deeper into tissue. However, they are easily stopped by a thin sheet of metal foil. Gamma rays have no mass or electrical charge, and travel much greater distances than either alpha or beta particles. This means their energy is deposited over a longer path and is relatively unlikely to damage living tissue unless the exposure rate is high.[20] It was gamma radiation that was measured from the pipes removed from the Hale Bathhouse from naturally enhanced ^{226}Ra (Appendix I).

Radium

Radium, formed upon the radioactive decay of uranium and thorium, is a naturally occurring silvery-white radioactive metal that can exist in several forms called isotopes. Two of the main radium isotopes found in the environment are ^{226}Ra (uranium decay series; Appendix I) and radium-228 (^{228}Ra, thorium decay series). Historically, radium has been used as a radiation source for treating cancer and in radiography of metals. It has been combined with other metals as a neutron source for research and radiation instrument calibration. Radium was also a component of luminous paints used for watch and clock dials, aircraft instrument panels, military instruments, and compasses. The EPA has set a drinking water limit of 5 pCi/L for ^{226}Ra and ^{228}Ra (combined).

Radon in Air

Radon is a colorless, odorless, tasteless, radioactive gas formed from the radioactive decay of radium in the uranium decay chain (Appendix I). Uranium and radium are found around the world in soil, rocks, and water at various concentrations. Because radon is a gas, it may escape into the air from the material in which it is formed; therefore radon gas is ubiquitous outdoors as well as indoors. High concentrations of radon can accumulate in poorly ventilated indoor locations or when a large amount of ^{226}Ra is present. As shown in Appendix I, radon decays with a half-life of about 4 days into a series of solid, short-lived radioisotopes commonly called radon daughters or progeny. Two progeny, polonium-218 and polonium-214, emit alpha particles and are responsible for most of the health effects associated with inhalation of radon and its decay products. The following chart shows the concentration limits for radon and radon progeny developed by several national and international agencies which are intended to limit the health effects from exposure to these radioactive materials.

NIOSH Recommended Exposure Limits	1	WLM / year (2040 hrs per year)
	0.083	WLM (170 hrs)
	0.083	WL (average concentration per work shift)
	20.8	pCi/L (40% Equilibrium Factor; EF)
	16.6	pCi/L (50% EF)
	8.3	pCi/L (100% EF)
OSHA Permissible Exposure Limits (1971 regulation)	100	pCi/L (40 hr work week)
	25	pCi/L (posting requirement for airborne radioactivity)
	3	pCi/L (40 hr work week for workers less than 18 yrs old)
NRC Occupational Exposure Limits	30	pCi/L (yearly avg); Derived Air Concentration
	3	pCi/L (yearly avg for workers less than 18 yrs old); 10% adult
EPA Recommended Public Limit	4	pCi/L (non-occupational action limit to initiate remediation efforts)
IAEA Recommended Occupational Dose Limits*	4	WLM
	32.4	pCi/L (2000 hrs per year; 40% EF)

WLM = Working Level Months pCi/L = picoCuries per liter
* The IAEA recommendations correspond to an annual effective dose of 2 rem (0.02 Sievert, Sv).

The major route of radon exposure is inhalation. The typical concentration range for radon in ambient air is 0.003 to 2.6 pCi/L. A typical level of radon found indoors in homes, schools, or office buildings is about 1.5 pCi/L, although much higher concentrations (> 200 pCi/L) have been measured. Persons who work with uranium and phosphate fertilizers, persons living near uranium mines and processing facilities, and persons handling fossils and other artifacts rich in uranium or radium have a greater chance of being exposed to higher levels of uranium, radium, and radon than the general population.

OSHA Interpretation of Radon in the Workplace

In December 2002, OSHA provided guidance on its regulations regarding proper interpretation of the workplace radon standards (Appendix II).[21] The OSHA standard refers to airborne radioactive material exposure limits in Table I and Table II of Appendix B to 10 CFR Part 20 that was published by the Atomic Energy Commission (AEC) in 1969. Both the AEC and the OSHA limits were for a 40-hour exposure in any workweek of 7 consecutive days. In 1996 the OSHA standard was redesignated as 29 CFR 1910.1096, although no changes were made to the exposure limits. The Nuclear Regulatory Commission (NRC) has since changed the format of the tables in Appendix B of 10 CFR Part 20 and converted the limits to annual averages, reduced the radon exposure limits, and moved limits for miners from the table to the regulatory text.

Case law supports the interpretation that the original version of a referenced federal regulation is the enforceable regulation. Therefore, the 1969 version of Appendix B to 10 CFR Part 20 that was referenced in the original OSHA ionizing radiation standard in 1971 is enforceable. The applicable ^{222}Ra exposure limit issued by OSHA in 1971 for adult employees is 100 pCi/L averaged over a 40-hour work week. However, many requirements of the current NRC regulation provide as much or more protection than the OSHA standard for workers exposed to airborne radioactive materials. A series of questions and answers regarding radon exposure in the workplace is provided in Appendix II.

EPA Recommendations and Action Levels for Radon

The recommendations and action levels for indoor radon provided by the EPA are not enforceable for a working environment. However, the EPA and the U.S. Surgeon General issued a Health Advisory that recommends testing all homes for radon below the third floor and testing schools nationwide for radon.

They also recommended abating homes with radon levels that are at or above 4 pCi/L, the EPA National Voluntary Action Level. This level represents a radon concentration where the cost of remediation is warranted by the risk of health effects. The EPA believes that the indoor radon concentration can be lowered to 2 pCi/L fairly simply, and encourages homeowners, home builders, and building code organizations to construct radon-resistant homes. Radon testing is encouraged when existing homes are sold. The EPA and has published a pamphlet entitled “A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon," which is available from the EPA website, http://www.epa.gov/iaq/radon/pubs/citguide.html.

Radon in Water

The EPA is proposing new public health standards for radon in drinking water. The proposal provides two options to states and community water systems for reducing radon health risks in both drinking water and indoor air. Information about the proposed rule and information relating to the status of the rule can be found at: www.epa.gov/safewater/radon.html.

The proposed regulation provides that states may adopt Multimedia Mitigation (MMM) programs and the Alternative Maximum Contaminant Level (AMCL) in water of 4,000 pCi/L. According to the EPA, the AMCL is the most effective approach for radon risk reduction and the one the EPA expects most states to adopt. In the absence of this regulatory expectation, small (10,000 or fewer customers) Community Water Systems (CWS) are expected to comply with a level of 4,000 pCi/L in drinking water, and develop and implement a state-approved local MMM program plan to reduce indoor radon risks from soil and rock under homes and buildings. If Arkansas has an approved MMM program plan, the 4,000 pCi/L standard for radon in drinking water would be adopted to obtain primacy. Under the proposed requirements, an MMM program plan must address four criteria:

1. Public involvement in development of the MMM program plan
2. Quantitative goals for existing homes fixed and new homes built radon resistant
3. Strategies for achieving goals
4. Plan to track and report results

The CWS must monitor radon in drinking water[22], and report its results to the state. If the radon level is below 300 pCi/L, the CWS will need only to continue to meet monitoring requirements and will not be covered by the requirements regarding MMM programs.[22]

Health Effects from Radium and Radon Exposures

Cancer is the major health effect of concern from exposure to radium, radon, and its short-lived progeny. Oral exposure to radium is known to cause lung, bone, brain, and nasal passage tumors in humans. Inhalation exposure to radon may cause lung cancer in humans. The EPA has classified radium as a Group A, human carcinogen, but it has not classified radon for carcinogenicity. Chronic exposure to radon in humans and animals via inhalation has resulted in respiratory effects (chronic lung disease, pneumonia, fibrosis of the lung), while animal studies have reported effects on the blood and a decrease in body weight. Smokers exposed to radon are at greater risk for lung cancer (approximately 10 to 20 times) than are nonsmokers similarly exposed. No information is available on the acute (short-term) effects of radium or radon in humans.[23]

RESULTS AND DISCUSSION

Historical Radiation Characterization

Studies of the springs at HSNP have found that the radioactivity is due mostly to dissolved radon and radon progeny with a small contribution from radium.[5] In 1953, the radon concentration among 25 springs ranged from 140 to 30,500 pCi/L. In 1990, indoor basement radon concentrations among the eight bathhouses ranged from 3.1 to 43.7 pCi/L, with the highest levels in the Hale Bathhouse. Radon concentrations in all the remaining bathhouses were below 10 pCi/L. In 1979, the EPA reported radium concentration in the waters to be 2.1 ± 0.22 pCi/L.

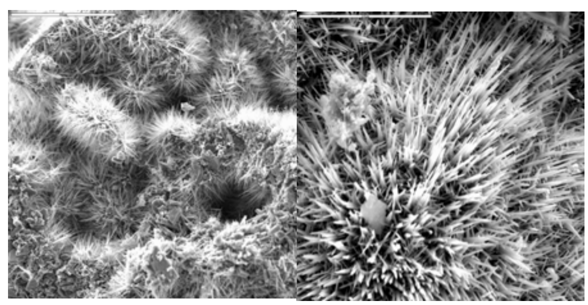
Radiation Measurements

The radiation levels in the six current bathhouses ranged from 5 to 50 µR/hr and were in general agreement with historical values (Table 1). The exceptions were a few localized areas, identified as "hot spots," which had radiation levels above background (greater than 100 µR/hr) when measured on contact with the surface (Photo 6). These stationary "hot spots" are located along the pathway of the natural spring water, where NORM (radium) concentrates in the rock matrix (see Soil and Rock Samples discussion below). The radiation intensity is greatly reduced, however, with increasing distance from these stationary locations and present little hazard to building occupants because these "hot spots" were in non-occupied bathhouse basements.

Photo 6: Radiation measurement in the Hale Bathhouse basement. A natural spring is on the left behind a wooden wall. The radiation intensity exceeded 2,500 µR/hr at wall contact.

Soil and Rock Samples

The USGS used X-ray diffraction to analyze samples taken from the east foundation wall of the Hale Bathhouse (Photos 7–8). The non-black rock sample was primarily quartz (93.2%) and kaolinite (6.8%). The black rock sample consisted of calcite (58.8%), quartz (5.6%), romanechite (28.9%), and wurtzite (6.7%). Romanechite is a hydrated barium manganese oxide and is not a well known mineral. It is the primary constituent of psilomelane, which is sometimes treated as a mineral, a mixture of minerals, or as a rock. However, romanechite is being used as the name for specimens previously known as psilomelane.[24] The floor dust sample consists of quartz (91.2%), calcite (5.3%), and albite (3.4%).



Photos 7 and 8: Scanning Electron Microscope images from the Hale Bathhouse foundation wall (May 2004; USGS). X-ray analyses identified the mineral romanechite.

Three factors may contribute to the elevated external radiation levels and radon concentrations measured in the Hale Bathhouse. First, most of the lower level of the Hale Bathhouse is a full basement with a small, unexcavated crawl space. While this configuration is not unique to the Hale Bathhouse, park officials believe that a low production, uncaptured geothermal water source may run between the overburden and the bedrock, striking the northeast basement wall and under the dirt crawl space. The floor is a porous mixture of concrete and natural soil base that permits radon to easily diffuse from the soil into the basement. The lack of concrete foundation walls also presents less shielding for radium in the soil and ground water. Second, a natural spring exists in the accessible basement northeast area that may serve as a radon source if the enclosure is opened and the active ventilation system is turned off (Photo 9). The third factor is the natural rock wall foundation, which contains deposits rich in NORM material. Direct measurements of external radiation were highest near dark-colored foundation material. Radioactivity analyses of samples from the basement foundation indicate large amounts of ^{226}Ra and its decay products (^{214}Pb, ^{214}Bi, and ^{210}Pb) are in secular equilibrium with ^{226}Ra (Table 2). Secular equilibrium conditions exist when the decay products chemically stay with the parent and eventually reach the same concentration as the parent. This occurs because the decay product half-lives are shorter than their respective parent (see Appendix I).

Photo 9: Natural spring in the basement of the Hale Bathhouse. The white pole was used to obtain the water samples.

These three factors suggest that ^{226}Ra concentration has been naturally enhanced, most likely due to a geochemical process involving the minerals calcite and romanechite identified by USGS in the black- colored foundation material. These minerals are chemically similar to radium and attract, or scavenge, the radium in the water migrating through the rocks and soil, thereby enhancing the radium concentration in the mineral. Although calcite and romanechite are not naturally radioactive, they can become so by this scavenging process.

Two other observations from the data presented in Table 2 are worthy of discussion. First, a portion of the sample of refuse obtained from the black wall may have contained basement floor soil. The other basement floor sample was obtained from an area beneath the northwest staircase (see Photo 3). According to park officials, the spring water migrates beneath this area toward the main drainage conduit in front of the building. This area also had elevated external radiation levels with high enough activity to identify ^{226}Ra with the Exploranium GR-135 portable gamma spectrometer. This basement soil sample contained calcite (5.3%), which may serve as the chemical scavenger for radium from the spring water, thereby accounting for the elevated radium concentration.

The second observation is the unexpected disparity between the radionuclides of ^{226}Ra and ^{228}Ra, with an activity ratio of ^{226}Ra / ^{228}Ra ranging between 1,380 to 2,006 in the black foundation samples; 117 to 120 in the refuse from the foundation sample, 48 to 53 in the basement soil samples, and 1.8 to 2.5 in the non-black foundation sample. Actinium-228 (^{228}Ac, half-life of 6.2 hr) is a gamma-emitting decay product in the ^{232}Th decay series and is the first progeny of ^{228}Ra (half-life of 6.7 years). Because ^{228}Ac is always in equilibrium with ^{228}Ra, it is used to estimate ^{228}Ra concentrations. The apparent difference in the concentration of ^{226}Ra (from the uranium decay chain) and ^{228}Ra (from the thorium decay chain) in the spring water, rock, and soil is likely due to geological and geochemical factors and the significantly greater solubility of uranium that often results in greater amounts of ^{226}Ra relative to ^{228}Ra.[25] Additionally, there is less information on ^{228}Ra concentrations in groundwater than for ^{226}Ra. However, the data show that high concentrations of ^{226}Ra occur more frequently than ^{228}Ra, which may also be due to the higher mobility of uranium than thorium or to a local enrichment in the uranium through which the spring water migrates.[26] In general, the ^{228}Ac results indicate that the thorium decay series only contribute to natural background radiation levels in the Hale Bathhouse.

Radon Concentrations in Air

Because radium was identified as the radionuclide of concern during the first site visit in January 2004, NIOSH and the DOI recommended conducting radon measurements in the Hale Bathhouse and other locations throughout the park.[27] The park purchased real-time radon monitoring equipment and collected hourly radon measurements in several park buildings (Table 3). These data are included in this report because the measurements are relevant to the findings, conclusions, and recommendations[c]. The real-time hourly indoor radon measurements were conducted at various times and in various locations of every bathhouse and the Administration Building between May 2004 and February 2005. Only the Hale Bathhouse and the Administration Building exhibited elevated radon concentrations.

Hale Bathhouse Radon Remediation

Prior to remediation, the Hale Bathhouse radon levels ranged between 45 to 90 pCi/L at the natural spring near the northeast basement wall, and up to 225 pCi/L in the crawl space (Photo 10). During the second site visit, we evaluated the ventilation system in the Hale Bathhouse basement. Two fans (one near the northeast corner, the other near the southwest corner) exhausted basement air to the outside, potentially creating negative pressure in the basement, which could increase diffusion of radon from the surrounding soil into this space. Following a NIOSH recommendation, park officials reversed the airflow in the southwest fan to supply outside make-up air to the basement (the northeast fan continued to exhaust air). This interim ventilation adjustment eventually reduced the radon concentration in the basement and crawl space to 40 pCi/L and 125 pCi/L, respectively. In January 2005, HSNP replaced these fans with four higher capacity units balanced so that three fans exhausted air to the outside while one supplied outside air to the basement. The exhaust fans were installed in the crawl space, near the basement northeast wall, and near the northwest staircase. The supply fan was installed in the southwest basement area. This more efficient ventilation system reduced the basement radon concentrations to below 2 pCi/L. Because the general basement area was below the EPA action limit of 4 pCi/L, continued monitoring of the crawl space was not warranted.

Photo 10: Crawl space in the Hale Bathhouse

Administration Building Radon Remediation

A 285,000 gallon tank is located below the administration building and serves as the main reservoir for the spring water (Figure 1). Radon emanating from this tank is the main source for radon in this building. Prior to any remediation efforts, the radon concentrations throughout the Administration Building ranged between 40 and 50 pCi/L in the basement “Tower Room,” 10 and 12 pCi/L in the general basement area (outside the Tower Room), and up to 12 pCi/L on the first and second floors.

Supply and return air for the building’s ventilation system was located in the basement, an arrangement that provided an opportunity for radon-enriched air from the basement Tower Room area to migrate into the general basement area and eventually be distributed throughout the building. Park officials recognized this problem and installed a plastic sheet barrier (June to August timeframe) in the way door to the Tower Room to minimize cross contamination. This effort successfully reduced the radon concentrations in the basement to 4 to 5 pCi/L and the first and second floor radon concentrations to less than 2 pCi/L. The Tower Room radon concentration was also reduced to 20– 25 pCi/L via a small exhaust fan. Before this interim remedial action, park officials stated that the small exhaust fan in the Tower Room was likely overwhelmed by the blower fan in the building ventilation system. They have since installed a permanent door between the Tower Room and the general basement area that has reduced radon concentrations down to 2–4 pCi/L in the general basement area. The Tower Room radon concentrations did not change.

[c] Permission to use these data was obtained through personal communications between the author and a HSNP official, 2005.

Working Level (WL) Measurements and Equilibrium Factor (EF) Estimate

WL measurements of radon progeny were performed in the Hale Bathhouse and Administration Buildings (Table 4 and Photo 11). The concentration of progeny in equilibrium (EF=100%) with 100 pCi/L of radon gas in air is defined as 1 WL. The concentration of the radon progeny in air is very dependent upon ventilation and humidity, so the EF varies accordingly. The EF estimates provide a site-specific factor to convert radon concentration measurements from pCi/L to WL estimates. WL exposure estimates determine if workplaces are compliant with recommended exposure limits and also provide guidance on the appropriate level of personal protection needed if administrative and engineering controls are unable to reduce radon levels to acceptable concentrations. Without a site-specific EF estimate, the average residential indoor environmental value of 40% is typically used.[28]

Photo 11: Ludlum Model 2000 scaler counter and Ludlum Model 43-10 detector used to count alpha activity on Teflon filters. The detector efficiency was 0.38 cpm / dpm.

Vogiannis et al. reported that EFs in thermal baths range between 5% and 75%.[29] The EFs measured in the Hale Bathhouse ranged between 5% and 8% and are consistent with Vogiannis et al. This means these building environments represent chronic exposure scenarios found in thermal spas (e.g., similar temperature and humid conditions). The Hale Bathhouse WL measurements demonstrate the significance of ventilation and humidity on the EF. The EF in the basement area near the northeast corner was reduced when the building ventilation was activated. The radon concentration and EF were reduced from 91 pCi/L to 31.5 pCi/L and 8.16% to 4.98%, respectively, over a period of about 16 hours. More dramatic reductions were realized in the Hale basement crawl space measurements, even though the crawl space was passively ventilated. Although humidity was not measured, a NIOSH investigator conducted the WL measurements in the crawl space and noted that it was substantially hotter and more humid than the general basement area. Vogiannis et al. reported that high humidity under chronic conditions reduces the EF because of the solubility of radon in water vapor.[29] This may explain why the crawl space EF estimate was lower than the general basement EF estimate.

The EF for the Administration Building (9.05%) was greater than all the values for the Hale building. One explanation is that the Administration Building, with lower temperatures and relative humidity, is more like a residence than a thermal spa. However, the EF was still lower than the 40% typically assumed for residential housing. This difference may be explained several factors affecting EF estimates.

EF Uncertainties

Several factors could affect the EF estimates including ventilation rates, sampling errors, aerosol profiles, sampling times relative to various activities in the building, and meteorological conditions (e.g., humidity and atmospheric pressure). The two factors that have a significant impact on the estimates are ventilation rates and humidity. Increased ventilation rates tend to decrease the EFs by removing radon progeny from the environment. Vogiannis et al. reported that high humidity under chronic conditions lowers EFs, probably because of the increased "washout" of aerosols. High humidity may also reduce the detection efficiency of the Pylon AB-5 Continuous Passive Radon Detector, thereby resulting in a higher EF than true conditions. While it is difficult to say if the "washout" effect offsets the lower radon gas detection efficiency, the high humidity (from its climate and internally housed natural springs) is a factor at the HSNP. Additionally, NIOSH learned that the filter cassette sampling method may have leaked, resulting in some of the sampled air bypassing the filter and lowering the effective sampling rate. NIOSH tested some of the unused cassettes in an effort to determine if this air leakage could have significantly reduced the estimated EFs. A bypass leak of up to 5% percent was detected in one of the unused cassettes, greater than the typical 0.2%.[30, 31] While the leak test cannot accurately predict mass losses from the filter after sampling, it suggests that this problem could be another reason for the low EF estimates.

Radium and Radon Concentrations in Water

Water samples collected at the Hale Bathhouse natural spring and publicly accessible fountain next to the Administration Building were analyzed for ^{226}Ra and ^{222}Rn (Table 5). The ^{226}Ra concentrations were below the proposed EPA MCL (5 pCi/L) from the Hale spring and Administration Building fountain. The ^{222}Rn concentration in water from the Hale spring was above the proposed EPA MCL (300 pCi/L), while the water from the Administration Building fountain was just below this level. This difference may be due to the presence of a 280,000 gallon reservoir tank below the Administration Building which is filled by natural springs. The ^{222}Rn off-gasses before reaching the fountain so the concentration is further reduced.

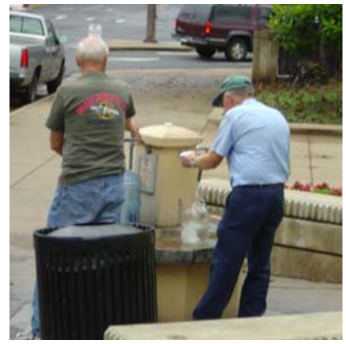


Photo 12: The general public filling containers at the Adm. Building fountain.

Additional off-gassing occurs at the fountain as storage containers are filled by the public. (Photo 12). The park can ensure that radon concentration in water consumed from public fountains is below the proposed radon EPA MCL by introducing interim storage tanks or taps that enhance off-gassing. The variation of ^{226}Ra and ^{222}Rn in water with time and location of publicly accessible fountains was not evaluated.

Personal Protective Equipment

NIOSH research has determined that a radon progeny exposure limit of 1.0 Working Level Month (WLM) per year is technically achievable in mines if effective work practices and engineering controls are implemented.[7] Over a 30-year working lifetime, this exposure limit will reduce the risk of lung cancer associated with exposure to radon progeny. NIOSH considers respirators to be one of the last options for protecting workers, especially for ^{222}Rn. Instead, work practices and engineering controls are more effective means for limiting exposures and providing safe environments. Also, respirator use in the HSNP may not always be practical for physiological and safety reasons. Therefore, NIOSH recommends using administrative and engineering controls where it is technologically reasonable to achieve control of occupational exposure to radon progeny.

The impact of adopting an annual radon progeny exposure limit of 1 WLM implies that the average monthly occupational exposure will be 1/12 WL. Assuming an equilibrium factor of 0.40, the average radon concentration limit for 2040 hours per year is approximately 21 pCi/L.

An EF factor of 40% was selected for this purpose because (1) it is consistent with the value used for residential indoor environments, (2) it is a conservative assumption based on the estimated EF values in the Hale Bathhouse basement and Administration Building (5% to 9% respectively), and (3) it should not present an undue burden in keeping potential exposures below the NIOSH recommended exposure limits. For average work shift concentrations above 1/12 WL (21 pCi/L; 40% EF), NIOSH investigators recommend mandatory respirator use as well as implementation of administrative and engineering controls to reduce exposure to radon progeny. Based on recent radon concentration measurements conducted throughout the Park (Table 3) after implementation of remedial actions, no areas require this level of protection.

Respirator Selection

NIOSH investigators make the following recommendations for respirator selection based on the fact that radon progeny exists as particles and that workers in HSNP are not exposed to hazardous concentrations of non-particulate contaminants. If protection against non-particulate contaminants is required, different types of respirators must be selected.

1. A respirator is not required for exposure to average work shift concentrations less than or equal to 1/12 WL (21 pCi/L radon; 40% EF).
2. For exposure to average work shift concentrations greater than 1/12 WL (120 pCi/L radon; 40% EF), NIOSH recommends those respirators listed in Table 6.

CONCLUSIONS

Radiation

Radiation measured throughout the park was due to NORM, predominantly from ^{226}Ra. The highest exposure rate (2,500 µR/hr) was found in the Hale Bathhouse basement on contact with a localized area of contamination on the east foundation wall. While this is substantially higher than the background rate of 5 to 10 µR/hr, this location poses no immediate danger to building occupants as the area is not routinely accessed by workers or the public. Furthermore, the radiation levels decrease to background about 10 feet from the localized spot with the highest exposure rate.

Disposal of Pipe Containing NORM

The HSNP hired a contractor to handle and dispose of NORM-contaminated pipe removed from the Hale Bathhouse.

Radon Concentrations in Air

Radon concentrations above the EPA action limit of 4 pCi/L were measured by HSNP in only two buildings, the Hale Bathhouse and the Administration building. The park has implemented successful remediation techniques to reduce radon concentrations below the EPA action limit in most locations. The one exception is the Tower Room, located in the basement of the Administration Building. Although the radon concentrations in this room were only reduced to about 20 pCi/L, it is not routinely occupied by park officials and the park has posted a sign on the door warning of the elevated radon exposure potential.

Radium and Radon Concentration in Water

Radium concentrations in the water samples collected from the Hale spring and the fountain just outside the Administration Building were below the EPA MCL of 5 pCi/L. Radon concentration in the Hale spring was above the EPA MCL of 300 pCi/L but the foundation water sample was below this limit.

RECOMMENDATIONS

Radiation

Identify and limit access to areas within the HSNP where the elevated external radiation exceeds 5100 µR/hr. The most cost effective and efficient method to reduce unnecessary external radiation exposures is to avoid occupying these areas or maintain sufficient distance between the radiation source and the individual. The value of 50 µR/hr was chosen because it can result in an occupational dose of 100 mrem during a work year, which is the recommended dose limit for the general population (2,000 hours per work year times 50 µR per hour = 100,000 µR or 100 mR per work year; 100 mR is considered equal to 100 mrem for the purpose of this report).

Disposal of NORM

Consult with the Arkansas Department of Health (24-hour telephone: 501-661-2136) to develop appropriate disposal procedures for any NORM materials uncovered during renovation projects.

Radon Concentrations in Air

Continue the routine radon measurement program to check indoor radon concentration in each of the bathhouses and the Administrative Building office spaces. Depending on results of the monitoring, mitigation may include sealing foundation cracks, sealing exposed dirt in crawl spaces, and increasing or installing ventilation. Other remediation actions to reduce radon levels are available in an IAEA document entitled “Radiation Protection Against Radon in Workplaces Other than Mines.” This document is free online at http://www-pub.iaea.org/MTCD/publications/PDF/Pub1168_web.pdf.

Radium and Radon Concentrations in Water

Start a routine water monitoring program to measure radium and radon concentrations in the drinking water available to the general public. Although water samples from the Administration Building fountain were below the proposed EPA MCLs (5 pCi/L for ^{226}Ra and 300 piC/L for ^{222}Rn), the radon concentration in the Hale spring water exceeded the proposed EPA MCL. The EPA provides guidance to States and community water systems (CWSs) regarding implementation of “The Radionuclides Rule” published in the *Federal Register* on December 7, 2000 (65 FR 76708). A guidance document is available online at http://www.epa.gov/safewater/rads/final_rads_implementation_guidance.pdf.

REFERENCES

1. Radtke T [2004]. Memorandum of January 29, 2004, from T. Radtke, Office of Managing Risk and Public Safety, Department of the Interior to Superintendent, Hot Springs National Park.

2. NPS [2000]. Glimpses of our National Parks (On-line Book). [http://www.cr.nps.gov/history/online_books/glimpses1/glimpses19.htm]. Date accessed: June 16, 2004.

3. NPS [2002a]. The Hot Springs of Arkansas through the years: A chronology of Hot Springs Events. [http://www.nps.gov/hosp/expanded/text/history/chronology/chronology2.htm]. Date accessed: June 16, 2004.

4. NPS [2002b]. The Hot Springs of Arkansas through the years: A chronology of Hot Springs Events. Brief Summary of Park History. [http://www.nps.gov/hosp/expanded/text/history/chronology/chronology1.htm]. Date accessed: June 16, 2004.

5. Epperson CE, Rhodes NR [1990]. Characterization of Radioactivity in Hot Springs National Park, Arkansas. Proceedings Arkansas Academy of Science *44:*125-127.

6. Thomas J [1972]. Measurement of Radon Daughters in Air. Health Physics 23:783-789.

7. NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100. [http://www.cdc.gov/niosh/88-101.html]

8. ACGIH [2005]. 2005 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

9. CFR [1997]. 29 CFR 1910.1000. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

10.NCRP [1993]. National Council on Radiation Protection and Measurements. Report No. 116. Limitation of Exposure to Ionizing Radiation. Bethesda, MD.

11. ICRP [1997]. International Commission on Radiological Protection. General Principles for the Radiation Protection of Workers, Publication No. 75, Pergamon Press, Oxford and New York (1997).

12. CFR [2003]. 10 CFR 835.202. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

13. CFR [1991]. 10 CFR 20.1201. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

14. 52 Fed. Reg. 2822 [1987]. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. January 27, 1987.

15. CFR [2003]. 21 CFR 1020.40. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

16. CFR [2003]. 49 CFR 173.441. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

17. IATA [2003]. 10.11 Radiation Protection and Quality Assurance. International Air Transport Association. Dangerous Good Regulation. 44th Edition. Montreal, Quebec, Canada.

18. IAEA [1999]. International Atomic Energy Agency. Safety Standards Series: Occupational Radiation Protection. Safety Guide No. RS-G-1.1. Vienna.

19. UNSCEAR [2000]. United Nations Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation.United Nations, New York. [http://www.unscear.org/reports/2000_1.html] Date accessed: April 4, 2005.

20. Department of Energy. Science, Society and America's Nuclear Waste: Ionizing Radiation Unit 2; First Edition. DOE/RW-0362 SR.

21. OSHA [2002]. 12/23/2002 – Occupational exposure limits, access restrictions, and posting requirements for airborne radioactive materials. [http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=24496]. Date accessed: June 15, 2004.

22. 64 Fed. Reg. 211 [1999]. Environmental Protection Agency: National Primary Drinking Water Regulations; Radon-222; Proposed Rule. (To be codified at 40 CFR Parts 141 and 142).

23. CFR [2005]. U.S. Environmental Protection Agency: Radiation information, World Wide Website, March 28, 2005. http://www.epa.gov/radiation/radionuclides/radon.htm

24. Mineralogical Society of America [2005]. Romanechite Mineral Data. Website: http://webmineral.com/data/Romanechite.shtml

25. Eisenbud, M [1987]. Environmental radioactivity from natural, industrial, and military sources. 3rd ed. New York: Academic Press, pp. 133-134.

26. IAEA [1990]. International Atomic Energy Agency Technical Reports Series No. 310: The Environmental Behavior of Radium, Volume 1. Vienna.

27. Radtke T [2004]. Memorandum of January 29, 2004, from Industrial Hygienist, Office of Managing Risk and Public Safety, Department of the Interior to Superintendent, Hot Springs National Park.

28. IAEA [2003]. International Atomic Energy Agency Safety Reports Series No. 33: Radiation Protection against Radon in Workplaces other than Mines. Vienna. Available for free at [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1168_web.pdf].

29. Vogiannis E, Niaounakis M, Halvadakis CP. [2003]. Contribution of 222Rn-bearing water to the occupational exposure in thermal baths. Environmental International 30:621-629.

30. Baron P. [2002]. Using a Filter Bypass Leakage Test for Aerosol Sampling Cassettes. Applied Occupational and Environmental Hygiene. 17(9):593-597.

31. Baron PA, Khanina A, Martinez AB, Grinshpun SA. [2002]. Investigation of Filter Bypass Leakage and a Test for Aerosol Sampling Cassettes. Aerosol Science and Technology. 36: 857-865.

TABLES

Table 1
Radiation Measurements*
HETA 2004-0094-2978: Hot Springs National Park
January 26 and 27, 2004

Bathhouse	Location	µR/hr**
Lamar	1st floor and basement	5–10
	Near boilers	10
Ozark	1st floor and basement	5–12
	North side stairwell at floor level	40–42
Quapaw	1st floor and basement	5–10
	In display spring and above mineral deposits	20–30
	In spring drain	500
	Jack-hammered open dirt	220
Maurice	1st floor and basement	5–10
Maurice Spring	In the spring opening	50
Hale	1st floor contractor office desk	5–10
	Above basement hotspot:	25
	Basement hotspot	**2,500**
Superior	1st floor in tubs	15
	Throughout 1st floor and basement	5–10
	On floor near open drain in basement	30–35
	On dirt pile in NE corner of basement	50
Ral Spring	On ground in depression	1,100

* Radiation measurement obtained by DOI and State of Arkansas Radiation Officer using the NIOSH radiation instrument Inovision 451P ionization chamber.

**µR/hr = microRoentgen per hour. An exposure rate to external radiation equal to 1,000 µR/hr is approximately equal to a dose rate of 1 mrem / hr. Natural background radiation rates in this area range between 5 to 10 µR/hr.

Table 2
Gamma Spectrometry Results From Soil and Rock Samples
Hale Bathhouse Basement Foundation and Floor
Analyses by U.S. Geological Service, Denver Federal Center
HETA 2004-0094-2978: Hot Springs National Park

Location	Activity in disintegrations per minute per gram of material					
	Decay products in the ^{238}U series (Appendix I)					Decay product, ^{232}Th series
	^{234}Th	$^{226}Ra^{\#}$	^{214}Pb	^{214}Bi	^{210}Pb	^{228}Ac
East Foundation Wall (Photo 6) Non-black rock sample						
GE-A[@]	ND[@]	2.3	2.2	2.1	ND	0.9
GE-1	0.5	2.6	2.1	2.1	2.1	1.4
East Foundation Wall Black rock sample						
GE-A	ND	3,010	2,735	2,630	ND	1.5
GE-1	<7	2,760	2,760	2,750	2,565	2.0
Refuse from black wall sample*						
GE-A	ND	144	149	141	ND	1.2
GE-1	0.8	129	143	133	137	1.1
Basement floor soil sample						
GE-A	ND	70	67	75	ND	1.3
GE-1	2.7	72	69	68	75	1.5

* Refuse from the black wall sample also contains portions of the basement floor materials.

[#] For comparison, most natural soils and rocks contain approximately 0.5–5 pCi/g (1.1–11.1 dpm/g) of total radium.[‡] A nominal background value of 1.4 pCi/g (3.1 dpm/g) has been used for various clean-up efforts.

[@] The designation of ND indicates "not determined." The gamma-ray energies of detector GE-1 is more sensitive than detector GE-A for measuring ^{234}Th (63.3, 92.4, 92.8 keV) and ^{210}Pb (46.5 keV) are too low to be adequately detected.

‡ USGS [1999]. Naturally Occurring Radioactive Materials (NORM) in Produced Water and Oil-Field equipment - An Issue for the Energy Industry. [http://pubs.usgs.gov/fs/fs-0142-99/fs-0142-99.pdf] Date accessed: March 30, 2005.

Table 3
Radon Concentration in Air*
Collected by Hot Springs National Park Officials
HETA 2004-0094-2978: Hot Springs National Park
May 2004 to February 2005

Location	Radon Concentration (pCi/L)
Hale Bathhouse Basement	
Prior to remediation	
Basement area behind the natural spring near the east wall	45–90
Crawl space (1/3 basement)	up to 225
Modified existing ventilation (Push/Pull) July 1, 2005	
Basement area behind the natural spring near the east wall	leveled off to about 40
Crawl space (1/3 basement)	leveled off to about 125
Final remediation (Push/Pull) January, 2005	
Basement area behind the natural spring near the east wall	less than 2
Crawl space (1/3 basement)	not measured
Administration Building (285,000 gallon tank)	
Prior to remediation (open doorway)	
Basement (Tower Room)	40–50
General basement area (outside Tower Room)	10–12
First and Second Floors	up to 12
Installed plastic sheets	
Tower Room (exhaust fan in pump room operational)	20–25
General basement area (outside Tower Room)	4–5
First and Second Floors	less than 2
Installed permanent door	
Tower Room (exhaust fan in pump room and signage)	20–25
General basement area (outside Tower Room)	2–4
First and second floors	less than 2
Superior Bathhouse **Maurice Bathhouse** **Fordyce Bathhouse** **Quapaw Bathhouse** **Ozark Bathhouse** **Buckstaff Bathhouse** **Lamar Bathhouse**	All real-time radon measurements taken on all floors at various times between May, 2004 and February, 2005 were below 4 pCi/L. If the basement concentration was below 4 pCi/L then the remaining upper floors were not measured.

* Cardarelli J [2005]. Telephone conversation on March 29, 2005, between J. Cardarelli, NIOSH and S. Rudd, Hot Springs National Park, Chief Park Ranger.

Table 4
Working Level (WL) and Equilibrium Factor (EF) Estimates
HETA 2004-0094-2978: Hot Springs National Park
June 30 – July 1, 2004

Location	Gross Alpha Counts per time interval[@] post sample (time) = (cts)	Radon Progeny Conc. (pCi/L)	Measured ^{222}Rn Conc.[$] (pCi/L)	WL[#]	EF (%)
Hale basement near northeast corner (ventilation off) June 30 2:40 pm	(2 to 5) = 3,083 (6 to 20) = 8,190 (21 to 30) = 4,532	^{218}Po = 18.6 ^{214}Pb = 4.5 ^{214}Bi = 1.7	91	0.074	8.16
Hale basement near northeast corner (ventilation on) July 1 7:36 am	(2 to 5) = 720 (6 to 20) = 1,637 (21 to 30) = 886	^{218}Po = 6.7 ^{214}Pb = 1.3 ^{214}Bi = 0.6	31.5	0.016	4.98
Hale basement crawl space[&] (ventilation off; very humid) June 30 3:23 pm	(2 to 5) = 6,362 (6 to 20) = 14,093 (21 to 30) = 7,436	^{218}Po = 59.2 ^{214}Pb = 9.8 ^{214}Bi = 5.3	224	0.132[§]	5.90
Hale basement crawl space[&] (ventilation on; very humid) July 1 – early morning	(2 to 5) = 944 (6 to 20) = 2,178 (21 to 30) = 1,192	^{218}Po = 8.7 ^{214}Pb = 1.7 ^{214}Bi = 0.7	38.6	0.021	5.33
Hale basement crawl space[&] (ventilation on; very humid) July 1 – late morning	(2 to 5) = 736 (6 to 20) = 1,809 (21 to 30) = 1,002	^{218}Po = 6.4 ^{214}Pb = 1.5 ^{214}Bi = 0.7	33.1	0.017	5.05
Administration Building basement Tower Room (ventilation on), July 1, morning	(2 to 5) = 1,060 (6 to 20) = 1,755 (21 to 30) = 877	^{218}Po = 12.3 ^{214}Pb = 0.9 ^{214}Bi = 0.1	20*	0.018	9.05

[@] Five-minute air samples were collected on 37 mm Teflon (Polytetrafluoroethylene) filters (0.5 µm pore size) with a flow rate of 22 liters per minute. The background count rate was 3.28 counts per minute with a detector efficiency of 0.38 counts per minute/disintegrations per minute.

[$] Radon concentrations were measured with a Pylon AB-5 monitor with a continuous passive radon detector. Each result is the average concentration measured during the sampling period.

[#] One Working Level corresponds to radon progeny concentration in equilibrium with 100 pCi/L radon.

[&] Ventilation in the crawl space was only passively affected by the building ventilation system.

The radon concentration was estimated based on previous measurements in this location.

Table 5
Radium-226 and Radon-222 Concentration in Spring Water
HETA 2004-0094-2978: Hot Springs National Park
July 1, 2004

Laboratory	Analyses	Hale Spring Water pCi/L	Fountain Water pCi/L
General Engineering Laboratory	Radium-226[#]	3.14 ± 0.47	2.03 ± 0.13
	Radon-222	369 ± 74	203 ± 69

[#] Radium-226 results are below the EPA limit for drinking water (5 pCi/L).

Table 6
Respirator Recommendations for Radon Progeny
HETA 2004-0094-2978: Hot Springs National Park
July 1, 2004

Average work shift concentration of radon progeny **(WL) or radon concentration (pCi/L at 40% EF)**	Respirator recommendations
0 to .083 (1/12) WL or 0 to 20.8 pCi/L	No respirator required
> 0.083 to ≤ 0.42 WL or > 20.8 to ≤ 105 pCi/L	Any disposable respirator equipped with a HEPA[$] filter
> 0.42 to ≤ 0.83 WL or > 105 to ≤ 208 pCi/L	Any air-purifying half-mask respirator equipped with a HEPA filter
	Any SAR[#] equipped with a half-mask and operated in a demand (negative-pressure) mode
> 0.82 to ≤ 2.08 WL or > 208 to ≤ 520 pCi/L	Any powered PAPR* equipped with a hood or helmet and a HEPA filter
	Any supplied-air respirator with a hood or helmet and operated in a continuous flow mode
> 2.08 to ≤ 4.15 WL or > 520 to ≤ 1,038 pCi/L	Any air-purifying, full facepiece respirator equipped with a HEPA filter
	Any PAPR equipped with a tight fitting facepiece and a HEPA filter
	Any SAR equipped with a full facepiece and operated in a demand (negative-pressure) mode
	Any SAR equipped with a tight-fitting facepiece and operated in a continuous-flow mode
	Any self-contained breathing apparatus (SCBA) equipped with a full facepiece and operated in a demand (negative-pressure) mode

pCi/L = picoCuries per liter

WL = working level

[#] SAR = supplied-air respirator

* PAPR = powered air-purifying respirator

[$] HEPA = high-efficiency particulate air

NOTE: This table was adopted and edited for Hot Springs National Park applications from Table I-1 of NIOSH [1987]. An EF factor of 40% was selected for this purpose because (1) it is consistent with the value used for residential indoor environment, (2) it is a conservative assumption based on the estimated EF values in the Hale Bathhouse basement and Administration Building (5% to 9% respectively), and (3) should not present an undue burden in keeping potential exposures below the NIOSH recommended exposure limits.

APPENDICES

Appendix I

Uranium-238 Decay Series (4n + 2)a

Nuclide	Half-life	Major Radiation Energies (MeV) and Intensities[b]					
		α		β		γ	
		MeV	%	MeV	%	MeV	%
$^{238}_{92}U$	4.468×10^{9} y	4.15 4.20	22.9 76.8			0.496	0.07
↓							
$^{234}_{90}Th$	24 .1 d			0.076 0.095 0.096 0.1886	2.7 6.2 18.6 72.5	0.0633 0.0924 0.0928 0.1128	3.8 2.7 2.7 0.24
↓							
$^{234}_{91}Pa$	1.17 m			2.28	98.6	0.766 1.001	0.207 0.59
↓							
$^{234}_{91}Pa$	6.7 h			22 ßs E Avg = 0.224 Emax = 1.26		0.132 0.570 0.883 0.926 0.946 0.053 0.121	19.7 10.7 11.8 10.9 12 0.12 0.04
↓							
$^{234}_{92}U$	244,500 y	4.72 4.77	27.4 72.3				
↓							
$^{230}_{90}Th$	7.7×10^{4} y	4.621 4.688	23.4 76.2			0.0677 0.142 0.144	0.37 0.07 0.045
↓							
$^{226}_{88}Ra$	1600 ± 7 y	4.60 4.78	5.55 94.4			0.186	3.28
↓							
$^{222}_{86}Rn$	3.823 d	5.49	99.9			0.510	0.078
↓							
$^{218}_{84}Po$	3.05 m	6.00	-100	0.33	0.02	0.837	0.0011
↓							

Appendix I Continued

Nuclide	Half-life	Major Radiation Energies (MeV) and Intensities[b]					
		α		β		γ	
		MeV	%	MeV	%	MeV	%
$^{214}_{82}Pb$	26.8 *m*			0.67 0.73 1.03	48 42.5 6.3	0.2419 0.295 0.352 0.786	7.5 19.2 37.1 1.1
↓							
$^{214}_{83}Bi$	19.9 *m*	5.45 5.51	0.012 0.008	1.42 1.505 1.54 3.27	8.3 17.6 17.9 17.7	0.609 1.12 1.765 2.204	46.1 15.0 15.9 5.0
↓							
$^{214}_{84}Po$	164 μs	7.687	100			0.7997	0.010
↓							
$^{210}_{82}Pb$	22.3 *y*	3.72	0.000002	0.016 0.063	80 20	0.0465	4
↓							
$^{210}_{83}Bi$	5.01 *d*	4.65 4.69	0.00007 0.00005	4.65 4.69	0.00007 0.00005		
↓							
$^{210}_{84}Po$	138.378 *d*	5.305	100	5.305	100	0.802	0.0011
↓							
$^{206}_{82}Pb$	*stable*						

[a] This expression describes the mass number of any member in this series, where n is an integer. For example: $^{206}_{82}Pb$ (4n + 2)…(4 x 51) + 2 = 206

[b] Intensities refer to percentage of disintegrations of the nuclide itself, not to original parent of series. Gamma %s: in terms of observable emissions, not transitions.

Appendix II
OSHA Interpretation of Radon Exposures in the Workplace

The following are excerpts from a recent interpretation of the OSHA regulations provided to the U.S. Army Corps of Engineers (USACE) concerning occupational exposure limits to radon gas. These questions and answers may also apply to the HSNP radon situation.[d]

Question 1: Although the USACE does not use or transport radon, is the presence of radon in structures considered "possession," making 29 CFR 1910.1096 applicable to USACE structures?

Reply: Yes. If the presence of radon in a structure controlled by the employer exposes employees to hazardous concentrations of airborne radiation as set forth in the standard, 29 CFR 1910.1096 would apply.

Question 2: If workers are only required to enter an area occasionally during a calendar quarter, can their exposures be averaged over the calendar quarter instead of one week to determine whether they should be allowed to enter the area?

Reply: No, not for airborne radioactive materials. Neither the OSHA nor the NRC ionizing radiation standard allows airborne radon concentrations to be averaged over a calendar quarter. The OSHA radon exposure limit is an average concentration for 40 hours in any workweek of 7 consecutive days. The still applicable 1971 radon-222 exposure limit for adult employees is 1×10^{-7} microcuries per milliliter (μCi/ml) [100 picoCuries/liter (pCi/L)] averaged over a 40-hour workweek. However, OSHA would consider it a *de minimis* violation if an employer complied with the current NRC radon-222 (with daughters present) exposure limit for adult employees of 3×10^{-8} μCi/ml [30 pCi/L] averaged over a year (DAC-derived air concentrations).

Question 3: Does the provision at 1910.1096(c)(2), dealing with exposure to airborne radioactive materials by employees under the age of 18, apply to USACE structures?

Reply: Yes. According to paragraph 1910.1096(c)(2), the radon-222 exposure limit for employees under the age of 18 is 3×10^{-9} μCi/ml [3pCi/L] averaged over a 40-hour workweek as it was in 1971. However, OSHA would consider it a *de minimis* violation if an employer complied with the current NRC radon-222 exposure limit for employees under the age of 18 of 3×10^{-9} μCi/ml [3pCi/L] averaged over a year (i.e., 10% of the adult limit).

Question 4: Are we required to monitor and track workplaces where radon concentrations are below 4 pCi/L?

Reply: No. You must make surveys in order to comply with the provisions in 1910.1096. In addition, you must supply appropriate personnel monitoring equipment to adult employees who enter a restricted area and receive, or are likely to receive, a dose in any calendar quarter in excess of 25% of the applicable value in 1910.1096(b)(1). Likewise, personnel monitoring equipment must be supplied to employees under the age of 18 who

---

[d] OSHA [2002]. 12/23/2002 – Occupational exposure limits, access restrictions, and posting requirements for airborne radioactive materials. [http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=24496]. Date accessed: June 15, 2004.

enter a restricted area and are exposed to 5% of the applicable value in 1910.1096(b)(1). The OSHA dose limit for whole body radiation is 1.25 rem per calendar quarter.

It should be noted that the Environmental Protection Agency (EPA) and other public health officials publish radon guidelines, but these guidelines are not occupational safety and health standards and do not carry the weight of law. EPA recommends remediation when the radon level is 4 pCi/L or higher. However, radon levels less than 4 pCi/L pose a risk and in many cases may be reduced.

Question 5: Must we restrict individuals under the age of 18 from entering areas where the radon concentration is greater than 3.0 pCi/L? Note: USACE feels this would place an undue burden on organizations that either employ persons under the age of 18 or that allow members of the public under the age of 18 to enter their facility.

Reply: Yes. You must provide access control to areas where your employees may be exposed over the applicable limits. This may be accomplished by restricting the employees' exposure time. OSHA does not regulate the general public.

Question 6: 29 CFR 1910.1096(e)(4)(i)(b) defines an "airborne radioactivity area" as *"Any room, enclosure or operating area in which airborne radioactive materials exist in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in column 1 of Table 1 of appendix B to 10 CFR part 20."* Are we required to post areas that exceed 4 pCi/L if they are occupied for more than 75 hours a week? Are we required to post continuously occupied areas that exceed 1.8 pCi/L? Is there a lower concentration where posting is no longer required?

Reply: You are required to post airborne radioactive areas. The 1971 version of Appendix B to 10 CFR Part 20 lists the adult limit for radon-222 in column 1 of Table 1 as 1×10^{-7} microcuries per milliliter (μCi/ml) [100 pCi/L]. Thus, you must post a sign in accordance with 29 CFR 1910.1096(e)(4)(ii) when the weekly average exceeds 25% of these levels.

The NRC uses similar language to define "airborne radioactive area," except that the regulation at 10 CFR 20.1003 refers to the derived air concentrations (DAC) in Appendix B §§ 20.1001-20.2401 or the average weekly intake by an individual of 0.6 percent of the annual limit. Using the NRC's definition of an airborne radioactive area, posting is required in areas where the weekly average radon exposure limit is 0.18 pCi/L (30 pCi/L x 0.006 = 0.18 pCi/L). OSHA does not enforce this posting limit.

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226-1998

OFFICIAL BUSINESS
Penalty for private use $300

NIOSH

**Delivering on the Nation's promise:
Safety and Health at work for all people
through research and prevention**

To receive NIOSH documents or information about occupational Safety and Health topics contact NIOSH at:

1-800-35-NIOSH (356-4674)
Fax: 1-513-533-8573
E-mail: pubstaft@cdc.gov
or visit the NIOSH web site at:
www.cdc.gov/niosh/homepage.html

S A F E R • H E A L T H I E R • P E O P L E™