NUREG/CR-4057
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Radiological Assessment of the Town of Edgemont

Prepared by P. O. Jackson, V. W. Thomas, J. A. Young

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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Prepared by
P. O. Jackson, V. W. Thomas, J. A. Young

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2217

ABSTRACT

Congress, in 1980, gave the Nuclear Regulatory Commission (NRC) the responsibility to coordinate and conduct a monitoring, engineering assessment, and remedial cleanup program in Edgemont, South Dakota. The congressional intent was to locate public properties in Edgemont that had been contaminated by radioactive materials from a local uranium mill, and to clean up those properties. Because the Atomic Energy Act of 1954 gave NRC the authority to monitor for contamination but not to clean up contamination, Congress later assigned the remedial cleanup responsibility to the Department of Energy (DOE). NRC, through Battelle Pacific Northwest Laboratory (PNL), conducted a radiological survey of 96% of the properties in Edgemont and vicinity during the time period of September, 1980, through April, 1984. (Out of 976 total properties, 941 were surveyed.)

The strategy of the survey was to screen properties for the possible presence of contamination by using short- and long-term radon progeny measurements, indoor and outdoor gamma exposure rate measurements, and soil radium-226 measurements. Properties that failed the screening surveys were measured more extensively to determine whether the elevated readings were due to residual radioactive materials from the uranium mill. This report contains the historical perspective of the Edgemont survey, explains the development and modifications of survey protocols, examines the problems encountered during the survey, and lists a summary of the results. The report also presents conclusions about the effectiveness of the survey techniques and about the rationale of a comprehensive survey of a whole community. The appendices section of this report contains all the protocols, a list of all the properties showing survey results for each, and reports on special studies conducted during the survey. These special studies contain many valuable insights that may prove beneficial to future radiological assessment surveys.

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HISTORICAL PERSPECTIVE

Edgemont is an isolated community in southwest South Dakota at the southern fringes of the Black Hills. In the recent past, Edgemont has depended on two sources for its economic viability - the railroad and the uranium industry. The uranium mill at Edgemont is an integral part of the town, located just across the Burlington Northern Railroad tracks from Edgemont's main business district. An Environmental Protection Agency (EPA) survey in 1971-72 identified Edgemont as one of a number of western communities that had been contaminated by materials that possibly originated from a local uranium mill. This EPA survey, along with several similar surveys at other communities and other studies, generated much concern about the health of the general public living in the environs of uranium mills.

In 1978, Congress passed the Uranium Mill Tailings Radiation Control Act (UMTRCA). Title I of UMTRCA established a program by which the Department of Energy (DOE) would clean up certain inactive uranium mill sites and contaminated vicinity properties. Because the Edgemont Uranium Mill had an active Nuclear Regulatory Commission (NRC) license, UMTRCA did not include the mill in the Title I sites to be cleaned up by DOE. Instead, the present owner of the mill would clean up the mill site under the conditions of the license. However, the present owner was not legally obligated to clean up contamination off the site, except for that contamination created by windblown tailings.

In 1978 EPA, with assistance from NRC, the mill owner, and the State of South Dakota, conducted a survey to determine whether contamination other than windblown tailings existed on Edgemont public properties. This survey revealed sixty properties where radioactive material may have been transported and placed by man. In 1979, the State requested that the NRC conduct a radiological assessment of Edgemont. NRC agreed to cooperate in a radiological assessment of Edgemont; however, NRC could not, either directly or through the mill owner licensee, perform remedial cleanup of contaminated offsite properties. During 1980 the Department of Housing and Urban Development (HUD) determined that homeowners or potential homeowners in Edgemont would not be eligible for HUD housing assistance if the house in question contained unacceptable levels of radiation. A house would need either a passing radiological survey or, if it had a high radiation level, remedial cleanup before HUD assistance would be granted. The EPA surveys and the HUD action prompted much interest in an Edgemont remedial action program both for health reasons and for economic reasons.

Congress, in 1980, gave NRC the responsibility to coordinate and conduct a monitoring, engineering assessment, and remedial cleanup program in Edgemont. However, there remained considerable doubt about NRC's authority under the Atomic Energy Act for any action other than monitoring. In September, 1980, NRC's contractor, The Pacific Northwest Laboratory (PNL) operated for the Department of Energy by the Battelle Memorial Institute, began the Edgemont radiological survey. In January 1983 Congress amended Title I of UMTRCA to include Edgemont vicinity properties. This gave the responsibility for engineering assessments and remedial action cleanup to the DOE. NRC then began relaying radiological assessment and other survey results to DOE so that DOE could plan and conduct remedial cleanup at contaminated public properties in Edgemont. The NRC Edgemont radiological survey was completed in early 1984; and shortly thereafter, in April of 1984, PNL closed its Edgemont field office.

GOALS AND PROTOCOLS

In August, 1980, representatives of the Division of Waste Management (DWM) in the Office of Nuclear Materials Safety and Safeguards (NMSS) of the NRC requested that PNL perform the radiological surveys that were needed in Edgemont. PNL was requested to provide detailed radiological surveys of all developed properties in Edgemont and its vicinity. Properties in the vicinity of Edgemont were defined later to be Dudley, farms and residences within Edgemont, vacant lands within 50 feet of the perimeter of the city limits and farms and residences bordering Edgemont where owners requested a survey. Personnel of the State of South Dakota had been performing radiological surveys following a protocol defined by HUD (Region 8) with the assistance of EPA (Region 8). The PNL survey was sufficient for HUD's need; therefore, the PNL survey replaced the HUD survey and PNL, through the State, supplied HUD with the information necessary for its property evaluations. For NRC purposes, PNL was not required to re-survey the 192 properties that had previously been surveyed by the State.

The NRC work statement to PNL specified the required sampling protocols and action levels to be used in the surveys and included a flow diagram describing the survey process. The diagram is shown in Figure 1 and the work statement protocol is in Appendix A. The work statement protocol was patterned after the protocol established by HUD-EPA for the State of South Dakota. It was intended to meet the needs of HUD as well as evaluate the status of a property in comparison with the proposed EPA standards in 40 CFR 192, "Proposed Cleanup Standards for Inactive Uranium Processing Sites" (EPA, 1981). The proposed standards stated that remedial action shall be required if residual radioactivity caused:

(1) average annual indoor radon daughter concentrations (including background) to exceed 0.015 working levels (WL)[1];

(2) indoor gamma radiation levels to exceed 20 micro-roentgens per hour above background; or

(3) average ^{226}Ra concentrations in soil or other materials to exceed 5 pCi/g in any 5 cm thickness within 1 foot of the surface, or any 15 cm thickness below 1 foot.

If a property failed any one of these criteria because of residual radioactivity from the uranium milling industry, then remedial action would be required. In addition to the EPA requirements, properties are not eligible for federally guaranteed financing administered by HUD if: (1) indoor radon daughter weighted working levels are greater than 0.02 WWL[2], or (2) average gamma exposure rates on open land are greater than 14.5 μR/hr.

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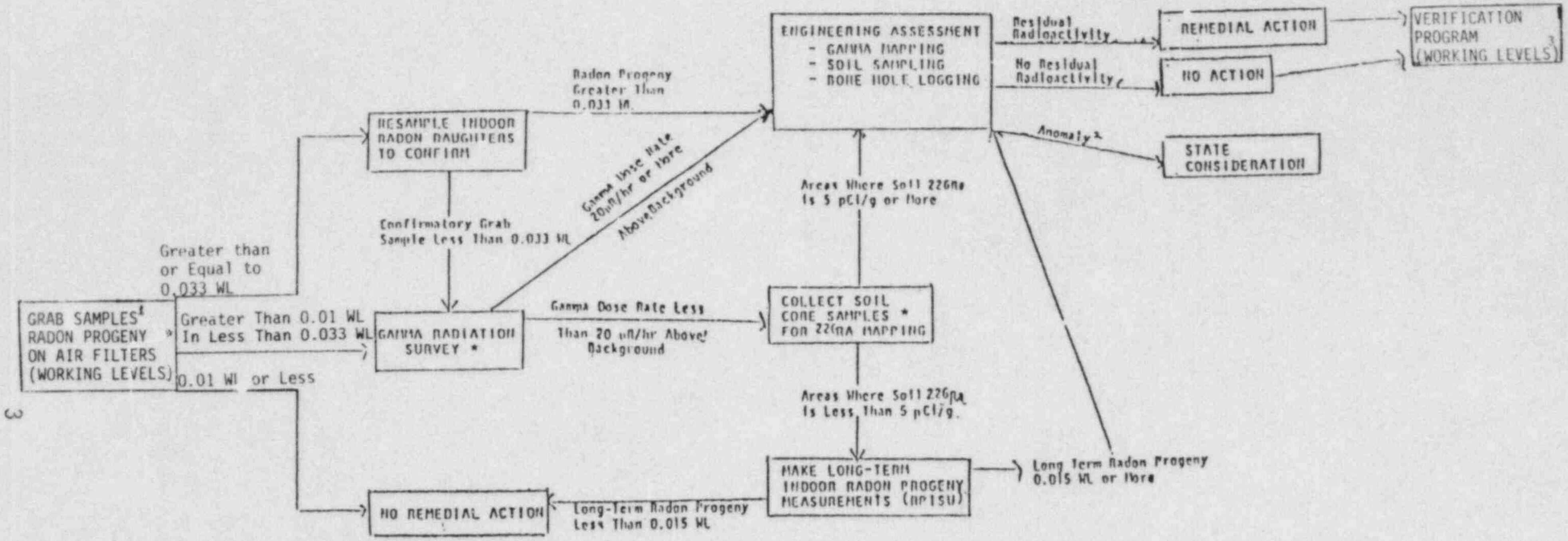
(1) One working level (WL) is defined as any combination of short-lived radon decay products in 1 liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

(2) One weighted working level (WWL) is defined as 0.6 times the "grab" working level measured in a closed up structure.



(1) U. S. Nuclear Regulatory Commission and the State of South Dakota Protocol.

(2) Anomaly may be natural terrestrial radioactivity resulting in radiological exposure in excess of EPA Standards.

(3) The same screening and measurement program that is used for identifying involved structures would be repeated to confirm EPA Standards are met before a structure is finally cleared.

* Grab WL, Gamma Surveys, and Soil Sampling shall be completed for each property.

FIGURE 1. Flow Diagram for Edgemont Radiological Assessments as Specified in the Original Statement of Work

The survey protocol (and diagram) were modified and improved with time and experience in Edgemont to best meet the needs and goals of NRC, HUD, the State of South Dakota and the property owners. The major goal of the initial radiological measurements was to locate all sources of elevated radioactivity so that structures and properties potentially requiring remedial action could be identified. However, the measurement procedures, of necessity, represented a compromise between the need for accurate, representative measurements of radiological parameters, and the requirement that decisions concerning remedial action be made as quickly as possible. Any delays in carrying out remedial action caused by a too exhaustive measurement program could have resulted in a greater total population dose than minor errors in deciding where remedial action was required. Therefore, some of the measurements had to be made with less than the maximum possible detail and accuracy in order to expedite the implementation of remedial action. The protocols that were considered by PNL to represent the best compromise between expediency and accuracy are documented by Perkins et al. (1981) and are excerpted in Appendix A. These protocols were approved by NRC personnel after discussions with PNL staff and participation by the NRC staff in the initial radiological surveys in Edgemont.

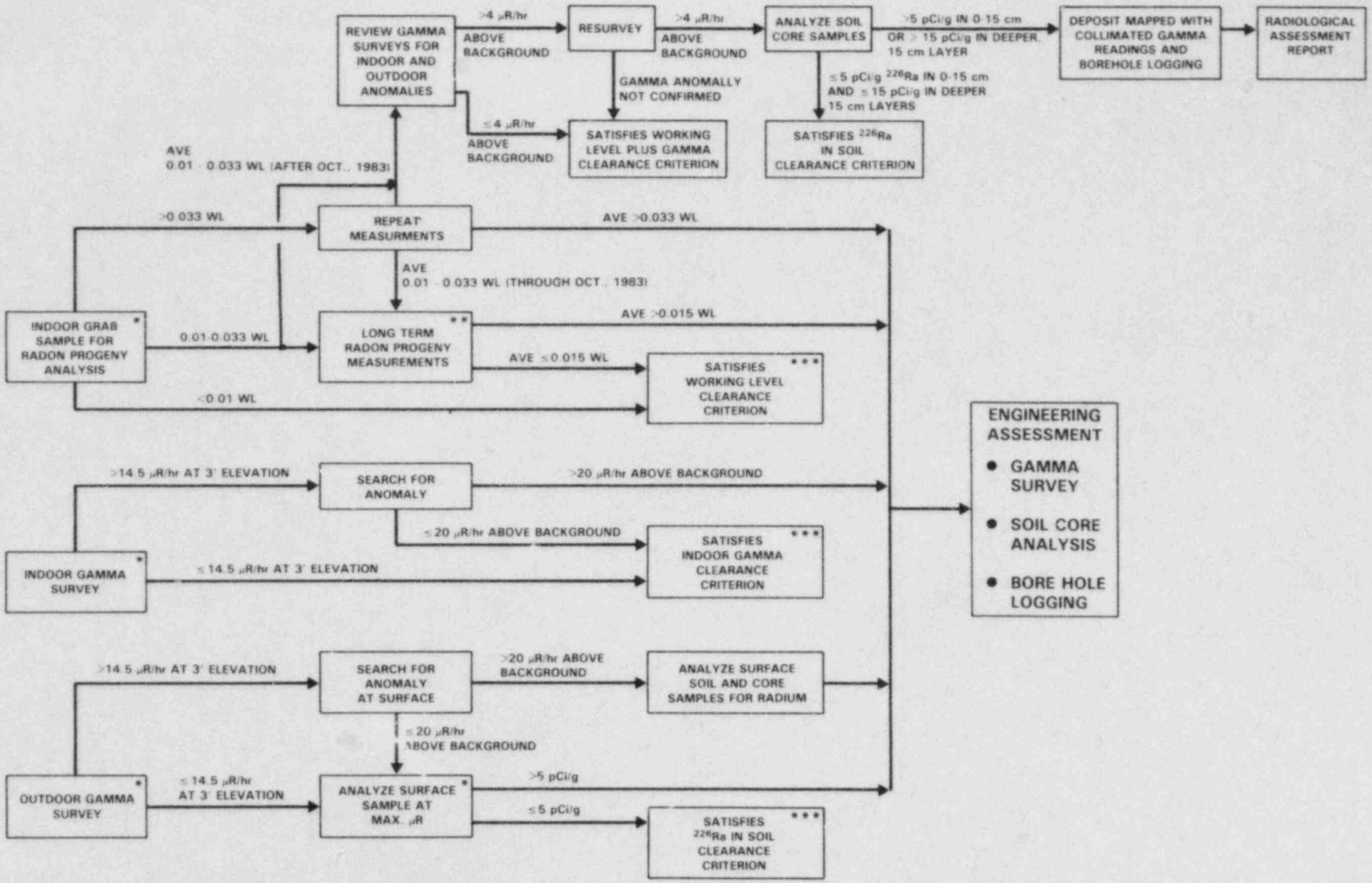
In January, 1981, PNL conducted a workshop in Denver, Colorado, at the request of NRC. Representatives from federal and state agencies, Indian nations, federal contractors and interested parties from the private sector, all of whom were concerned with monitoring for compliance with 40 CFR 192, were invited to attend. Many of the participants were or had been actively engaged in similar radiological surveys. At that meeting the participants evaluated the detailed protocols. Those suggested procedural changes which were generally considered to be necessary were implemented in subsequent field studies. The conclusions of the workshop and protocol changes are also given by Perkins et al. (1981) and included in Appendix A.

In October, 1983, NRC further modified the protocol in order to reduce the length of time required for the measurement of annual radon daughter concentrations in residences where the radon daughter grab sample result was in the range of 0.01 to 0.033 WL. This was accomplished by relying on quicker gamma exposure rate and soil measurements rather than on long-term Radon Progeny Integrating Sampling Unit (RPISU) measurements. Protocols for RPISU measurements and for the modified procedure that replaced the RPISU measurements are included in Appendix A. Figure 2 illustrates the final Edgemont Radiological Assessment protocol.

INITIATION OF THE RADIOLOGICAL SURVEY

PROMOTION OF THE SURVEY

In late August and early September, 1980, meetings were held in Rapid City, S.D. and Denver, Colorado, to provide to interested parties a description of the plans and schedules for the radiological surveys and to permit comments and evaluation. Personnel of NRC, the State of South Dakota, the City of Edgemont, HUD, and PNL attended the meetings. PNL equipped a mobile laboratory for the program during the same time interval.



* PERFORMED AT EACH PROPERTY SURVEYED
** NOT PERFORMED UNLESS ALL OTHER CLEARANCE CRITERIA ARE SATISFIED
*** ENGINEERING ASSESSMENT IS PERFORMED UNLESS ALL THREE CLEARANCE CRITERIA ARE SATISFIED

FIGURE 2. Final Flow Diagram of Radiological Assessment Protocol Used for Edgemont, South Dakota

In the first week of September, a town meeting was held at the Edgemont school to inform local residents of the plans and of the mechanism for requesting surveys. Since the requests for surveys that had previously been performed by the State had been submitted to personnel at the Edgemont City Hall, it was decided to continue the practice of having requests submitted there. The radiological reports, needed for HUD financing, would also be sent to the State of South Dakota in Pierre for filing. A copy would be sent to the Edgemont City Hall where residents could inquire and pick it up. PNL submitted monthly reports to NRC, tabulating the number of properties requesting surveys, number surveyed, and numbers of properties that fell into distinct survey categories.

After the initial attempt to call attention to the program at the town meeting, PNL promoted the program by using a prominent billboard style announcement painted on each side of the mobile laboratory stationed in Edgemont and by interviews and photographs in the local weekly newspaper. When the rate of requests slowed in November, an advertisement was placed in the November 12 edition of the newspaper to stimulate participation. Copies of one of the news reports and the advertisement are shown in Figures 3 and 4. The program announcement can be seen on the photograph of the PNL mobile laboratory.

THE FIRST MONTH

On September 16, PNL initiated the survey of Edgemont. During the first month, initial surveys were performed at 38 properties. These surveys were not totally completed because of the necessity for re-sampling air from habitable structures when radon progeny concentrations exceeded 0.033 WL during the first measurement. One property that was included in early surveys was the Edgemont school grounds, where EPA (Thrall, Hans, Jr., and Kallemeyn 1980) reported the possible presence of residual radioactive material. At one location on vacant land near the athletic fields, PNL detected a deposit of ^{226}Ra and later confirmed the presence of uranium mill tailings. PNL also discovered one additional tailings deposit at a location near the rear steps of the high-school gymnasium.

PROPERTY INVENTORY AND CLASSIFICATION PROBLEMS

In October, 1980, when it became apparent that initial estimates of the number of properties in Edgemont were far too low, PNL initiated an effort to determine the exact number by using tax and utility records and by counting houses. PNL determined that the total number of properties in Edgemont, Dudley and the Cottonwood District of Edgemont was 690 rather than the initial estimate of 500 received from the city. This estimate was continually revised as more detailed information on current ownerships became available. Initial estimates were not entirely accurate because parcels had been subdivided and structures built or demolished. Also, city records were incomplete and property owners occassionally failed to record transactions with the county. PNL had to carefully define a residence unit and vacant land parcels for the purpose of determining survey statistics. It was necessary to modify some of the initial property definitions because unexpected situations arose. For example, a multiple residence unit structure such as a quadruplex or duplex apartment could be considered a single structure with one owner on a single property. However, since each unit required an individual radiological

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Petitions circulating for public hearing

By Dan Jorgensen

Opponents to the ETSI coal slurry pipeline from both Hot Springs and Edgemont have begun circulating petitions calling for a public hearing to be held in Edgemont on the first draft of the pipeline Environmental Impact Statement (EIS).

One petition will be sent to Gov. William Janklow and Robert Neufeld, state secretary of Water and Natural Resources. Another will be sent to the Fall River County Commission.

That second petition requests that the commissioners seek injunctive relief in Federal District Court to obtain a court order to hold the public hearing.

As of now, the only public hearing on the proposed pipeline scheduled for South Dakota will be Dec. 17 in Rapid City. Opponents here say that is not enough, particularly since Southern Black Hills communities will be deeply affected by the line through loss of water from the Madison Formation.

ETSI's proposal calls for pumping between 20,000 to 30,000 acre feet of water from the Madison each year to mix with powdered coal at Gillette, Wyo., and then transport that coal through a pipeline to an unloading point in Louisiana. The water will be pumped from a well field straight west of Edgemont just across the border into Wyoming.

Between 40 and 50 wells are expected to be dug to a depth of some 3,000 feet to obtain the water.

Ground Water expert Dr. Perry Rahn of the South Dakota School of Mines and Technology says that if that happens, communities in the Black Hills, particularly the southern hills, and in the northwestern Nebraska counties will, in essence, dry up. The people of those Nebraska counties have been fighting the pipeline in the Nebraska Unicameral and using Rahn as their expert witness.

"[illegible] ETSI has a 'Plan B' to get [illegible] and go through Colorado or across Kansas with their pipeline," noted Chuck Colgan, who along with Edgemont's Matt Brown, is leading the anti-ETSI fight.

"Our own South Dakota officials tend to discount Rahn's opinion, but yet the state geologists, ETSI's geologists and even the geologists from the U.S. Geological Survey have differing opinions on the pipeline's effects on the Madison. Who's right? We're just afraid that by the time they try the pipeline and find out it's going to hurt our water supply, it will be too late.

"Our county will be sucked dry."

Both Colgan and Brown, along with members of the Sixth District Council of Local Governments, met with Neufeld in a closed meeting on the pipeline and at that time Colgan said that Neufeld said "Future alternatives (in regard to the pipeline) are a crapshoot; especially in Fall River County."

"Neufeld gave us copies of correspondence between his office and ETSI

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Paula Harrod hired as head librarian

The Edgemont Public Library Board announced the hiring of a new head Librarian.

Paula Harrod was named to the spot and will be filling the position that will be vacated by the retirement of Bill Kennedy. Kennedy's retirement will be effective October 1.

Paula is married to Dean Harrod and they have four girls. The Harrod's have lived in Edgemont for 4 years and Paula has worked at the Public Library for 3½ of those years. She also works part-time at the Edgemont School System as a baker.

Previous library experience included working in school libraries during her junior and senior high school years.

As head Librarian, Paula will be in charge of ordering new books each month for adults and children, managing the Inter-Library Loans, which is borrowing books from the state library if this library doesn't have the requested book and all other regular library duties.

Paula invites everyone to come in and look over the selection. The library is open Tuesday through Saturday from 1:30 to 5:00 p.m.

[illegible] assistant librarian has also been hired by the board. Wendy Anderson, daughter of Mr. and Mrs. Clarence Anderson of Edgemont, has been employed by the board through the CETA Program. She will work at the City Hall in the morning and at the [illegible]

Fifty year Masonic pin presented to Ted Barney

District Master Owen Johnson of District #22 A.F. & A.M., presented Ted R. Barney of Edgemont with a 50 year Mason pin for his longtime service in Masonry.

Barney joined the Gateway Lodge #130 A.F. & A.M. of Dallas, South Dakota on September 30, 1930. The Barneys lived south of Dallas for 30 years.

Five members of Edgemont's Mount View Lodge were present at the awarding at the September 18 meeting.

News Briefs

Driver's license schedule

The Driver's License Testing Schedule for October is as follows for Edgemont, Custer and Hot Springs. Custer is October 3, 10, 17, 24 and 31, to be held at the City Hall from 8-5 on those days. Edgemont is October 8 and 22, to be held at the City Hall from 9-5. Hot Springs is October 7, 14, 21, 27 and 28, at the City Hall from 8-5.

All are closed during the lunch hour.

Wood Burning seminar scheduled

On Wednesday, October 1, the Fall River County Extension Service will host a seminar on "Burning Wood to Reduce Winter Heating Costs".

Mr. Lloyd Marsden, manager of the Energy Shed in Rapid City will be here to conduct this seminar. The Energy Shed in Rapid City is one of several such establishments in a three state area whose purpose is to provide information concerning energy conservation and alternate energy products of interest to energy conscious consumers.

This seminar will be conducted in the meeting room of the Courthouse in Hot Springs, starting at 7:00 p.m.

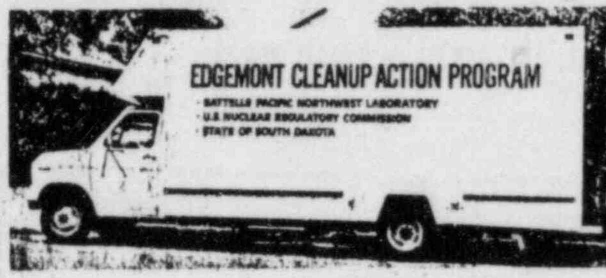
Elk Mountain campground to close

Elk Mountain Campground at Wind Cave National Park will close on Wednesday, September 24 it was announced this week by Superintendent Lester F. McClanahan.

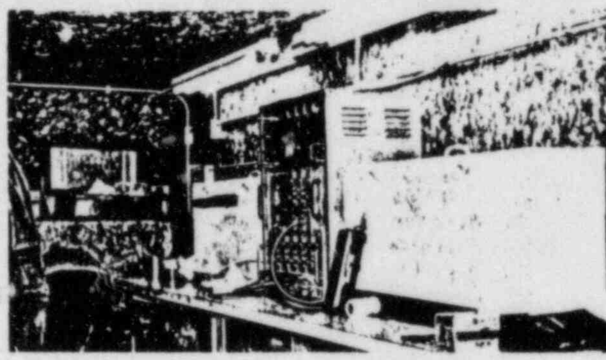
A revised schedule of guided cave tours will go into effect on October 1 when tours will be offered only at 10 a.m., 1 p.m. and 3 p.m. daily. Starting November 1 only the 1 p.m. and 3 p.m. tours will be conducted. Educational or group tours will be offered upon request. For information call Park headquarters at 745-4600.

The visitor center will be open from 8 a.m. to 5 p.m. daily.

Battelle starts testing



A large van, a crew of five and lots of sensitive equipment are making the rounds of Edgemont testing homes for radiation. Residents are urged to sign up their homes for the tests if they have not already done so. The testing will go on for the next three months.



Testing of houses for radiation has started once again in Edgemont. Battelle Pacific Northwest laboratories of Richland, Washington has started testing 150 homes that were signed up for the tests.

With a crew of five members, the tests will take about three months to complete. Testing was started on Friday, September 19, and as of Monday only four homes had been tested. They hope to test up to eight homes per day.

A spokesman for the testing crew sited the biggest problem being the houses aren't being closed up for the specified period of time. The homes scheduled for tests have to be closed up for eight hours before the tests can be taken. If they aren't the testing is postponed and rescheduled. The crew spot checks the area they will be testing the next day to make sure the scheduled homes have all windows and doors shut. They say an accurate test is to the home owners advantage, if tailing are found the Nuclear Regulatory Commission will pay for the clean up.

The Sampling Programs consists of four phases. (1) They measure the radon daughter concentration in the living room and in the basement, if it is finished. (2) Monitor every 25 square feet of floor area with a Micro R Meter, which measures the gamma dose. (3) Measure the outside property every 50 square feet with the Micro R Meter. (4) Take soil samples at the spot where the highest reading occurs and check it for radon level.

After the surveys are completed for the day the results are calculated and a report is filled out. They make a copy of the report and send it to the state to be filed there.

Houses that do not pass the tests go into assessment engineering. Core samples of the yard, pictures of the yard for re-landscaping and other tests will be done to locate the cause of radiation will be done.

Battelle's legal staff is presently in the process of letting contracts for the eight homes that were engineered by ARIX.

The total project should take from 3½ to 4 years. So far 139 homes were passed by the state. Battelle will test another 300 which leaves about 150 homes not signed up for tests. The city hall and Battelle are urging residents that aren't signed up to do so now. There is no cost for the test and this is Edgemont's chance to get out from under the radiation stigma.

Abdnor reports census tally

Preliminary figures show Fall River county listed 8,481 persons with the 1980 Census, according to Rep. James Abdnor, R.-S.Dd.

Included in the report were 4,008 housing units in the county.

Communities had the following population totals: Ardmore 18, Dryden 54, Edgemont 1,471, Hot Springs 4,731, Northeast Fall River 1,266, Oelrichs 128, and Southwest Fall River 419.

Totals reported for townships included: Antelope 56, Argentine 25, Cottonwood 51, Harmony 44, Provo 189, and Robins 39.

"These preliminary figures may be superseded by final counts as Census processing continues. Final figures are expected within the next few months," Abdnor said.

South Dakota's preliminary total is 687,643, up 3.5% from the 1970 Census figures.

A total net loss if not a disaster

In a broad attack on the anti-uranium mining initiative, the chairman of the group opposing the measure today warned its passage will mean "a total net loss if not a disaster" to the people of South Dakota.

Moreover, it will add "absolutely nothing" to existing environmental or health safeguards, according to Angus Anson, chairman of the statewide Citizens Against the Ban.

"Starting today, we will wage a concerted awareness campaign to unmask half-truths and dispel confusion about this ill-conceived initiative," Anson said. "This measure will be decided at the Nov. 4 elections."

Anson outlined what he said are the key issues in the battle over the controversial initiative.

If approved, he said it will mean:

-The loss of traditional property rights by telling citizens how they can or cannot use their property.

-A weakened economy at a time when South Dakota is already edging close to bankruptcy.

-The loss of Close-to-home decision making powers by taking local control out of local hands.

-The loss of untold millions to local schools in income from mineral rights on state lands.

-The loss of additional millions in uranium mineral severance taxes paid by development firms.

-The loss of jobs in closing down an important segment of industry in South Dakota.

The further weakening of our national effort to become independent of unstable Mideast oil exporters.

"These are the obvious consequences in store if this initiative passes," Anson said. "Very few voters are now aware of them.

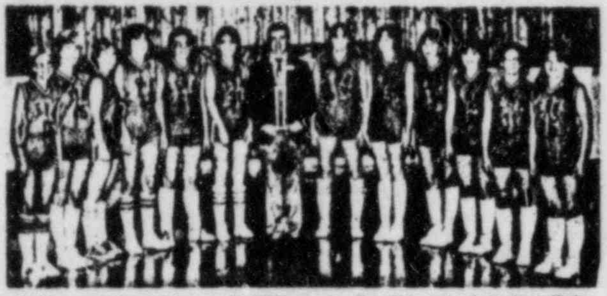
"Reports from every corner of the state confirm that right now there's a low level of information and a high level of confusion surrounding the initiative."

Continued on page 5

FIGURE 3. Edgemont Newspaper Announcement of Initiation of Radiological Assessment Program

WEDNESDAY, NOVEMBER 12 EDGEMONT HERALD-TRIBUNE PAGE 7

Mogul cagers bring Hill City trophy home



The Edgemont Girls Basketball team traveled to Hill City last week to play three tight games and bring home the trophy. They will be starting district play on Monday November 17 at Red Cloud where they take on OCHS.

Moguls end season with win over New Underwood

Winter schedule at Wind Cave announced

GOOD NEWS TODAY! CALL 662-7201 & WE WILL PUT IT IN THE LOCAL NEWS

THANK YOU

I want to Thank all my friends in Edgemont who voted for me in the General Election on November 4.

I deeply appreciate your support of my candidacy for re-election.

Marshall Truax
State Senator District 25
Paid for by Marshall Truax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- ATTENTION -

Property Owners and Residents of Edgemont and Dudley

The Edgemont Cleanup Action Program is a Federally financed effort to locate and remove residual radioactive material from properties in Edgemont and vicinity. If you have not requested a survey **NOW** is the time to sign-up. Inquire at City Hall 662-7422 day or at the Cleanup Program office 662-7693, evenings. This service is performed **WITHOUT COST** to the property owner.

FIGURE 4. Advertisement Placed in the Edgemont Newspaper to Encourage Participation in the Radiological Assessment Program (Lower Left Corner)

survey, it was more appropriate to classify each as a residence unit in determining the level of effort expended per time period. Two other examples are mobile homes and large residential properties such as ranches. Initially PNL surveyed all mobile homes as residential structures. However, after several months, a number of mobile homes were removed from their sites after receiving indoor radiological surveys. Subsequently, mobile homes were classified as temporary structures unless remodeling indicated that the structure was intended to be permanent. The property was surveyed as vacant land. Surveys of large ranches were time-consuming because the outdoor radiological survey grid for residences required many more measurements per unit area than vacant land. Therefore, land within 50 feet of the principal residence(s) was surveyed using the residence grid, while land beyond 50 feet was surveyed as vacant land. This kind of property was then tallied as both a residence unit and a vacant land parcel.

At the start of the program, PNL received the master list and tabulation of survey results of those properties where owners had requested surveys from personnel of the State of South Dakota. There were several problems with the list. Not all entries were from property owners requesting a survey; a portion of the list consisted of properties where the EPA mobile van surveys detected the possible presence of residual radioactive materials. In some cases, the property owners did not want surveys. There were multiple entries because some property owners had requested surveys more than once. Later, when PNL started to make surveys, some owners who had received surveys from the State requested them again. Another difficulty with the records resulted from remodeling, or sale of portions of properties. Sometimes the street address did not fit with the location of the front door of a residence. It was essential that the radiological surveys cover all of a requested property, but not infringe on neighboring properties where no request had been received.

In 1980, the City of Edgemont gave to PNL copies of a plat map of the city that had been prepared in 1962 and revised in 1979. PNL immediately attempted to reconcile that map with the ownership records available at the county recorder in Hot Springs, South Dakota. After the records had been checked, the boundary of each owner's property was indicated. The map and State master list were revised on several occasions. Nonetheless, occasional errors in records were discovered throughout the period of the survey. A reduction of the latest version of the map is shown in Figure 5. PNL kept a copy of all current county property records for Edgemont at it's Edgemont field office. An alphabetical cardex file was established by property owner, showing the address, state number, and PNL number. These maps and lists were essential for determining the status of the program and for contacting property owners.

PROPERTY OWNER PARTICIPATION

After completing the review list of property owners in Edgemont, PNL staff found that a substantial fraction of owners had still not requested radiological surveys. PNL staff asked the South Dakota Department of Health, Division of Environmental Health, to give assistance in contacting and encouraging participation of all those who had not participated as of December, 1980. The State prepared a form letter (Figure 6) and, in January, 1981, mailed a copy to each property owner on the list of non-participants. The response to the form letter was good. More than half of the known non-par-

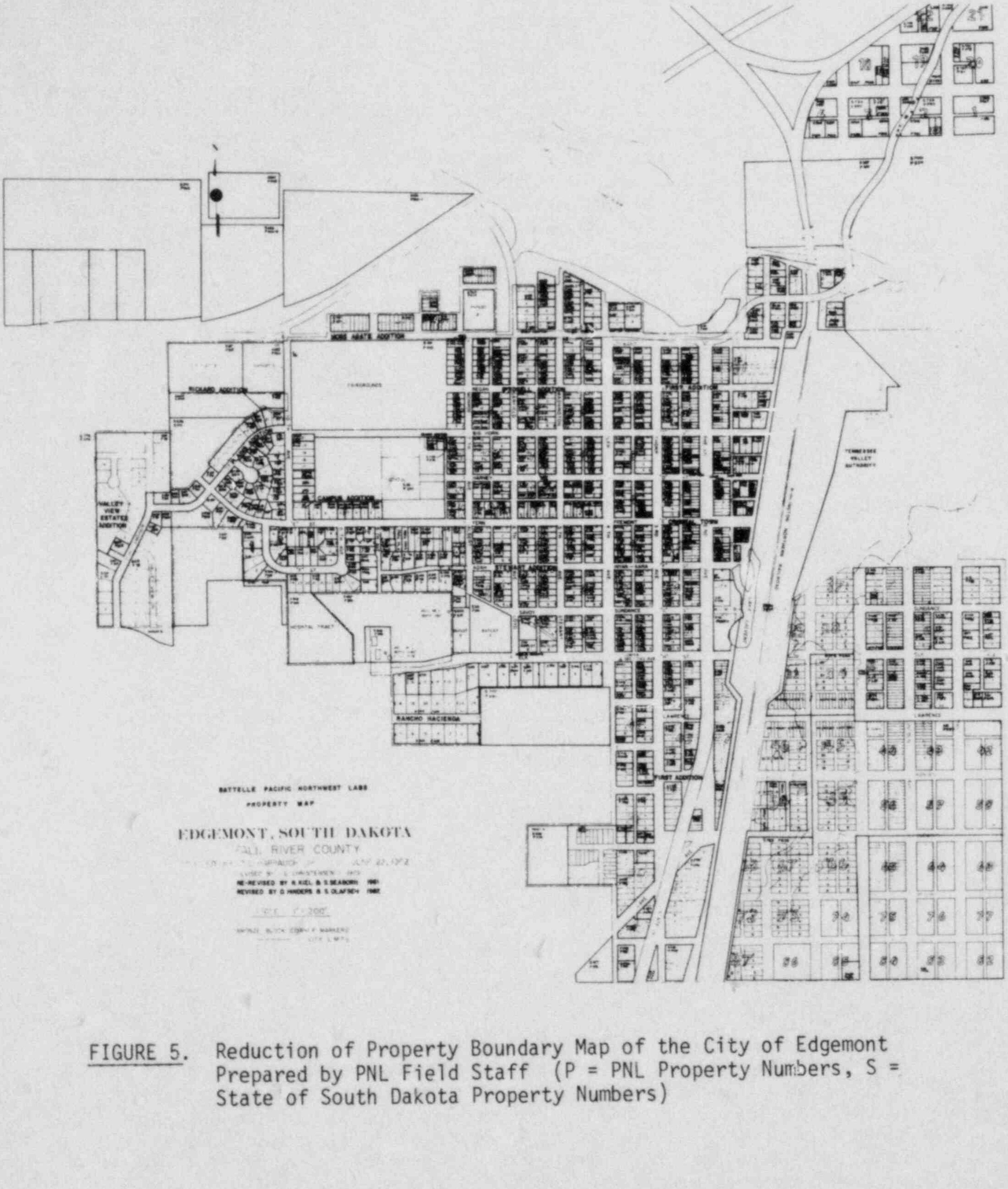

FIGURE 5. Reduction of Property Boundary Map of the City of Edgemont Prepared by PNL Field Staff (P = PNL Property Numbers, S = State of South Dakota Property Numbers)

SOUTH DAKOTA
Department of Health
DIVISION OF ENVIRONMENTAL HEALTH
Joe Foss Building
Pierre, South Dakota 57501
(605) 773-3329

Dear

The South Dakota State Health Department desires to inform you of a radiological evaluation that is presently being offered, at no cost to the property owner, through a joint effort of the United States Nuclear Regulatory Commission, Battelle Pacific Northwest Laboratories, and the State of South Dakota. This program has been in progress for several months and phase 1 is expected to terminate early in 1981. The purpose of the evaluation is to locate and identify anomalous radiation sources that are the result of residual radioactive materials.

At the present time, all federally guaranteed loans and many private lenders require the evaluations and a letter of certification from the State Health Department attesting to the results, prior to the issuance of a loan on property in Edgemont and vicinity. The radiological evaluation is being offered at no charge in order to assist you in meeting the federal lending requirements. In the event that uranium mill tailings are located, the federal government has the authority to finance the remedial action.

A considerable financial burden may be realized by those who do not request the evaluation and desire to sell their property at some future date after the remedial action program has ended. For example, you might have to make arrangements for a special evaluation and should the evaluation indicate anomalous radiation. the property owner could be required to finance the remedial action, prior to the issuance of a federally guaranteed loan.

Therefore, if you desire to apply for the evaluation please fill out the enclosed consent and indemnity form and return it to John Krueger at Edgemont City Hall or the Battelle office at P.O. Box 8, Edgemont, SD 57735. If you do not return the consent and indemnity form to the Battelle office or contact the Edgemont City Hall and fill out a request form within two weeks of the receipt of this letter, then it will be assumed that the evaluation is not desired.

Sincerely,

Joel C. Smith
Director

JCS:RFB:pjl

Enclosure

cc Greg Eadie
Pete Jackson
John Krueger
Pete Zeimet

FIGURE 6. Letter Sent by the State of South Dakota to Edgemont Property Owners that were not participating in the Radiological Assessment Program as of December, 1980

ticipants requested surveys. To encourage the remainder, the City of Edgemont drafted and sent a form letter to the remaining known non-participants, and in November, 1981, PNL staff also sent a letter by certified mail to the remaining non-participants. Enclosed with the letter was a form on which the owners were requested to sign and to indicate whether or not they desired a survey. Written refusals were documented. Finally, each remaining non-participating property owner was contacted in person or by telephone and asked to sign a refusal form if they did not want a survey. Those who would not sign any form were documented by the staff member making the contact. A number of property owners were out-of-town residents. Those who could be located were mailed the letter and form. Those who did not respond were telephoned. A few property owners could not be contacted or failed to respond. Those owners were documented as nonresponsive.

"Partial refusals" occurred when an owner or resident initially participated in the program but later declined to permit completion of all phases of measurements as required in the protocol. One example was encountered at some properties where radon progeny concentrations were below 0.033 WL (0.02 WWL) but above 0.01 WL. Those concentrations were below the original HUD criterion for withholding federally insured mortgages on the properties. However, according to the NRC/PNL protocol, a long-term RPISU sampling program was necessary to determine whether the concentrations actually exceeded the proposed EPA annual average standard of 0.015 WL (including background). Some owners may have felt that there was a risk of jeopardizing HUD financing for those properties if the RPISU measurements led to an annual average above the HUD limit. Thus, some owners participated in most of the survey, but refused long-term testing. Others refused or dropped out of the long-term sampling after a time because of annoyance with the disturbance created by the presence of the RPISU. Where possible, those properties were tested using an alternate sampling protocol that is discussed in Appendix A of this report. Where conclusive test results could not be derived from the data at the time of the termination of measurements, such properties were tabulated as refusal cases.

SURVEY PROTOCOL MODIFICATIONS

By November of 1980, it became apparent that some radon progeny measurements were being influenced by rapid indoor and outdoor air exchange rates or by plateout of radon daughters on interior surfaces. PNL developed a radon daughter turnover time screening test based on a model in Morken and Scott (1966). The test examined the ratios of the radon progeny in comparison with the ratios predicted for a well-mixed closed system having a constant radon input and given numbers of pure air exchanges per unit of time. The characteristic turnover times per complete air exchange were computed for the first 2-3 months of measurements using the procedure outlined in the protocols excerpted from Perkins et al. (1981). (See Appendix A.) Only 10% of the results showed turnover times less than once in 32 minutes (Figure 2 of Perkins et al., 1981). That value was chosen as an acceptable exchange time; thereafter, measurements with shorter times were repeated. Property owners were notified of the reason for making new measurements to insure their added care in preparing for them. When examining these data, PNL staff also noted that short turnover times and extremely low radon progeny concentrations (<0.01 WL) often occurred when samples were collected on windy days. Measurements taken with wind speeds of 8 mph or less did not exhibit this effect. Thus, the protocol was also modified so that sampling would not be done when wind speed was above 8 mph.

No indoor measurements were taken at properties when the measured outdoor radon progeny concentrations exceeded 0.015 WL. During 1980, the outdoor measurements were made at one location - the PNL Edgemont field office. That procedure was modified in February, 1981, because outdoor radon progeny concentrations can be time and location dependent. Thereafter, outdoor radon progeny measurements were made near the properties where indoor measurements were taken. PNL took the outdoor measurements immediately before or at the same time as the indoor measurements. Measurements taken when the outdoor concentrations exceeded 0.015 WL were not used for interpreting the status of a property; instead, new measurements were made.

Beginning in early 1981, PNL continued and expanded the long-term radon progeny sampling program begun by the State of South Dakota. In May, 1981 the RPISU sampling program was modified. Previously, the sampling of some residences for a total of 100 hours required several TLD filter-heads because filters plugged after less than 24 hours in some cases from cigarette smoke. Because only a limited supply of detector heads was available from the EPA at that time, it was decided to discontinue sampling at a residence if more than three sampling heads was required to achieve a total sample of 100 hours. Thus, the available heads were to be used primarily for residences of non-smokers until the supply of sampling heads could be increased. Later, those measurements that could not be completed were either completed in the same bimonthly sampling intervals in the following year, or else the revised abbreviated radiological assessment, discussed below, was used in place of long-term radon progeny measurements.

Later in 1981, it became apparent that the completion of long-term radon progeny analysis by RPISU measurements in Edgemont might require 2-3 years with the equipment that was available. The RPISU is a custom-made instrument, borrowed from the EPA laboratory in Las Vegas, Nevada. The EPA Las Vegas laboratory also supplied the detector heads and performed the calibrated readouts of exposed heads. The limited supply of sampling units, heads and head reading capability dictated the rate at which measurements could be completed. Over 300 structures at Edgemont needed long-term radon progeny measurements. According to the protocol, which was based on extensive EPA experience, each of these structures would require 100-hr RPISU measurements every other month for one year to determine whether they would require engineering assessment because of average annual working levels greater than 0.015 WL. In an attempt to reduce the excessive time required by the long-term radon progeny analyses, PNL, under NRC direction, developed an abbreviated engineering assessment protocol. (See Appendix A.) The RPISU measurements were to be bypassed using the abbreviated engineering assessment. This abbreviated engineering assessment protocol was the same protocol contained in the engineering assessment protocols (Appendix A) for buildings that had five-minute measurements exceeding 0.033 WL or annual averages exceeding 0.015 WL, but where none of the other remedial action criteria were exceeded during the initial screening survey.

There were two problems with the abbreviated engineering assessment protocol. The first problem was that most of the grab radon progeny measurements between 0.01 and 0.033 WL apparently were not associated with the presence of residual radioactive materials. Residual radioactive materials were discovered during abbreviated engineering assessments on only one of 50 properties that had grab radon progeny measurements between 0.010 and 0.033 WL. Secondly, the abbreviated engineering assessment did not make a direct measurement of the parameter specified by the proposed EPA standard, 40 CFR 192, namely the annual average radon progeny concentrations. Therefore the abbreviated engineering assessment protocol was discontinued. Later, the EPA issued the final version of 40 CFR 192 that states that the annual indoor radon progeny concentration may exceed the specified standard (0.02 WL in the final version) when it is due to sources other than residual radioactive materials as defined in UMTRCA. It also states: "Remedial actions are not required when there is reasonable assurance that residual radioactive materials are not the cause of an observed excess." Results of previous property surveys in Edgemont revealed that radon progeny measurements were a poor screening test for the presence of residual radioactive materials. However, gamma-ray exposure rate measurement and soil sampling survey techniques gave reasonable assurance of the presence or absence of contamination on a property. Therefore, in August, 1983, PNL, under NRC direction, developed a new protocol for detecting the possible presence of residual radioactive material at properties originally scheduled for long-term radon progeny measurements. In that protocol, properties where the radon progeny concentrations averaged less than or equal to 0.01 WL were presumed to be below the final EPA working level standard of 0.02 WL, and did not need additional measurements. Properties where previous radon progeny concentration measurements averaged more than 0.010 WL required additional evaluations of the existing exposure rate measurements and, in some cases, additional testing. This additional testing, consisting of gamma-ray and ^{226}Ra in soil measurements, satisfied the reasonable assurance stipulation in the final EPA standard. A copy of the alternate protocol is in Appendix A.

To clarify the status of existing radiological surveys that had been performed by the State of South Dakota at Edgemont prior to the NRC program, PNL hired as a consultant the former State radiation protection officer who had performed those surveys. He reviewed the completed State surveys and summarized the results. The results revealed several incomplete surveys and a lack of engineering assessments. There were no detailed maps showing the locations of high gamma exposure rates and no consistent program of soil analysis. PNL staff proposed an arbitrary criterion: If the highest corrected outdoor gamma exposure rate exceeded 16.5 μR/hr at a property, PNL would repeat the outdoor survey and then prepare a site map and perform soil analyses necessary for any followup engineering assessment. That level was chosen because of the high frequency of State measurements that fell between 14.5 μR/hr and 16.5 μR/hr. It appeared that there was a bias in the State calibrations; PNL's own measurements indicated that only for a very small number of those cases where ^{226}Ra in soil exceeded 5 pCi/g in a significantly large area did the dose rate fall below 17 μR/hr. In July 1981, NRC staff approved the criterion and the resurveys.

In July of 1982, PNL initiated outdoor radiological surveys at properties adjacent to the uranium mill at Edgemont. Those surveys had been deferred because of the difficulty of making gamma exposure measurements in the field of gamma rays from the nearby mill tailings areas. PNL developed a modified survey protocol for determining the presence or absence of residual radioactive material on such properties. The survey protocol utilized a lead "shadow" shield on the gamma exposure-rate meter. By holding the shadow shield in the proper orientation, the influence of nearby radiation sources could be reduced and gamma-rays from beneath the detector were emphasized. At properties within one city block of the mill the gamma field intensity was still too high to determine the location of residual radioactive material. For those properties, 12 soil cores were taken from the top 15 cm in a grid array on the property. If any of those cores contained more than 5 pCi ^{226}Ra/g of soil, a core was taken from the 15-30 cm depth at that location. If that core contained more than 5 pCi ^{226}Ra/g of soil, the property would receive an engineering assessment survey.

In August of 1982, PNL staff requested a minor modification to the original protocol for outdoor surveys of vacant land. The original protocol required that a grid of exposure rate measurements be made at 5 grid points on the longer side of a property and four grid points on the shorter side. Because some properties were extremely long and narrow, or irregularly shaped, NRC approved a change to allow more flexibility in the survey protocol. The modified protocol called for a total of at least 20 measurements to be made in a pattern that spaced the grid points as uniformly as possible in the case of properties whose length to width ratios exceeded 2 to 1.

PROPERTY REPORTS

ENGINEERING ASSESSMENT

PNL was required to submit formal engineering assessment reports to NRC for those properties found to be contaminated with residual radioactive material from the uranium milling industry. In July of 1981, a draft "Protocol for Engineering Assessments of Properties at Edgemont, S.D." was submitted to NRC. During that month, the equipment necessary for performing engineering assessments was assembled at the PNL Laboratory in Richland, WA. The primary tool for the engineering assessment was a borehole logging detector. To determine the depth and extent of underground deposits of residual radioactive material, the draft protocol specified that boreholes would be augered and a gamma-ray detection probe lowered into the hole and positioned at intervals to measure the gamma rays from ^{214}Bi, a short-lived daughter of ^{226}Ra. A measurement probe was constructed, a temporary calibration facility for the probe was built and the probe was calibrated. During the week of July 27, 1981, PNL initiated the Engineering Assessment measurements. Revisions to the draft protocol made by NRC staff were implemented in the field work and, later, the final protocol for engineering assessments was submitted to NRC. A copy of that protocol is included in Appendix A.

Late in 1981, a subcontract was let to ARIX, Inc., to provide architect-engineering services in the preparation of engineering assessment reports. ARIX was to prepare the engineering assessment reports using the results of PNL's radiological assessment data. A total of 11 such reports were prepared and submitted to NRC for evaluation. After reviewing the reports, NRC staff indicated that they were more detailed in scope than NRC had intended and that the architect engineering portion of engineering assessments should be prepared by the agency performing remedial action. When DOE was given the responsibility in January of 1983 to clean-up public properties in Edgemont under Title I of UMTRCA, NRC directed PNL to develop a report format for the purpose of transferring information to DOE. DOE is currently in the process of making remedial action decisions based on all radiological data available on Edgemont, including State survey reports, NRC engineering and radiological assessments, and other unpublished PNL survey data.

RADIOLOGICAL ASSESSMENTS

In February of 1983, a draft of the PNL "Radiological Assessment" report form was sent to the NRC. Those reports were to be prepared by PNL only for properties where deposits of residual radioactive materials had been located in the engineering assessment surveys. The draft contained a tabulation of the radon progeny measurements, maps showing the gamma exposure-rate measurements, soil analysis results, and borehole logging results. The report also contained a "significance of findings" section which compared survey results to the final EPA standards published in January, 1983. Since the start of the program, all measurements had been designed to detect contamination in excess of the proposed EPA standards for vicinity properties (40 CFR 192). Because DOE's remedial cleanup was to be based on the final standards, NRC requested that PNL staff base the significance of findings section on the final standards rather than the proposed standards. This change required a considerable effort and delayed the submission of the first reports. Reports were submitted in groups throughout 1983, with the last group of reports submitted in November of that year.

RESULTS SUMMARY

The combined results from the State and NRC/PNL Edgemont radiological surveys are presented in Summary Tables One through Five. Summary Table One summarizes the property inventory. Out of 976 total properties, 941 were surveyed. 97% of the residential properties received a survey. Summary Table Two is a tabulation of the screening survey results. Thirty-five percent of all properties (39% of residential properties) failed one or more screening test. Summary Table Three is a tabulation of engineering assessment results. A total of 311 properties (those that failed the screening survey) required an engineering survey; however, only 278 engineering surveys were performed because contamination contiguous on two properties were covered by a single assessment and because some owners refused the assessment. Of the 278 engineering assessments, 166 detected residual radioactive materials on a total of 199 properties. This represents 21% of the properties surveyed and 20% of the total properties in Edgemont and vicinity.

Although one out of five properties in Edgemont were found to be contaminated, the magnitude of contamination throughout the town is not great. Most deposits of tailings were small and did not exceed the EPA standard for a significant size deposit - 100 square meters. Summary Table Four lists the deposits and their sizes. In addition, 39 of the 199 contaminated properties contained only windblown contamination. (There are five properties with both windblown and deposited contamination.) Most of the nineteen properties with both structural involvement of residual radioactive materials did not present a significant health hazard because of the relatively small involvement. Summary Table Five lists the nineteen properties and explains the structural involvement.

A master list of all the properties in Edgemont and vicinity surveyed by the State and NRC/PNL is included in this report as Appendix B. For each property, the results of the screening survey and the engineering survey, if required, are given and appropriate comments are annotated.

SUMMARY TABLE 1. Property Inventory

Property Type	Surveyed	Survey Refused	No Response	Row Totals
Residential	612(1)	17	2	631(1)
Commercial	57	2	1	60
Industrial	3	-	-	3
Government	4	-	-	4
School	6	-	-	6
Church	6	-	-	6
Vacant Land	248	9	4	261
Other(2)	5	-	-	5
Column Totals	941(1)	28	7	976(1) Grand Total

Notes:

(1) These totals include one residential property surveyed at the request of a new owner.
(2) Lodges, meeting halls, etc.

SUMMARY TABLE 2. Screening Results

Property Type	Radiological Screening Results - Numbers of Properties in Each Classification						
	C	RG	RR	IG	OG	S	RGS
Residential	382	88	24	7	78	111	4
Commercial	34	2	3	2	9	15	-
Industrial	2	-	-	-	-	1	-
Government	2	-	-	-	-	2	-
School	-	2	-	1	1	1	-
Church	4	-	1	-	-	2	-
Vacant Land	203	-	-	-	32	45	-
Other	3	-	2	-	-	1	-
Total	630	92	30	10	120	178	4

Legend:

Classification Code	Meaning
C	1. All criteria satisfied
	2. Six failure pathways
RG	a) Failed average radon progeny grab (greater than 0.033 WL)
RR	b) Failed RPISU (greater than 0.015 WL)
IG	c) Failed indoor gamma (greater than 20 μR/hr + BKGD)
OG	d) Failed outdoor gamma (greater than 20 μR/hr + BKGD)
S	e) Failed Ra-226 in soil (greater than 5 pCi/gm)
RGS	f) Failed radon/gamma/soil (0.01 WL-0.033 WL, greater than 4μR/hr + BKGD, greater than 5 pCi/gm)

SUMMARY TABLE 3. Engineering Assessments

Property Type	Engineering Assessment Results - Numbers of Properties				
	N	HS	OD	SI	W
Residential	95	-	80	19	23
Commercial	6	1	13	-	1
Industrial	-	-	1	-	-
Government	1	-	1	-	-
School	-	1	-	-	-
Church	1	-	1	-	-
Vacant Land	8	-	19	-	20
Other	1	-	1	-	-
Column Totals	112	2	116	19	44

Legend:

Classification Code	Meaning
N	1. No residual radioactive materials (RRM) discovered
	2. Four categories of contamina-tion
HS	a) "Hot spots" or easily removed contamination
OD	b) Outdoor deposits (broken down in separate Table 4)
SI	c) Structuralinvolvement (broken down in separate Table 5)
W	d) Windblown

SUMMARY TABLE 4. Outdoor Deposits

Property Type	Volume (cubic yards) <1	1-5	5-10	10-20	20-50	50-100	>100	Totals	
R	11	24	8	10	14	7	10	84	
CO	0	4	2	2	1	1	0	10	
I	0	0	0	0	1	0	0	1	
G	0	1	0	0	0	0	0	1	
S	0	0	0	0	0	0	0	0	
CH	1	0	1	0	0	0	0	2	
V	1	7	1	2	6	0	2	19	
O	1	0	0	0	0	0	0	1	
Column Totals	14	36	12	14	22	8	12	118	Grand Total

Legend:

Classification Code	Meaning
R	Residential (i.e.- any property with an occupiable building)
CO	Commercial
I	Industrial
G	Government
S	School
CH	Church
V	Vacant Land
O	Other (e.g.,-lodges, meeting halls)

SUMMARY TABLE 5. Properties Having Structural Involvement With Residual Radioactive Material

Property Identifiers(1)				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	29	--	239	RG, IG, OG S	May, 1983	OD* SI**	*Owner refused borehole through front porch **Either the concrete slab in the porch or the material used for fill under the slab contains radioactive material
R	57	--	431	RG, IG, OG, S,SI*	May, 1983	OD	*Uranium-bearing material not native to this property was found adjacent to the garage and uranium mill tailings were beneath the rear porch
R	82A	--	411	RG, OG, S	March 1983	OD SI*	*Uranium bearing material on roof of root cellar
R	98	--	354	RGS	May, 1984	SI*	*Tailings material used in stucco on structure addition
R	150 office	72-40524	1	IG	July, 1983	SI*	*Tailings material identified beneath floor of office living room during ARIX Engineering Assessment
R	179	--	485	OG, S	March, 1983	SI* OD**	*It appears that a stone containing a uranium mineral was used in the concrete to construct a small masonry planter wall **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	250	--	358	OG	June, 1983	SI*	*Contaminated sewer vent pipe
R	261	--	86	OG, S	March, 1983	OD SI*	*Garage built on uranium mill tailings

SUMMARY TABLE 5 (continued)

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	319*	--	581E	OG	April, 1983	SI**	*See PNL 328 also **Radioactive rocks in concrete foundation and sidewalk
R	366	--	467	RGS	May, 1984	SI*	*Radioactive material under disintegrating concrete basement floor in vicinity of sewer line
R	403	--	251	OG, S	Nov, 1983	SI* OD	*Radioactive material beneath three-quarters of the garage concrete floor
R	453A	--	571	OG, S	May, 1983	OD* SI**	*A rock wall also contained contaminated stones **Uranium bearing materials were used in a concrete patio slab
R	627	72-40557	773	OG, S*	June, 1980*	OD SI**	*Engineering Assessment performed by ARIX **Tailings mixed in basement wall plaster
R	649	--	61	IG, OG, S*	Nov, 1983	SI** OD W	*State and PNL residence, PNL outdoor surveys **Soil under the residence floor was contaminated
R	703	7811-74 72-40538	3	RG, OG, S*	June, 1980*	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were identified under and around east enclosed porch
R	705	72-40556	6	RG, IG, OG, S*	July, 1980*	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were found under the basement floor slab and beneath the crawl space

SUMMARY TABLE 5 (continued)

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	709	7811-71	13	OG, S*	July, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were mixed into basement wall plaster
R	735	--	175	RG, OG, S*	July, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings identified beneath north wooden porch and decks
R	1021	7811-67	15	OG, S*	June, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Radioactive material beneath southeast stoop

Notes:

(1) Codes are explained in Explanation of the Master Table, Appendix B

CONCLUSIONS

THE SURVEY PROGRAM

The radiological assessment program for Edgemont provided the regulatory and scientific community with the most detailed and complete radiological survey ever performed in an entire community. A rigorous protocol, detailed records, and legalistic decision levels based on regulatory levels were applied. The program was costly, but not much more costly on a per property basis than the radiological surveys performed in a less rigorous manner by other laboratories at other sites. A large part of the cost was determined by the kinds of measurements, records, and decision levels used for Edgemont. The approaches that were used were dictated, in part, by the kinds of regulations proposed by the EPA at the time that the program started. There were very few precedents to follow at that time, and it was desired to provide a survey that would ultimately be useful for determining the status of properties in relation to the final standards that would be set by the EPA.

The protocols used in Edgemont provided a more complete data base than would be necessary in the future for UMTRA sites. Some of the measurements could be eliminated or modified in future surveys if the only purpose were the discovery of residual radioactive materials. PNL, under contract to NRC, published a companion report to the Edgemont Survey program entitled, "Radiological Surveys of Properties Contaminated by Residual Radioactive Materials from Uranium Processing Sites." This companion report recommends various survey strategies and techniques based on the experiences and studies at Edgemont.

The survey program has provided all of the necessary information for DOE's remedial action planning. Very little rechecking of the surveys was required. On this basis, the program was successful.

SURVEY PROCEDURES AND TECHNIQUES

Radon Progeny Measurements

The protocol used in Edgemont for the measurement of radon progeny proved to be useful for making statistically valid judgements based on grab sampling in place of long-term measurements. Using a subdivision of properties into classes based on the radon progeny working levels in the residence units permitted rapid decisions to be made about their status, relative to EPA and HUD standards.

The restrictions on the conditions during sampling that PNL applied (air turnover time and windspeed) apparently succeeded in making grab samples much more meaningful relative to long-term averages than the grab sampling measurements taken in other programs. The correlation between single grab sample results and the annual averages was even better than that between single RPISU results and annual averages.

However, the restrictions had a significant effect on the cost of these measurements. A fairly high percentage had to be repeated because they failed to meet one of the restrictions at the time of sampling. The wind speed restriction greatly reduced the freedom of planning and scheduling activities. Thus, the usefulness of measurements in a major sampling program was limited by the necessity of using such restrictions to produce meaningful data.

The use of a year-long radon progeny measurement program for those properties with inconclusive grab sampling results was probably not justified by the additional information obtained. The measurement process is time-consuming, thus delaying any needed remediation, and it is relatively expensive. PNL cost estimates led to the conclusion that the long-term measurements could be by-passed, since all properties with radon progeny concentrations in excess of 0.01 working levels could have received engineering assess ments for about the same cost. Moreover, the only results derived from the long-term measurements were better estimates of the need for an engineering assessment. It was that assessment that provided the basis for remedial actions in Edgemont.

It had been reported that excessive working levels in Grand Junction, Colorado, were often associated with the presence of deposits of residual radioactive materials in or around the structures. In Edgemont, no such correlation was found, making all working-level measurements of little, if any, use for evaluating the presence or absence of residual radioactive material. Since very few, if any, of the highest working level measurements could be associated with deposits of residual radioactive materials, these measurements only provided information about the natural background in Edgemont that might be useful for other purposes than the program intended. Based on PNL's experiences, radon progeny concentration measurements are unnecessary and the cost of performing them would be better spent on making gamma-ray measurements, borehole logging, and soil analyses.

Indoor Gamma-ray Exposure Rate Measurements

Measurements of indoor gamma-ray exposure rates using the Edgemont protocol provided documents that can be extremely valuable as legal records of the status of a property at a given time, and for establishing proof that a survey had been made. They also provide some information that can be used to determine whether the protocols have been properly followed. The protocol had one major flaw. Residual radioactive material could be present that did not necessitate an engineering assessment, because of the use of a decision level based on the EPA exposure-rate standards for residences. Because there could be a considerable distance between deposits and the accessible locations for exposure rate measurements, it is possible that a deposit that exceeds EPA's standards for ^{226}Ra in soil will not exceed their standard for gamma exposure rate. The protocol called for a detailed search at the surface for more elevated exposure rates when any indoor grid measurement exceeded 14.5 $\mu R/hr$. However, unless a measurement exceeding 20 $\mu R/hr$ above the ambient background was discovered, an engineering assessment was not required. In practice in Edgemont, field personnel attempted to investigate the source of unusually high exposure rates even though complete engineering assessments were not required.

The appropriate level for requiring engineering assessments should be any exposure rate significantly above the ambient background that cannot be explained by a visible source, such as natural quarry tile or certain porcelain tiles. Inside a structure, this could be as little as 3 μR/hr above the ambient background, based on Edgemont experience.

The additional cost of the resulting additional engineering assessments could be balanced, in part, by not drawing interior survey maps unless evidence of a deposit was observed. The readings for each room could be tabulated to document them by location.

In making both indoor and outdoor gamma exposure rate measurements, much effort was made to use an instrument that could be cross-calibrated with a pressurized ionization chamber. This was necessitated by the legalistic levels chosen in the protocol. However, for screening surveys, the detection of the possible presence of residual radioactive material is at least as important as establishing the indoor exposure rates. For this purpose, an uncalibrated instrument with more sensitivity would give a higher count-rate per unit of exposure rate, and that would improve the counting statistics, making it possible to use a threshold closer to the average background for a decision criterion. Automatic instruments are available with a count-rate dependent threshold for the audible response. These instruments are superior to a metered instrument for detecting small quantities of radioactivity because they can be set to be silent until the exposure rate exceeds the desired criterion level, at which time the alarm sounds, immediately causing the surveyor to search for the cause. With this kind of instrument, no records of exposure rates would be maintained. If a record of exposure rates was necessary to compare with EPA standards, a single calibrated measurement could be taken in each room and recorded.

Outdoor Gamma Exposure Rate Measurements at Residences

The protocol for the measurement of outdoor gamma exposure rates near structures also provided good legal documentation of the property and survey. In this case, however, the decision criterion was arbitrarily set to match that for the indoor measurements, since there was no EPA standard for outdoor measurement. The level of 20 μR/hour above background was also too high to achieve the original goal of detecting any deposit with a total radium concentration of 5 pCi/g, as was shown by a correlative study of the relationship between exposure rates and ^{226}Ra concentrations in nearby soil. However, in most outdoor cases, it was possible to have a favorable geometric relationship between the detector and the deposits of residual radioactive materials, making the decision level more nearly correct than the indoor decision level. In addition, the collection of soil samples at the location of maximum gamma exposure rate gave a backup mechanism for establishing the need for an engineering assessment. The proper decision level for deciding to do an engineering assessment outdoors should have been about 7-10 μR/hr above background to achieve the maximum stand-alone detection efficiency while avoiding false positives.

PNL staff associated with the surveys found that the existing protocol for outdoors was adequate. However, in no case did we feel that a significant deposit had gone undetected. The criterion that calls for a detailed exploratory survey in contact with the surface at any place where the exposure rate exceeded 14.5 μR/hr was the key to the success of the survey. A grid survey taken with the probe elevated above the surface has good sensitivity to deposits fairly close to the grid point, and the contact measurements has a higher response when right above the source. The grid spacing was about right, but the detection efficiency could have been improved a bit by making the grid spacing five instead of seven feet, or by using more sensitive instruments with larger detectors. This could have resulted in the detection of a few more insignificant deposits, but would not have significantly increased the probability for detecting deposits in excess of the EPA's final standard that requires the average ^{226}Ra concentration shall not exceed 5 pCi/g above background in the top 15 cm over any 100 m^2 area. The probability of detecting deposits of this size was already essentially 100% for the protocol used.

Outdoor Surveys of Vacant Land

The protocols for vacant land surveys on parcels of various sizes were a compromise intended to give a reasonable probability of detecting significant deposits of residual radioactive material at a tolerable cost. The grid map record again had the legal applications already described. However, the use of a very limited grid on a large vacant area was not very useful for detecting residual radioactivity. It was the random walk survey, performed with the detector at waist level while traveling between grid indices, that gave the highest probability of detecting deposits of residual radioactive material. Small survey instruments would have very little probability of detecting a deposit near the specified limit of the final EPA standard from a distance of more than 20 feet. Thus, the grid served primarily as a frame of reference in such surveys since the spacing often exceeded 20 feet. Investigation of the detection capability of the DOE mobile scanning van indicates that it has difficulty detecting such sources from distances greater than 30 to 50 feet, even though the detection system in the van has a NaI(Tl) crystal that has a volume that is approximately 1000 times that of a hand-held instrument. If surveys of outdoor vacant areas are needed, the available information indicates that a walk-through survey with the spacing similar to that used on residential properties in Edgemont should be specified. The use of the random walk between grid points was equivalent to that kind of a survey. For very large areas, however, it is difficult to be systematic in a random walk survey. A modification that should be added in the future is some kind of position determining system such as flags or strings that can be spaced at the necessary close intervals and followed. To make the spacing of the survey measurements or the spacing between walked lines larger, a back-pack detector could be developed that uses a larger (i.e., 3 inch X 3 inch) sodium iodide detector for greater sensitivity. Held at the top of such a pack, the detector could permit a rapid walk-through survey of large areas with more sensitivity than either a hand-held probe or a scanner van on the perimeter of a property.

Analysis of Radium-226 in Soil

The use of a large volume, NaI(Tl) gamma detector for the measurement of ^{226}Ra in soil was an extremely satisfactory technique for field surveying. The sensitivity was adequate for the measurement of ^{226}Ra concentrations well below the EPA standards in very short times. It was possible to measure the radium content of 5-10 samples per hour. Soil sampling gave a backup measurement that often detected small radium deposits that did not produce gamma dose rates exceeding the exposure rate criterion. Because of the ease of collecting such samples, more could have been taken. This was done in the Cottonwood areas where gamma exposure rate measurements were not meaningful because of shine from mill tailings piles. The soil samples should have been cores, however. A practicable core sampling protocol could have determined the concentrations in the 0-15 cm, 15-30 cm, and 30-45 cm depth layers at each sampling site. These cores would give information about the depth profile of deposits that could have eliminated many borehole logging measurements.

The collection of soil samples only at selected properties where gamma exposure rates indicate the possible presence of residual radioactive materials should be considered. The core samples would be collected at sufficient points to define the contaminated areas in conjunction with exposure rate measurements. In many cases the depth profile would also be defined.

Some laboratories have interpreted the EPA standards to be based on the dry weight of soil. PNL has used the as-sampled weight, since dried weight was not specified in the standards and because of the time requirements for drying. Although the as-sampled weight is subject to variability with time, these measurements give a reasonably good concentration result that appears to fulfill the needs of the survey.

Identification of Uranium Mill Tailings by High Resolution Gamma Spectroscopy

This protocol specified that the samples that contained measured ^{226}Ra concentrations in excess of 5 pCi/g should be analyzed to determine the degree of equilibrium between uranium and its long-lived daughter products. The uranium milling process reduces the concentration of uranium relative to its daughters. Thus, it is possible to identify whether uranium mill tailings are the cause of excess radium concentrations. This analysis process was very effective in establishing the presence of mill tailings in soil samples. The only problem encountered in the Edgemont program was caused by the lack of a high resolution gamma counting system that could be taken to the field and dedicated exclusively to the program. Thus, the radium concentration in samples had to be measured once in the field for screening purposes. The samples then had to be shipped to the PNL Richland laboratory for the second analysis. This sometimes caused delays because of scheduling the equipment usage.

One question that must be asked is whether it is necessary to know whether elevated ^{226}Ra concentrations are due to tailings. If the ^{226}Ra is due to ore from the mining and milling operation, it is still classified as residual radioactivity, and thus requires remedial action. Only if it is due to natural, undisturbed material is it exempt from remedial action. It might, therefore, be useful to emphasize the measurement of a larger number of background samples to determine whether natural materials containing ^{226}Ra concentrations in excess of the EPA ^{226}Ra standard are likely to be present on a given property. If such material were not likely to be present, then it would not be necessary to determine whether elevated ^{226}Ra concentrations on the property were due to tailings. Any soil containing more than the background levels would be assumed to be contamined with residual radioactive material. Thus, high-resolution gamma-ray measurements would not have to be taken at all. Changing the protocol in this manner would not have significantly changed the number of remedial actions in Edgemont, but would have decreased considerably the effort needed for soil analyses.

Engineering Assessments

The engineering assessment protocol was adequate to establish the extent and depth of significant deposits of residual radioactive materials. Borehole logging is an effective measuring tool. However, its results are only approximate because the complexity of deposit geometries make precise calibrations for each geometry impractical. PNL's approach provided a relatively precise measurement with minimal effort. It is questionable whether making an additional effort to control other variables, such as soil moisture content and loss of radon from the soil would significantly improve the overall accuracy of a large number of measurements because the remaining uncontrollable geometry variables appear to be the dominant source of error in field sampling. Of course, that effort would improve the accuracy of calibration measurements in the carefully mixed and positioned sources used for evaluations. But it is much less certain that the added cost of such protocols would actually be justified by a significant improvement in the knowledge of the concentration and location of a deposit of residual radioactive material.

Borehole measurements cost more per site than soil core measurements if the deposit is confined to the top 30 cm of the soil. Thus, an improved cost effectiveness was achieved in Edgemont by reducing the numbers of boreholes and increasing shallow soil core analyses at some sites. This process was started in the later engineering assessments and radiological assessments. It could have been used for all properties, especially after one borehole indicated that the deposit was shallow.

The use of a lead collimated gamma-ray exposure ratemeter greatly improved the precision with which surface dose rate measurements could determine the perimeter of a deposit. Here, a definite grid of close (2.5 feet) spacing was used, because it was very important to keep records of the deposit location. This was time consuming, but necessary, especially since the final EPA standards for remediation were based on the area weighted concentration of radium in the soil.

Detecting Residual Radioactivity Around Structures as a Substitute for Long-term Radon progeny Measurements

Since the long-term radon progeny measurements specified in the original protocols for Edgemont required too much time to determine possible need for remediation, a substitute screening survey with lower gamma dose-rate decision levels and subsequent soil and borehole analyses was used at about 30 properties. Through this procedure, four additional properties were discovered to have deposits of residual radioactive material. The technique was practical and fast. The previous failure to discover these deposits was caused by the higher decision levels used in the indoor and outdoor gamma-ray survey protocols. In addition, the technique would stand alone, eliminating the need for any radon progeny measurements in the structures. If the original decision levels used for the gamma radiation surveys had matched this protocol, these four properties requiring engineering assessment would have been detected during the original radiological survey at very little extra cost. Thus, it appears that decision levels for those outdoor measurements within one meter of a structure should be lowered as close to the background exposure rate as possible, as in the case of indoor measurements. Then there would be no need for decision levels based on working level measurements.

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APPENDIX A

PROTOCOLS

INDEX PAGE

APPENDIX A

United States Nuclear Regulatory Commission
and
The State of South Dakota
Edgemont Cleanup Action Program

Criteria No. 1

Any weighted indoor Working Level[(a)] (WWL) determined to be above 0.02WWL (including background) in existing residence shall be classified as exceeding that level determined to be acceptable by the Department of Housing and Urban Development (HUD).

Criteria No. 2

If a weighted indoor working level measurement exceeds 0.02WWL, but is less than 0.05WWL, a confirmatory grab-WL sample or other special procedure such as a gamma radiation survey or soil sample analysis shall be made to verify the anomaly.

Criteria No. 3

Average size individual residential lots for which construction of residential dwellings has not yet begun may be screened by performing a gamma radiation grid survey[(b)] or soil sample analysis. Any gamma radiation grid survey's arithmetic average determined to be greater than 14.5 μR/hr shall be considered unacceptable by HUD.

Criteria No. 4

Large size individual residential lots or multiple lot development areas where construction of residential dwellings has not yet begun may be screened by performing a gamma radiation grid survey[(c)] or soil sample analysis. Any gamma grid survey's arithmetic average determined to be greater than 14.5 μR/hr shall be considered unacceptable by HUD.

Criteria No. 5

Unique circumstances not identified in the above Criteria shall be handled on a case-by-case basis with consultation of HUD/8 and EPA/8.

(a) Grab-Working Level samples shall be performed using the procedure outlined in Procedure I -- Grab-WL Sampling.

(b) The gamma radiation grid surveys shall be performed using the procedure outlined in Procedure II -- Gamma Radiation Survey-Small Lots.

(c) The gamma radiation grid survey shall be performed using the procedure outlined in Procedure III -- Gamma Radiation Survey-Large Lots.

Procedure I -- Grab WL Sampling

In determining acceptability of a residence for federally-supported financing in Edgemont, South Dakota, the South Dakota State Health Department (SDHD) will assure that indoor radon daughter measurements are made in the following manner:

1. For each measurement, an air sample having a minimum volume of 20 liters will be drawn through a Millipore Type AA filter having a pore size of 0.80 microns, Either the modified Kusnetz or Tsivoglou (Thomas) methods may be used for counting alpha activity with a scintillation counter. The radon decay product concentration in working levels (WL) will be calculated and recorded.

2. A house closed reading (HCR) shall be made on the ground floor after the residence has been sealed for an optimum period of eight hours, but a minimum period of three hours. Sealed means that all windows, doors and outside vents are closed. Wintertime conditions between November 15 and April 1 will be considered a substitute for the house sealed requirement.

3. If the house has a finished and routinely used basement sleeping quarter, an additional HCR shall be made in the basement. The two calculated HCR's will then be averaged and recorded.

4. The weighted working level (WWL) shall be used to approximate the annual concentration. In the Edgemont area, approximately seven months (60% of the year) are chosen as precluding the use of outside ventilation due to inclement weather. Accordingly, the WWL is derived as follows: WL (0.6) = WWL.

5. Special circumstances, such as air conditioning, hot water heating, space heating, wood burning stoves or life style, may be documented but will not be evaluated.

6. An alternate method of determining acceptability of a residence is the use of data acquired by measurement of an integrated indoor radon decay product sample, Individual data will be derived from a minimum sampling time of 100 hours since shorter integrating time periods are frequently the result of plugged filters for which the airflow is not readily determinable. The average of the data acquired in the period between November 15 and April 1 may be substituted for HCR. The arithmetic average of measurements taken at intervals over the entire year will be considered as equivalent to the weighted working level (WWL).

7. Confirmation of the grab sample measurements determined to be between 0.02WWL and 0.05WWL shall be performed to prevent unwarranted penalization of dwellings affected. This is necessary because of increased measurement uncertainty with the grab sampling technique in this range. The measurement uncertainty in this range is due, in part, to variables which may cause unrepresentative radon/radon decay product disequilibrium. In lieu of repeated grab-Working Level measurements, a combination of indoor and outdoor gamma

radiation surveys, soil sample analysis for radium-226 content, and bore hole logging techniques may be utilized to identify all radiation anomalies.

Procedure II -- Gamma Radiation Survey-Small Lots

Individual residential lots not exceeding 75' x 125' for which construction of a residential dwelling has not yet begun will be screened in the following manner:

1. The narrower side of the lot will be divided into four equal lengths and the wider side of the lot divided into five equal lengths, forming a total of twenty measurement areas;

2. The center of each measurement area will be measured for gamma radiation with a pressurized ion chamber rate meter (PIC) or portable radiation detector which is cross-calibrated with the PIC using the gamma ray energies of interest;

3. The center of the detector will be three feet from the ground. If a PIC is used, the digital rate meter and power supply will be separated from the ion chamber by the full cable distance during each measurement. At each measurement location, after the rate meter stabilizes, ten measurements will be taken at one second intervals and the average recorded;

4. After all measurements have been taken, the arithmetic average shall be determined;

5. If it can be shown that removal of surface radioactivity by scraping, leveling or other lot preparation will reduce an unacceptable gamma radiation level to an acceptable level, the lot will be reconsidered on a case-by-case basis.

Procedure III - Gamma Radiation Survey-Large Lots

Large size individual lots or multiple lot development areas for which construction of residential dwellings has not yet begun will be screened in the following manner:

1. A 200' grid measurement pattern will be developed utilizing a chain or a tape to determine measurement intervals. However, the entire lot will be screened by a walk-through gamma radiation survey to determine the presence of any area having greater than background radiation levels.

2. Measurements will be taken in the same manner as described for small lots.

3. After all measurements have been taken, the arithmetic average will be determined.

4. If it can be shown that removal of surface radioactivity can be removed in the same manner as described for small lots, larger lots will be reconsidered on a case-by-case basis.

Procedure IV -- Indoor Gamma Radiation Survey

A portable gamma survey meter (e.g. micro R meter) shall be used to complete the gamma radiation measurements both inside and outside of the structure. This survey meter shall be cross-calibrated with a Pressurized Ionization Chamber (PIC) in order to provide realistic exposure measurements. This survey shall be designed to detect the presence of any possible residual radioactivity under, within or around the structures. A map shall be provided indicating all locations having above background radiation levels. This survey need only be performed once for each qualifying structure.

Measurements shall be made at the three foot height level. Measurements shall be made on all floors and the basement at 25 square foot intervals, and averaged separately per floor. The outside gamma radiation measurements shall be made on a 50 square foot interval.

Procedure V -- Soil Sampling or Bore Hole Logging and Analysis

Appropriate soil samples shall be obtained and analyzed for the radium-226 concentration, and all areas having greater than 5 pCi/gm of radium-226 shall be indicated on a suitable site map.

Bore hole logging may also be substituted for actual soil sampling and analysis but the bore hole log shall indicate the radium-226 soil concentration.

MODIFIED PROTOCOLS (FROM PERKINS et al, 1981)

INTRODUCTION

The identification of offsite structures and properties that require remedial action because of elevated radiation levels caused by residual activity is being based upon three standards proposed by the U.S. Environmental Protection Agency in 40 CFR 192, Federal Register (1980), "Proposed Cleanup Standards for Inactive Uranium Processing Sites." These proposed standards state that remedial action shall be required if residual radioactivity causes (1) average annual indoor radon daughter concentrations (including background) >0.015 working levels (WL),[1] (2) indoor gamma radiation levels >20 microroentgens per hour above background, or (3) average ^{226}Ra concentrations in soil or other materials >5 pCi/g in any 5 cm thickness within 1 foot of the surface, or any 15 cm thickness below 1 foot. If a property fails any one of these criteria because of residual radioactivity, then remedial action is required. The measurement procedures are also designed to identify properties that are not eligible for federally guaranteed financing administered by the Department of Housing and Urban Development (HUD) because of (1) indoor radon daughter weighted working levels greater than 0.02 WWL,[2] (2) average gamma exposure rates on open land greater than 14.5 μR/hr.

In the following sections, the procedures that, in January 1981, were considered by Pacific Northwest Laboratory to represent the best compromise between expediency and accuracy are outlined. The flow diagram shown in Figure A1 outlines the measurement and decision making process. These procedures have evolved with time as experience has been gained in the field, new ideas have been obtained from current literature, and discussions have been held with investigators experienced in the field. Some of the early measurements that were made using the original procedures are being repeated using current procedures. If serious discrepancies between the original and the re-measurements are observed, these re-measurements will be continued. However, if serious discrepancies are not observed, the re-measurements will be discontinued because of the time and expense involved.

MECHANISM FOR THE INITIATION OF RADIOLOGICAL SURVEYS

Requests for Surveys

Since the Edgemont program is voluntary, a property owner must first request a survey before it can be performed. Initially, the property owners either phoned or went in person to the Edgemont City Hall where the city hall staff filled out a "Radiation Hazard Evaluation, Request for Test" form. These forms were then given to PNL for the scheduling of surveys. Later, as

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(1) One working level (WL) is defined as any combination of short-lived radon decay products in 1 liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

(2) One weighted working level (WWL) is defined as 0.6 times the "grab" working level measured in a closed up structure.

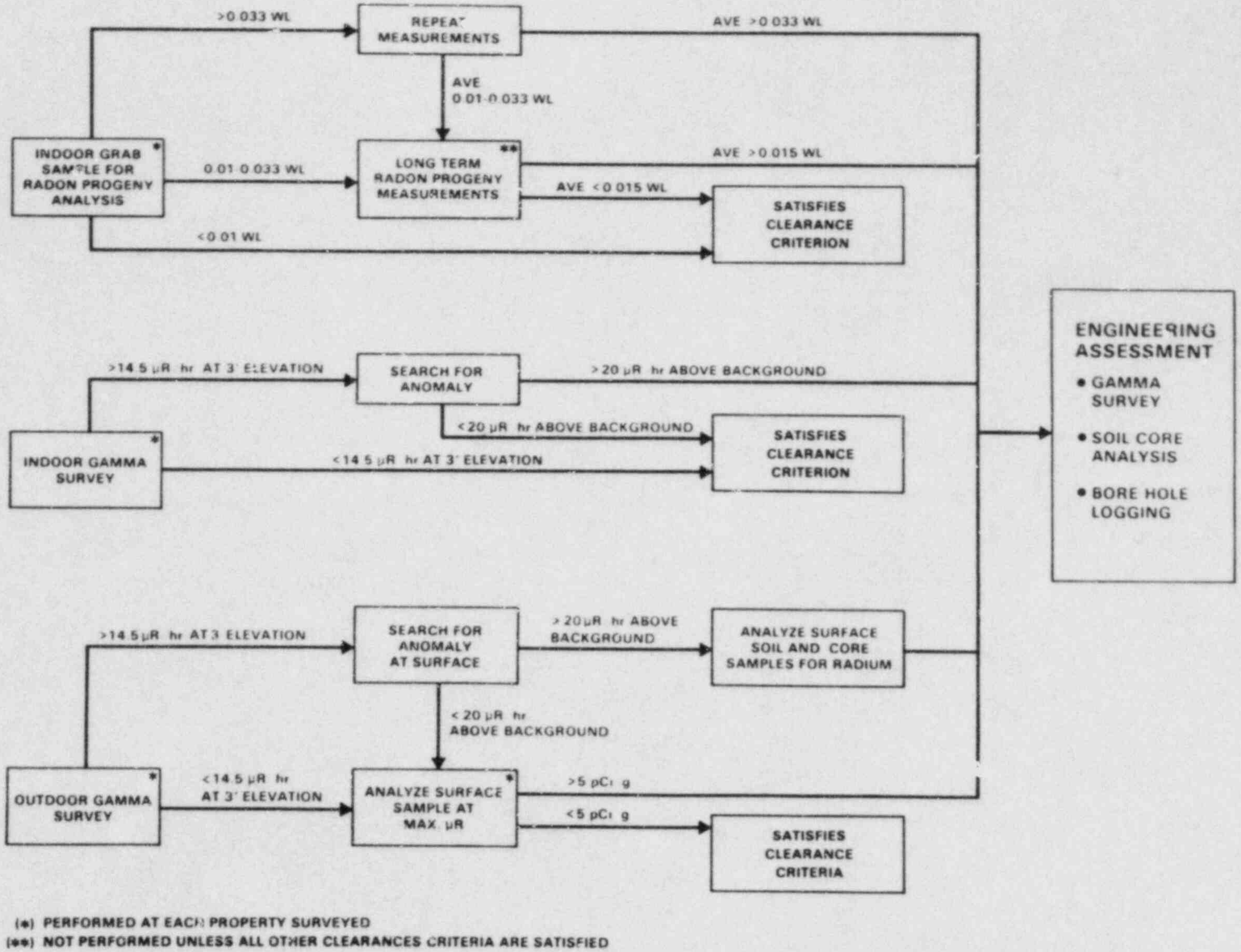

FIGURE A1. Flow Diagram of Procedures for Determination of Properties Requiring Remedial Action the number of requests for tests had begun to lag, a paid advertisement was placed in the local newspaper. The State of South Dakota also sent a letter to each property owner who had not requested a survey, advising them that it was in their own best interest to have the survey performed. A "Radiation Hazard Evaluation Test Request" form was sent with each letter. These letters were effective in eliciting additional requests for surveys. A final letter was then sent by the City of Edgemont to those remaining property owners who did not respond to the State's letter.

Scheduling of Surveys

Originally, the PNL staff delivered "Consent Release and Indemnity" forms to the owner(s) of the property and any resident other than the owner when the property was to be scheduled for survey. These forms gave PNL legal permission to enter the property and perform the tests. A questionnaire describing the property was filled out by the PNL staff member using information supplied by the occupant. Later, these forms were mailed to the owners of property that had not yet been surveyed. These forms were also enclosed in the letter sent by the State of South Dakota suggesting participation in the program. No property was surveyed until the "Consent Release and Indemnity" form had been signed.

The City Planning Office at the Edgemont City Hall notified PNL which properties were to be given priority because the owner needed clearance for HUD federally guaranteed financing. These properties were surveyed as soon as possible. An attempt is made to schedule residences in clusters of up to four, because radon progeny concentrations can be measured simultaneously in up to four buildings at once with the PNL mobile laboratory if the four buildings are close to each other. The day before a structure is to be surveyed, the owners and/or occupants are telephoned to request permission to survey the following day. No building is surveyed unless specific permission is obtained from both the owner and the occupants to survey on that particular day. If permission to survey is obtained, the occupant is instructed as to when and how to close up the building for the purpose of the radon progeny measurements.

FIVE-MINUTE WORKING LEVEL MEASUREMENTS IN HOMES

Introduction

The proposed cleanup standard (40 CFR 192) states that remedial action shall be required if average annual indoor radon daughter concentrations (including background) exceed 0.015 WL. However, the determination of average annual working levels requires extensive measurements over the course of a year and is therefore costly and time consuming. Therefore, to reduce the number of structures that require long-term measurements, and thereby to expedite the remedial action, five-minute radon daughter measurements under standardized conditions (windows and doors closed, air fans off) are being carried out to screen out those structures where the radon daughter concentrations are either (1) so high (>0.033 WL) that an engineering assessment to determine the need for remedial action is clearly required, or (2) so low (<0.010 WL) that if the proposed indoor gamma radiation exposure and average ^{226}Ra in soil standards are also satisfied, remedial action is not required. It is recognized that working levels vary considerably throughout the year, so that a single five-minute measurement cannot be used to estimate the annual average very accurately. Therefore, structures in which the radon daughter concentrations measured in five-minute samples are between 0.01 WL and 0.033 WL are being scheduled for long-term measurements using Radon Progeny Integrating Sampling Units (RPISU) to determine average working levels more accurately. Studies are also being initiated to determine the adequacy of Track Etch®[3] devices for determining annual average working levels.

Protocols

During the initial survey of structures at Edgemont, air filter samples are being collected over five-minute intervals for radon progeny working level measurement using 47 mm diameter Millipore type AA filters with a pore size of 0.8 microns. Air is drawn through the filters at flow rates of about 40 liters per minute using Gast rotary vane pumps. One filter is collected in the main living area on the ground floor of each structure and one in any habitable basement. The home owners are asked to keep windows, doors and outside vents closed, and to turn off air fans, but not heating systems, for eight hours (three hours minimum) prior to making the grab working level measurements to minimize the dilution of the indoor radon progeny concentrations by outside air. Prior to measurement, the homes are checked for open doors, windows or vents, and for operating fans. If any are noticed, radon daughters are not measured in that home that day.

Commencing less than seven minutes after the beginning of radon daughter sampling, the filters are counted for three minutes using a ZnS scintillator covering the entire face of a 12 cm diameter photomultiplier tube to determine the sum of the alpha emission rates of the radon progeny ^{218}Po and ^{214}Po. Two 10-minute counts are then taken commencing 8-1/2 to 12 minutes and 19 to 30 minutes after the beginning of sampling to determine the change in the emission rate with time. The counts are stored in electronic scalers. These measurements are used to calculate the concentrations of the radon daughters ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po and the working level by the general form of the method of Thomas (1972).

An air filter is collected each morning outside of the Battelle office at 107 N. 6th Avenue, because natural outdoor radon daughter concentrations in excess of 0.015 WL could cause indoor concentrations to increase to the point where structures would fail the working level criterion for clearance from remedial action. However, it has been observed that outdoor radon concentrations vary with time and location at Edgemont. Therefore, beginning in February of 1981, radon daughters will be measured outside of each structure before or during the indoor radon daughter measurement. If the outdoor radon daughter concentration exceeds 0.015 WL, indoor concentrations will not be measured until the outdoor concentration falls below 0.015 WL. If it is found that the outdoor radon daughter concentration in any part of town is significantly below 0.010 WL on a given day, no more outdoor radon daughter concentrations will be measured for the rest of that day. As soon as the necessary equipment is obtained, grab radon measurements will also be made outside and inside of the structures at the same time as the working level

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(3) Track Etch® is a registered trademark of the Terradex Corporation. Measurements are being made to provide information on the degree of equilibrium between radon and its daughters.

Turnover Time of Radon Daughters in a Structure

Radon daughter working levels in a structure depend not only upon the rate at which radon diffuses into the structure, but also upon both the rate of exchange of air inside the structure with outside air, and the rate of plateout of radon daughters on the surfaces of the structure. It is possible for unusually rapid plateout and/or exchange with outside air having low working levels prior to a five-minute working level measurement to decrease the measured working level significantly below the annual average for the structure. It is for this reason that the occupants are asked to close both windows and doors for eight (at least three) hours prior to the five-minute working level measurement. However, in order to tell whether the measured working level can be used to estimate the annual average, it is also necessary to have some method that can be used to determine whether the structure has in fact been closed up properly prior to measurement, or whether plateout or exchange has been unusually rapid for some other reason.

The turnover time of the radon daughters in the air in a structure prior to a five-minute radon daughter measurement can be calculated from the degree of disequilibrium between the daughters ^{218}Po, ^{214}Pb and ^{214}Bi using the following equations reported by Morken and Scott (1966).

$$^{218}Po = \frac{\left(^{222}Rn\right)\lambda_A}{\frac{F}{V} + \lambda_A} \qquad (1)$$

$$^{214}Pb = \frac{\left(^{218}Po\right)\lambda_B}{\frac{F}{V} + \lambda_B} \qquad (2)$$

$$^{214}Bi = \frac{\left(^{214}Pb\right)\lambda_C}{\frac{F}{V} + \lambda_C} \qquad (3)$$

Where

^{222}Rn, ^{218}Po, ^{214}Pb, and ^{214}Bi = Air concentration of these radionuclides (pCi/liter)

λ_A, λ_B, λ_C = Radioactive decay constants of ^{218}Po, ^{214}Pb and ^{214}Bi, respectively (min^{-1})

F = Continuous flow rate of clean, uncontaminated air into the structure (liters/min)

V = Volume of air in the structure (liters)

And

$\frac{V}{F}$ = Turnover time (minutes)

Equation 2 can be rearranged to give the turnover time as a function of ^{210}Po and ^{214}Pb:

$$\frac{V}{F} = \frac{^{214}Pb}{\left(^{218}Po - ^{214}Pb\right) \lambda_B} \tag{4}$$

equation 3 can be rearranged to give the turnover time as a function of ^{214}Pb and ^{214}Bi:

$$\frac{V}{F} = \frac{^{214}Bi}{\left(^{214}Pb - ^{214}Bi\right) \lambda_C} \tag{5}$$

and substitution of equation 2 in equation 3 gives the turnover time as a function of ^{218}Po and ^{214}Bi:

$$\frac{V}{F} = \frac{2}{-(\lambda_B + \lambda_C) + \left[(\lambda_B + \lambda_C)^2 - 4\lambda_B \lambda_C \left(1 - \frac{^{218}Po}{^{214}Bi}\right)\right]^{1/2}} \tag{6}$$

These equations are only approximate because they assume (1) steady state, (2) complete mixing within the structure, and (3) negligible radon concentrations in the outside air. None of these assumptions is strictly true for a typical house, but the calculated turnover times do provide a useful parameter for identifying measurements that were made under conditions of rapid plateout and/or air exchange.

The equations of Morken and Scott can be used to calculate the turnover time from the relative concentrations of any two of the three short-lived radon daughters, but in practice the turnover time is calculated from only the concentrations of the ^{218}Po - ^{214}Bi pair and the ^{214}Pb - ^{214}Bi pair using equations 4 and 6, respectively. Since ^{218}Po has only a three-minute half-life, the turnover time calculated from the concentrations of ^{218}Po and ^{214}Bi (or ^{218}Po and ^{214}Pb) is sensitive to conditions just prior to the measurement, but the turnover time calculated from concentrations of the longer-lived ^{214}Pb and ^{214}Bi is sensitive to processes occurring over a longer time period. If the calculated turnover times are unusually short, plateout or air exchange has been unusually rapid prior to measurement, suggesting that the measured radon daughter concentrations will tend to be uncharacteristically low.

Under ordinary conditions the radon daughter activities decrease in the order $^{218}Po \geq {}^{214}Pb \geq {}^{214}Bi$. However, statistical fluctuations in the measurements and/or rapid variations in the plateout rate (which is significantly greater for ^{218}Po than for either ^{214}Pb or ^{214}Bi) can result in changes in this order. The intermittent operation of a circulating heating system, for example, can cause rapid variations in the plateout rate. If the measured concentrations of ^{218}Po and ^{214}Pb become less than that of ^{214}Bi, the calculated turnover times become negative. If the departure from equilibrium is slight, indicating that plateout is slow, the calculated negative turnover time will be long. However, if the departure is large, indicating rapid plateout, then the calculated negative turnover time will be short. Review of past measurements has shown that positive turnover times calculated from either pair of radon daughters were longer than 32 minutes 90% of the time if the wind speed was less than 8 mph. Inspection of the turnover times has also shown that negative turnover times shorter than 100 minutes result from significant departure from equilibrium. Therefore, it has been decided to consider radon daughter measurements to be invalid because of excessive plateout and/or air exchange when either of the two calculated turnover times is positive and shorter than 32 minutes, or if either is negative and shorter than 100 minutes (unless the measured radon daughter concentration is >0.033 WL, in which case the measurement is considered to be valid).

If the radon daughter measurement in a structure is considered to be invalid because of short calculated turnover times, the structure is scheduled for re-measurement at a later date. If both of the calculated turnover times for the re-measurement are either positive and longer than 32 minutes, or negative and longer than 100 minutes, the re-measurement is accepted as valid and is reported. However, if the re-measurement also fails the turnover time criterion, it is considered that five-minute radon daughter measurements will not provide a sufficiently accurate estimate of the annual average working level, so the structure is scheduled for long-term radon daughter measurement. However, the measurement showing the longer turnover times will be considered to be the more representative of the annual average and will be reported as an interim value. It should be remembered that even if short turnover times are characteristic of a structure during the period of time that the five-minute measurements are made, future modification of the structure or the living habits of the occupants could lengthen the turnover time and cause the radon daughter concentrations to rise to unacceptable levels.

It has also been observed that there is a significant reduction in the number of measured working levels above 0.010 WL when the wind speed is above 8 mph. Therefore, the wind speed is now checked each morning and an attempt is made to avoid sampling when it is above 8 mph.

Decision Levels

Working Levels <0.01 WL. If the structure average of the five-minute working level measurements is less than 0.010 WL, and if the turnover times of the radon daughters for the measurements satisfy the criterion described above, the structure is considered to satisfy the radon progeny criterion for clearance from remedial action.

Working Levels > 0.033 WL. If the measured five-minute working level is greater than 0.033 WL on either floor, a second measurement is made at a later time to confirm the elevated concentrations. The valid measurements taken on each floor during the initial survey and during any repeat surveys are averaged floor by floor. (This is necessary since there may be more valid measurements available for one floor than for another.) The average for the structure is then calculated as the average of the individual floor averages. However, beginning on February 25, 1981, all indoor working levels above 0.010 WL measured on days when the outdoor working level is above 0.015 WL will be disregarded. The measurement will be repeated at a later date because the elevated indoor working levels could be due to outside air, and might not be characteristic of the structure. If the structure average is greater than 0.033 WL, the structure is considered to exceed the EPA annual average working level standard of 0.015 WL and is immediately scheduled for engineering assessment.

Working Levels of 0.01 to 0.033 WL. If the structure average of the valid working level measurement is between 0.01 and 0.033 WL, it is considered that grab samples will not provide an estimate of the average annual working level that is sufficiently accurate to provide a basis for a decision on remedial action. Therefore, the structure is scheduled for long-term radon progeny measurements, unless the structure or yard fails either of the other criteria for clearance from engineering assessment (e.g., indoor or outdoor gamma exposure rates >20 μR/hr above background, ^{226}Ra >5 pCi/g in soil). In the latter case, the property is scheduled for engineering assessment without further radon daughter measurements.

LONG-TERM RADON DAUGHTER MEASUREMENTS

Introduction

Where long-term radon progeny measurements are required, the measurements are being made using RPISU and, in some cases, Track Etch®, but the RPISU will be considered to be the standard instrument, at least until simultaneous measurements by RPISU and Track Etch® have shown that Track Etch® can provide annual average working levels that are of accuracy comparable to those provided by the RPISU.

Experimental Sampling Protocol

The RPISU's are shop-made and are obtained from the Las Vegas laboratory of the U.S. EPA. These units consist of an air pump and clock contained in a capped plastic pipe about 30 cm in diameter by 60 cm tall. The RPISU collects radon daughters on a filter located next to a thermoluminescent dosimeter (TLD) chip. A second TLD chip that is shielded from alpha and beta particles is also used to give a correction for background gamma radiation.

These components are contained in a small, externally mounted head which is detachable from the unit. The heads are received from the EPA laboratory and are returned there promptly after the air sampling has been completed. There, they are disassembled, and the thermoluminescent emissions are read and converted to radon progeny exposure rates using calibrations which the EPA has established for each batch of TLD Chips.

The total quantity of air sampled is determined using a rotometer supplied by the EPA to measure the flow rate at the beginning and completion of sampling. The running time clock readings are also recorded.

Track Etch® devices consist of thin sheets of alpha sensitive material that are passively exposed to the atmosphere. Alpha particles from radon and radon daughters produce damage tracks in the sensitive material. These tracks are later made visible by a suitable etching technique, and then counted. Working levels are calculated using an assumption about the degree of equilibrium between radon and its daughters (usually 50%).

The major advantages of the Track Etch® devices are that they are small and require no pumps, electricity or any other associated hardware. Therefore, they can be exposed over long periods of time without maintenance. However, potential errors produced by the assumption of a constant degree of equilibrium may limit their accuracy, and could lead to bias in their results in individual structures.

Protocols

Annual average working levels are determined from six integrated RPISU measurements taken during the course of a year on the main floor of each structure. PNL places the RPISUs in the structures to be measured and determines the air flow rate at the beginning and end of sampling using a rotometer supplied by the EPA. The flow rate is generally one to two liters/minute. The filter on the RPISU tends to plug up, causing a pressure sensor to turn off the instrument. When this occurs before 100 hours have elapsed, the filter and TLD chip will be replaced (they come as a sealed unit) and the measurement continued until a total sampling time of 100 hours has been obtained. When filter head plugging reduces the flow rate below a preset point, a safety switch turns the pump off to protect it from damage. The flow rate can be checked by installing a rotometer at the inlet and momentarily restarting the pump. A built-in time delay prevents shutdown for a long enough interval to take the reading. After each filter is changed, the running time meter is read to determine the number of hours of exposure. EPA has indicated that five working level liters is the smallest measurable sample. At a flow rate of one liter/minute and a working level of 0.015 WL, it requires about five hours to obtain five working level-liters. Therefore, any TLD chip that is not exposed for at least five hours is not included as part of the 100-hour sample.

Measurements of at least 100 hours duration are made. Each measurement is made approximately every other month for a year. If a problem occurs in sampling during a scheduled month, a sample is collected in the succeeding month. If that cannot be done, then it is necessary to repeat the sampling during a succeeding year sometime in the three-month interval which is centered on the scheduled month. (For example, if a sample were taken in February

1981 that could not be used for some reason, and for some other reason it was not possible to take a repeat sample in March 1981, then a repeat sample must be taken during January, February, or March of a later year).

Since the minimum sampling time is 100 hours, it is sometimes necessary to use more than one sampling head when there is frequent plugging of the filter after intervals shorter than 100 hours. (Filter plugging frequently occurs as a result of the accumulation of particulates from cigarette smoke.) If more than one RPISU sampling head is used to obtain the minimum total of 100 hours of sampling, the valid measurement is calculated from the time-weighted average of all the individual RPISU sampling head measurements as follows:

$$W.L. = \sum \frac{t_i\ W_i}{T} \qquad (7)$$

Where

$W.L.$ = time weighted Working Level

t_i = sampling time for the i th sample

W_i = Working Level for i th sample

T = $\sum t_i$ = total time for all sampling heads, and must be at least 100 hours.

If the annual average working level calculated from six RPISU samples is greater than 0.015 WL, the structure is scheduled for engineering assessment, but if the average is less than or equal to 0.015, the structure then satisfies the working level criterion for clearance from remedial action, since long-term measurements would not have been made if the property had not passed all of the other clearance criteria (e.g., gamma exposure rate less than 20 μR/hr above background and radium concentration in soil less than 5 pCi/g). Terradex Type F Track Etch® devices will also be placed in 50 structures in which RPISU measurements are being made to determine how well the working levels determined using Track Etch® correspond to those measured with the RPISU. The Type F device consists of the alpha sensitive detector taped to the bottom (inside) of a plastic cup and protected from ambient radon daughters by a filter. It measures only radon (and daughters produced by the decay of radon inside the cup). Working levels are calculated assuming 50% equilibrium with the measured radon concentration. This configuration avoids problems produced by the variability in the plateout of radon daughters on the surfaces of the structure or of the detector caused by variations in atmospheric parameters such as humidity and aerosol concentration. One Track Etch® will be placed for a period of one year in each of the 50 structures, and another will be changed every other month in these structures at the same time as the RPISU is installed. If these measurements show that the Track Etch® yields average annual working levels of comparable accuracy to those provided by the RPISU, then Track Etch® will be used in the future to measure annual averages.

INDOOR GAMMA SURVEYS

Introduction

According to 40 CFR 192, remedial action is required if residual radioactivity results in indoor gamma radiation exposure >20 microroentgens per hour (μR/hr) above background. In an earlier survey, J. E. Thrall, J. M. Hans, Jr. and V. Kallemeyn (1980) of the EPA determined that the outdoor gamma exposure rate at Edgemont averaged 13.2 μR/hr at locations not influenced by residual radioactivity, and that about 95% of these locations had average gamma levels less than 14.5 μR/hr. Therefore, 14.5 μR/hr was chosen as the background at Edgemont, so that only about 5% of the properties will exceed this background as a result of natural radioactivity. Our measurements at Edgemont have yielded average outdoor background levels very close to those reported by EPA. In any event, in most cases where residual radioactivity is present, gamma exposure rates much greater than 20 μR/hr above background are observed, so the exact value chosen for the background has relatively little effect on the decision as to whether engineering assessment is required.

Protocols

Indoor gamma surveys are made of all habitable floors and basements using gamma survey meters. The survey meters being used at Edgemont are Ludlum micro-R-scintillometers that employ sodium iodide crystals for gamma detection. These instruments are compared at least once a day to a calibrated Reuter-Stokes (Model S-111) pressurized ionization chamber on the ground floor of homes. The pressurized ionization chamber sensitivity is checked with a reference source daily. All instruments were calibrated at PNL prior to use and are periodically returned to PNL for recalibration. All pressurized ion chamber readings taken in the field are corrected to the standardized laboratory calibration. Micro-R-meter readings are corrected to equivalent pressurized ionization chamber readings using the ratios determined in the field on the day of measurement. Indoor gamma measurements are made at an elevation of about three feet at the grid points (approximately every 5 feet) of a 25 ft^2 grid starting at one wall. Measurements are also made at the far wall (unless this point is within a couple of feet of another measurement, such as in another room). The measurements are made with the survey meter set on slow response (long time constant). Readings are not taken until the needle has stabilized for a few seconds. The corrected readings are recorded on a detailed drawing of the floor plan of the structure that is drawn based on measurements taken using a tape measure (Figure A2). If none of the readings is greater than 14.5 μR/hr, the structure is considered to pass the gamma radiation criterion for clearance. However, if readings above 14.5 μR/hr are encountered, or if the meter shows a pronounced increase in the exposure rate at any location, a search is made for elevated readings in contact with surfaces of the structure. If a corrected contact reading greater than 20 μR/hr above background is observed, this reading is recorded. The contact reading is recorded beneath a line drawn under the surface reading. Unless the object causing the elevated gamma reading can be disposed of (e.g., small rocks, radium dial clock), the structure is considered to fail the gamma criterion and is scheduled for engineering assessment.

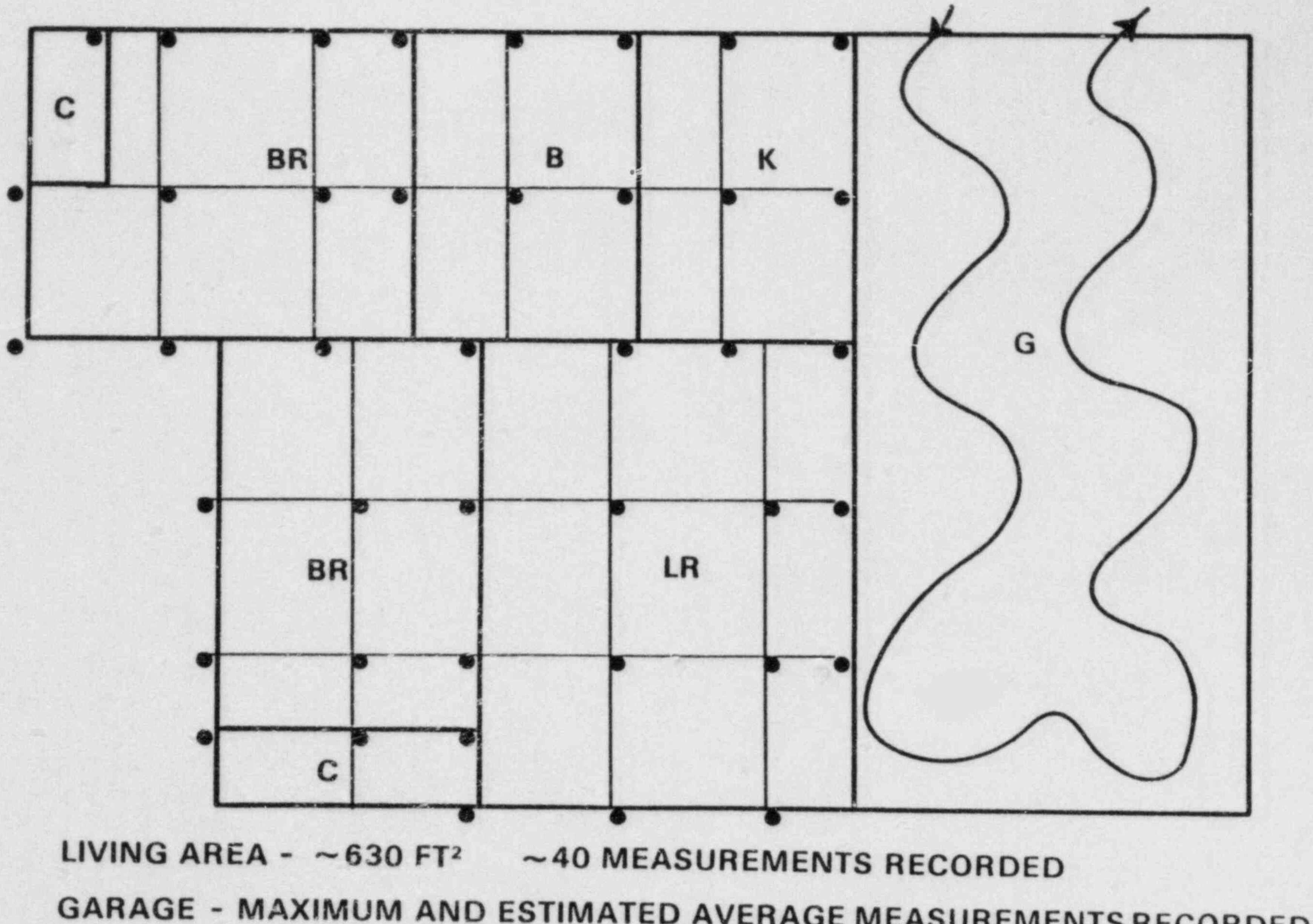


FIGURE A2. Illustration of Indoor Gamma Survey

It should be stressed that the primary purpose of the gamma survey is to locate any deposits of residual radioactivity. Therefore, the detector output is observed carefully, and any suspicious changes in the meter readings are followed up to insure that no deposits anywhere inside the structure are missed. The grid measurements serve as a record that a detailed survey has been made.

The Ludlum scintillometer is equipped with an audible signal that clicks at a rate proportional to the gamma exposure rate. Prior to the January 1981 workshop, the audible signal was not used because it does not provide a numerical signal, and because its clicking might cause the owner or neighbor to fear that his building was highly radioactive. However, the clicker does have the advantage that it provides a faster response than does the meter, so it might detect small amounts of residual radioactivity between grid points that the meter would not detect. At the workshop, it was suggested that the clicker has proven very useful for locating residual activity during surveys at other locations. Therefore, following the workshop the Ludlum scintillometers were fitted with earphones that will enable the surveyor to hear the clicker without disturbing the property owner. In the future, the earphones will be used in addition to the meter reading to locate residual radioactivity during both indoors and outdoors surveys.

GAMMA SURVEYS IN GARAGES AND NONHABITABLE BASEMENTS

Protocols

Prior to the January, 1981, workshop, gamma levels in garages and nonhabitable basements were measured at an elevation of about three feet with a Ludlum scintillometer set on fast response during a slow, serpentine walk-through (Figure A2). Brief stops were made to allow the meter to stabilize. If readings greater than 14.5 μR/hr were encountered, or if the reading showed a significant increase at any location, a search was made for elevated contact readings. If contact readings greater than 20 μR/hr above background were observed, the building was scheduled for engineering assessment. As a result of discussions at the workshop, gamma surveys in garages and nonhabitable basements are now being conducted using a 25 ft^2 grid and measurement procedures identical to those described in the previous section inside other structures.

OUTDOOR GAMMA SURVEYS OF LAND WITH STRUCTURES

Introduction

According to 40 CFR 192, remedial action is required if residual radioactivity results in average ^{226}Ra concentrations in soil >5 pCi/g in any 5 cm thickness within one foot of the surface, or any 15 cm thickness below one foot. Outdoor gamma radiation surveys are being conducted for the purpose of identifying locations where soil samples should be collected and analyzed because they are likely to contain the highest ^{226}Ra concentrations present at that property.

Protocols

Gamma measurements are made at an elevation of about three feet using Ludlum micro-R-meters (Model 12S) set at slow response at the grid points (approximately every seven feet) of a 50 ft^2 square grid in the yards adjoining homes. Readings are not taken until the meter has stabilized for a few seconds. The corrected readings are recorded on a drawing of the yard made using a tape measure (Figure A3). The house and other structures are shown on the drawing.

To save time, the distances between grid points are paced off, rather than measured. In the event that a lot is exceedingly large, only that portion that is within 50 feet of the structure(s) is surveyed using the 50 ft^2 square grid. The rest is surveyed using the procedures described below for open land. The Ludlum scintillometers are cross-calibrated at least once a day with a pressurized ionization chamber at a location that is to be surveyed. All Ludlum readings are corrected to the equivalent pressurized ion chamber reading before being recorded on the survey map.

Gamma Radiation Levels <14.5 μR/hr. If no corrected gamma exposure rates greater than 14.5 μR/hr (including background) are observed at the three-foot elevation, surface soil samples are collected for ^{226}Ra analysis at any two locations showing the highest readings, and contact readings are recorded at these locations. In the event that it is impractical to collect a surface sample at a location of maximum reading (e.g., because of the presence of pavement or valuable shrubs) an alternate location showing a high reading is sampled.

Gamma Radiation Levels >14.5 μR/hr, but no Surface Anomalies. If corrected gamma exposure rates greater than 14.5 μR/hr (including background) are observed at the three foot elevation, or if the readings show a significant increase at any location, a search is made for elevated readings at the surface, and contact readings are recorded on the drawing of the property (a line is drawn beneath the three-foot reading, and the contact reading is entered below the line). However, if the three-foot readings are consistently greater than 14.5 μR/hr, but no gamma anomalies are observed during the first two surface searches, no more surface searches are conducted unless a three-foot elevation reading shows an increase of one μR/hr or more. Surface soil samples are taken for ^{226}Ra analysis at two locations showing maximum gamma readings.

Contact Gamma Radiation Levels >20 μR/hr Above Background. If surface gamma readings greater than 20 μR/hr above the 14.5 μR/hr background are observed, up to five or six surface and core soil samples are collected for ^{226}Ra analysis at locations of maximum gamma exposure rates. The property is scheduled for a more detailed engineering assessment because it is assumed that material containing greater than 5 pCi/g of ^{226}Ra is present, even if the initial soil samples collected happened to miss it.

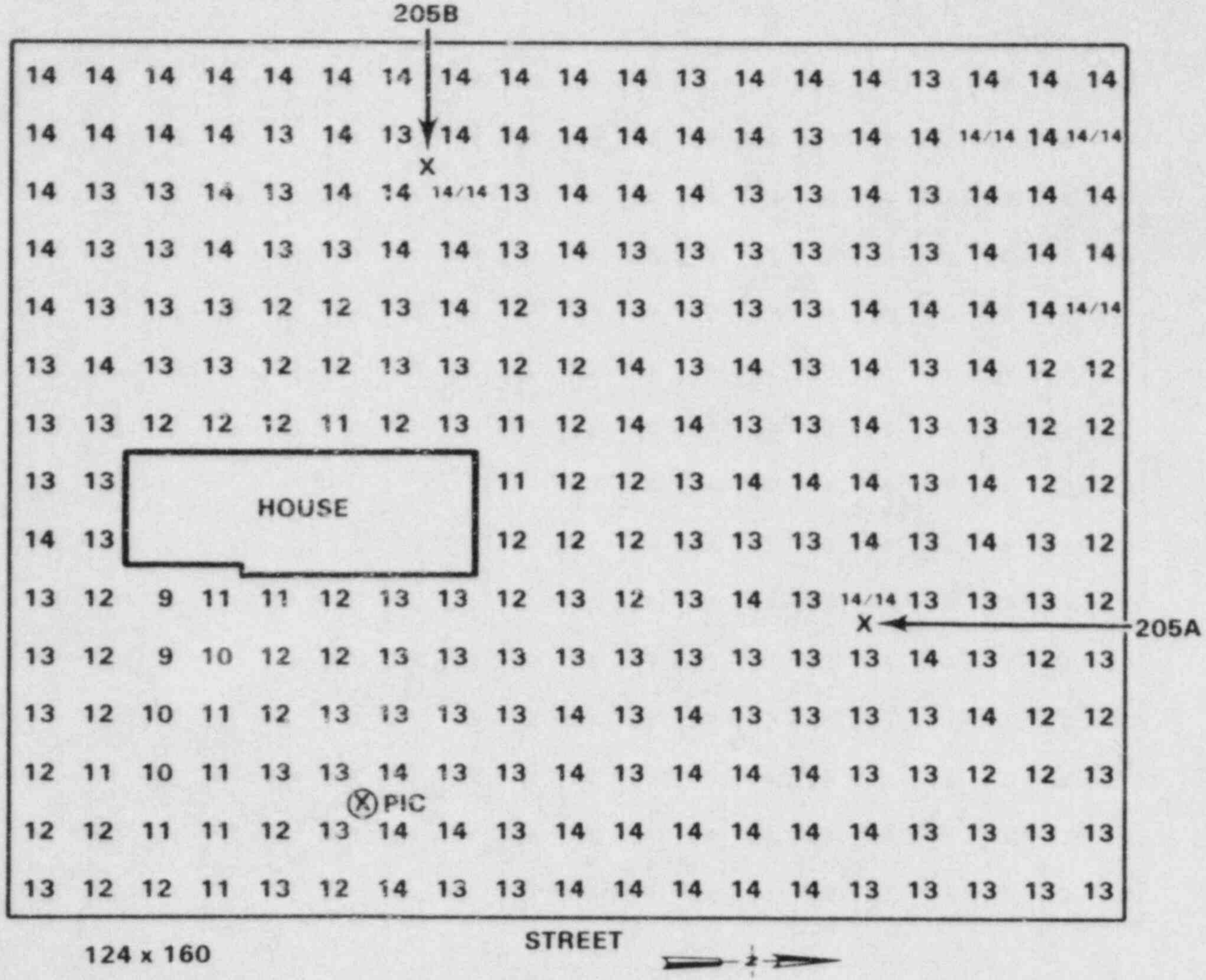


FIGURE A3. Illustration of an Outdoor Gamma Survey

GAMMA SURVEYS OF OPEN LAND

Introduction

According to 40 CFR 192, remedial action is required on open land if residual radioactivity results in ^{226}Ra concentrations in soil >5 pCi/g in any 5 cm thickness within one foot of the surface, or any 15 cm thickness below one foot. However, the land is also ineligible for HUD federally guaranteed financing if the estimated average gamma radiation exposure rate, including background, is greater than 14.5 μR/hr. Outdoor gamma radiation surveys are therefore conducted on open land to locate any soil containing greater than 5 pCi/g of ^{226}Ra and to determine the average gamma radiation exposure rate of the property.

Protocols

Open lots are divided into grids containing four survey blocks along the shorter dimension and five survey blocks along the longer dimension of the property (Figure A4). On very large lots extra rows of survey blocks are added to keep the maximum distance between measurements below 200 ft. Extra blocks may be added to irregularly shaped lots where the rectangular grid leaves unsampled areas. Gamma exposure rates are measured at an elevation of about three feet at the approximate center of each survey block with Ludlum scintillometers set on slow response. Readings are not recorded until the meter has stabilized for a few seconds. The scintillometers are compared to a calibrated Reuter-Stokes pressurized ionization chamber at one location on each lot, and a correction table prepared for each instrument. The corrected gamma readings are recorded on a drawing of the lot. A serpentine walk-through between each row of sampling locations is also made with the scintillometers set on fast response. The highest reading is recorded. The average gamma exposure rate for the property is calculated from the grid center measurements.

Gamma Radiation Levels <14.5 μR/hr. If no corrected gamma readings greater than 14.5 μR/hr (including background) are observed at the three foot elevation, one surface soil sample is collected for ^{226}Ra analysis at a location of maximum gamma exposure rate.

Gamma Radiation Levels >14.5 μR/hr but no Surface Anomalies. If gamma radiation levels greater than 14.5 μR/hr (including background) are observed at the three-foot elevation, or if the readings show a significant increase at any location, a search is made for elevated readings at the surface, and maximum contact readings are recorded on the drawing of the property. However, if consistent gamma readings above 14.5 μR/hr are observed at the three foot elevation, and no contact gamma readings greater than 20 μR/hr above the 14.5 μR/hr background are observed during the first two surface surveys, no more surface surveys are conducted unless the three-foot elevation reading shows an increase of one μR/hr or more at another location. If no contact reading greater than 20 μR/hr above background is observed at any location, one surface soil sample is collected for ^{226}Ra analysis at a location of maximum gamma exposure rate.

Contact Gamma Radiation Levels >20 μR/hr Above Background. If gamma radiation levels greater than 20 μR/hr above the 14.5 μR/hr background are

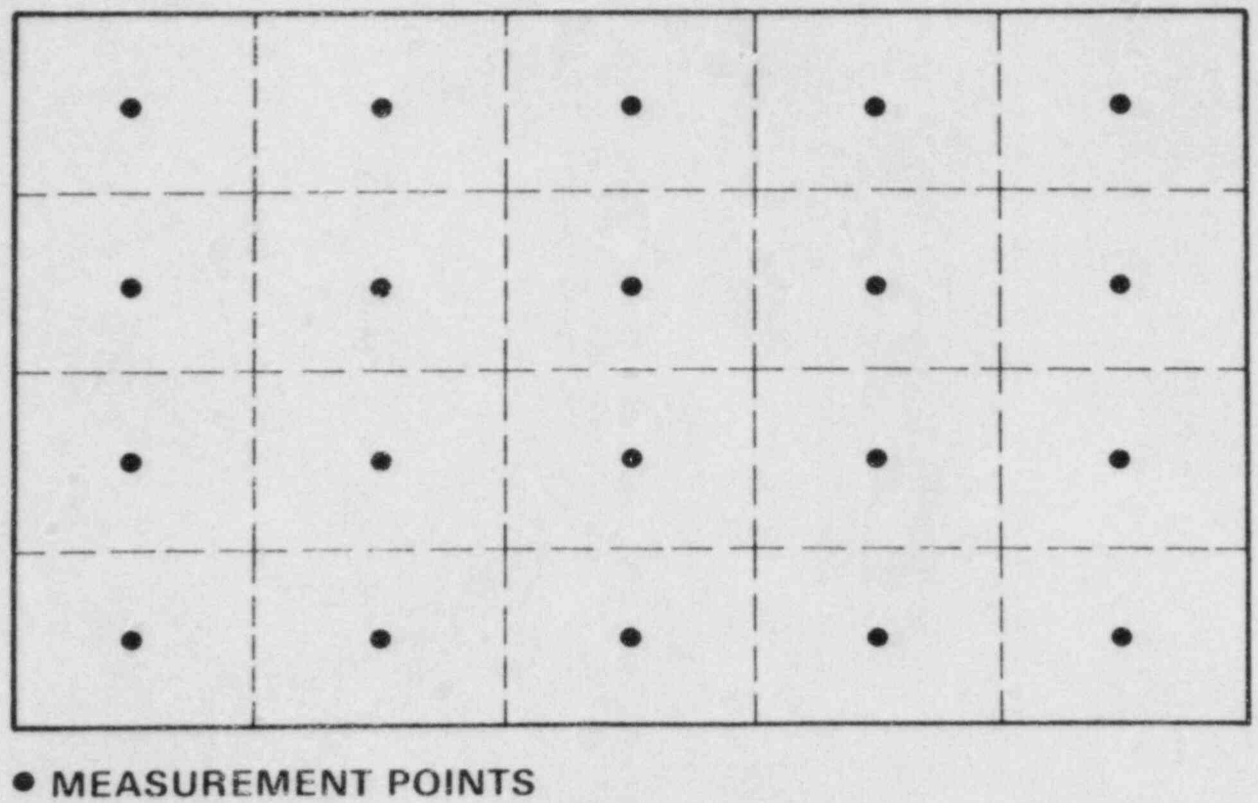


FIGURE A4. Gamma Survey Grid for Lots Without Structures observed at the surface, surface and core soil samples are collected for ^{226}Ra analysis at those locations. The property is scheduled for engineering assessment because it is assumed that material containing greater than 5 pCi/g of ^{226}Ra is present, even if it happened to be missed during initial soil sampling.

SOIL SAMPLING PROCEDURES

Surface Samples

The soil sampling procedures at Edgemont have changed with time. Before January of 1981, surface samples approximately 15 cm wide by 10 cm long by 8 cm deep were taken with a shovel with about a 15 cm wide blade. Beginning in January of 1981 surface samples are being collected, whenever possible, using a sampling device that samples a 200 cm^2 area to a depth of 5 cm. The device is driven into the ground and a small trench is dug next to each end of the sampler (preserving any grass sod for later replacement) to allow guillotine-type blades to be inserted into both ends of the sampler at the 5 cm depth to enclose the sample. However, this sampler does not work properly in frozen or very rocky ground, so in these cases a shovel is still used to collect soil samples, but the depth is kept to less than 5 cm. The surface samples are transferred to a plastic bag and shaken to separate the soil from leaves and grass, which are then replaced in the hole. If an insufficient soil sample remains, an adjacent surface sample is combined with the first sample.

Core Samples

Core samples are taken with a 3.8 cm diameter split tube corer that is driven into the ground to a depth of 46 cm. Before March of 1981 the entire core was homogenized to form a single sample. Beginning in March of 1981, the top foot of the core is being divided into five samples, each about 5 cm in length, with the remaining 15 cm of core forming a sixth sample. If necessary, the coring procedure is repeated at about the same location, combining samples from equal depths, until sufficient sample is obtained for analysis. This latter procedure has been developed to conform to the criterion proposed in 40 CFR 192 for ^{226}Ra concentrations in soil.

Procedure for the Analysis of Soil for ^{226}Ra

Each soil sample is homogenized, weighed and transferred to a metal can with about a 410 ml capacity. The cans are then sealed with a manually operated sealer. They are checked for leaks by immersing in nearly boiling water and inspecting for bubbles. The cans are stored for at least 10 days, and usually considerably longer, to allow radon and its short-lived daughter, ^{214}Bi, to grow in. The cans are then placed in plastic bags and the ^{214}Bi is counted for 10 minutes in a 23 cm diameter by 23 cm deep NaI(Tl) well counter. The cans used are the largest that will fit into the well. The gamma-ray spectra are stored in a multichannel analyzer. The efficiency of the detector is determined daily by counting a homogenized uranium mill tailings sample whose ^{226}Ra concentration has been established by comparison with an NBS ^{226}Ra standard. The background is determined daily by counting a can filled with distilled water.

The ^{226}Ra concentrations are calculated from the measured ^{214}Bi, after correcting for the fractional ingrowth of radon from the parent ^{226}Ra during the time between sampling and counting. In making this calculation, it is assumed that the radon concentration was 50% of equilibrium with ^{226}Ra at the time the can was sealed. Ten days after the can is sealed, the radon will be at 92% of equilibrium using this assumption, versus 84% if the radon concentration was zero at the time of sealing. Since most cans are allowed to sit considerably longer than 10 days before counting, the assumption of 50% equilibrium at the time of can sealing introduces little error.

If any soil sample from a property contains greater than 5 pCi/g of ^{226}Ra, that property is scheduled for engineering assessment. However, remedial action will not be undertaken if the ^{226}Ra is not due to residual radioactive materials, although for those cases the engineering assessment will still provide the property owners with an indication of the recommended procedures they may use at their own expense to remedy the problem. Therefore, soil samples that are shown by NaI(Tl) analysis to contain greater than 5 pCi/g of ^{226}Ra are shipped to PNL at Richland, Washington. There they are opened, homogenized, dried, re-weighed, and then counted on an intrinsic germanium gamma-ray spectrometer system. These analyses indicate (from the ratios of ^{234}Th to ^{230}Th, ^{226}Ra and ^{210}Pb) whether the ^{226}Ra is due to mill tailings or to natural terrestrial radioactivity. The activity of ^{234}Th, the 24-day half-life daughter of ^{238}U, should be much lower than the activities of ^{230}Th, ^{226}Ra, and ^{210}Pb in mill tailings, but should be nearly equal to the activities of these radionuclides in uranium ore, whether it is from a natural deposit or has been transported from a mining or milling site. (The concentrations of ^{234}Th, ^{230}Th, ^{226}Ra and ^{210}Pb are established by comparison to standards traceable to NBS or IAEA.) The resolution of the NaI(Tl) is not adequate to measure the concentrations of these radionuclides, so it cannot be used to determine whether the ^{226}Ra is due to mill tailings. However, its higher sensitivity permits a much more rapid screening of samples than would be possible using a germanium diode.

Visual observations of the physical characteristics of the soil samples and the deposits of the sampling sites are also used to indicate whether residual radioactivity is present. This is especially needed to differentiate between translocated ore (which is considered to be residual radioactivity) and ore in a natural, undisturbed deposit (which is not considered to be residual radioactivity).

WORKSHOP CONCLUSIONS AND PROTOCOL CHANGES

CONCLUSIONS FROM WORKSHOP

In order to acquaint interested investigators with the procedures PNL has developed and the measurements that have been performed at Edgemont using these procedures, and also to obtain suggestions for the improvement of these procedures, PNL organized a "Workshop on Radiological Surveys in Support of the Edgemont Clean-up Action Program" on behalf of the Nuclear Regulatory Commission. This workshop was held in Denver on January 21 and 22, 1981. On the first day of the workshop an in-depth discussion of the procedures employed in the entire radiological survey program at Edgemont was held. It included a description of the equipment, techniques and procedures employed in radon daughter measurements within structures, indoor and outdoor gamma radiation surveys, and ^{226}Ra measurements in surface and sub-surface soil samples. On the second day, the results of the measurements that have been conducted at Edgemont were presented. During the afternoon an open discussion of the radiological survey procedures used at Edgemont was held for the purpose of obtaining suggestions for the possible improvement of these procedures. Many useful suggestions were made and a few modifications in the survey procedures at Edgemont have been made in response to these suggestions.

No really important shortcomings of the PNL approach were brought out at the workshop. The purpose of the survey was to identify property requiring remedial action, and to release property that satisfied HUD criteria. The survey was not a research project. HUD does not intend to "split hairs" about meeting EPA clearance criteria.

The validity of grab working level measurements was questioned by several. However, grab measurements are probably appropriate for the purpose they were intended, which was to screen out structures having working levels much different (either higher or lower) from the 0.015 WL clearance criteria. However, a statistical study should be made of the grab working levels, the long-term working levels, and the subsequent results of engineering assessments to determine how accurately grab working levels identify structures that either clearly do not, or clearly do require remedial action.

There was a strong recommendation for the use of the audible signal and earphones during the gamma radiation surveys.

Some believed that more soil samples at greater depth should be taken. However, if no elevated gamma exposure rates or working levels can be detected, then the subsurface residual radioactivity, if any, will not produce a significant radiation dose to the population. When anomalous gamma exposure rates, ^{226}Ra concentrations in surface soil, or elevated working levels are observed, core samples and searches for the source of the radiation should be conducted.

Several attendees expressed their confidence in Track Etch® film techniques and recommend that Schiager's review of the Grand Junction program be studied carefully. The practical worth of these methods is still being questioned. It is clear that further research should be done to determine how accurately Track Etch® devices determine working levels, and to determine whether some films and techniques of mounting, track developing, calibration, and reading are better than others. This research should be done before replacing RPSIU working level measurements with Track Etch® measurements, to insure that large numbers of Track Etch® measurements of dubious validity are not made.

It was mentioned several times that barometric pressure changes affect indoor and outdoor radon and daughter concentrations. Although the Edgemont survey is not a research project, the barometric pressure data should be studied to determine whether it can be useful in accounting for or defining the range of uncertainty of the indoor working level measurements, or in estimating annual averages from either single or multiple five-minute measurements.

The question of simultaneous indoor and outdoor radon and daughter measurements was raised several times. As a result of the workshop, radon daughter concentrations are now being measured simultaneously inside and outside of structures being surveyed to identify cases where high outdoor concentrations could be causing increases in indoor concentrations. A large number of comparisons of indoor and outdoor radon and daughter concentrations could help to determine (1) whether radon or radon daughter measurements provide a better measure of the lifetime average working levels in a structure, and (2) whether multiple five-minute measurements or Track Etch® can replace RPISU's for determining annual average working levels.

The relationship of outdoor gamma dose rates to the ^{226}Ra concentration of soils (one of the questions raised) does not affect the existing protocol. Radium-226 measurements are being made in soil at every house regardless of the gamma exposure rates. The use of a gamma exposure rate criterion for outdoor surveys covers only those rare cases where there is a small deposit containing ^{226}Ra which the soil core samples miss, so that the radium measurements themselves do not show a need for an engineering assessment.

It was felt by many that a similar workshop to discuss the radiation surveys at Butte, Montana, at Edgemont, and at DOE remedial action sites should be held in about a year.

CHANGES IN EDGEMONT PROTOCOLS MADE AS A RESULT OF DISCUSSIONS AT THE WORKSHOP

As a result of suggestions made by attendees at the Denver workshop, we have made a few changes in the protocols used to conduct radiological surveys at Edgemont. These changes are reported in the protocols, but for the convenience of the reader, they are also listed below.

Beginning in February of 1981, radon daughter concentrations will be measured outside of structures before or during the time that radon daughter measurements are made inside the structures to determine whether the outdoor concentrations can be causing increases in the indoor concentrations. However, if it is found that the outdoor concentrations at any part of town on a given day are considerably below 0.010 WL, no more outdoor working levels will be measured for the rest of the day.

As soon as the necessary equipment is obtained, grab radon measurements will also be made outside and inside of structures at the same time as the indoor radon daughter concentrations are being measured. The data gathered will be used to determine whether radon measurements instead of working level measurements could be used for screening purposes in future surveys.

Terradex type F Track Etch® devices will be placed in 50 structures in which RPISU measurements are being made to determine how well the working levels determined using the Track Etch® correspond to those measured with RPISU. One Track Etch® will be placed for a period of one year in each of these structures, and another will be changed every other month at the same time as the RPISU samplers are installed.

Beginning in February of 1981, gamma surveys in garages and nonhabitable basements will be conducted using grid networks and measurements procedures identical to those used inside other structures (i.e., at the grid points of a 25 ft^2 grid). Previously, we had measured the gamma exposure rates during a serpentine walk-through of the garages and non-habitable basements.

The Ludlum scintillometers have been fitted with earphones. The audible signals will be used in addition to the meter reading to locate residual radioactivity.

ABBREVIATED ENGINEERING ASSESSMENT PROTOCOL

An abbreviated engineering assessment will be performed in lieu of RPISU measurements on structures where radon progeny concentrations measured by grab sampling were in the range from 0.010 WL to 0.033 WL, indicating that they could have annual average working levels greater than 0.015 WL because of natural or residual radioactive material in the soil around the structure. The abbreviated assessment will also be performed at those structures where, after two attempts, it was not possible to obtain a grab sampling measurement for which the ratios of radon progeny concentrations indicated that the turnover time between the air in the structures and outdoor air complied with the grab sampling protocol. A full engineering assessment and remedial action will be required only in cases where residual radioactive materials containing ^{226}Ra concentrations greater than 5 pCi/g are identified in the abbreviated assessment. It will not be necessary to search for radioactivity in the construction material of the structures because this was done during the original radiation survey. If gamma radiation exposure rates greater than 20 μR/hr above background were observed that were due to material that could not easily be removed, the structures were scheduled directly for engineering assessment without making RPISU measurements.

SAMPLING PROTOCOL

One borehole will be drilled into the soil exterior to each side of the building within two meters of the building at the location showing the highest gamma radiation exposure rate, unless that location is obstructed at or below surface by an object such as a sidewalk or a sewer pipe. In that case, the borehole will be drilled as close as possible to the location showing the highest exposure rate. If there is a garage, patio, or other structure attached to a side of the building that prevents the drilling of a borehole within two meters of the building, the hole will be drilled within two meters of the main building as close as possible to a point of attachment of the attached structure. The holes will be drilled to a depth of two meters below the surface, or to the level of the foundation, whichever is deeper. If obstructions make it difficult or risky to drill the hole, it will be hand-dug instead to as great a depth as practical (generally about one meter). If residual radioactive material is measured at the bottom of this hole, another hole will be drilled nearby, avoiding the obstruction, to determine the depth to which the residual radioactivity extends. The ^{226}Ra concentration surrounding the boreholes will be logged every 15 cm in depth (starting at the surface) using a NaI(Tl) gamma-ray detector.

If no ^{226}Ra concentrations greater than 5 pCi/g are measured in the boreholes, it will be assumed that the structure does not have elevated working levels due to residual radioactivity. Therefore, the structure will be cleared from remedial action. However, if ^{226}Ra concentrations greater than 5 pCi/g are logged in any hole, the property will receive a radiological assessment report documenting the extent and nature of the radioactive deposit.

Calibration procedures for the borehole logging detection system are included as a separate topic of this report.

RADIOLOGICAL PROTECTION

The responsibility for the control of residual radioactive materials that are removed from their existing location by people employed by Pacific Northwest Laboratory (PNL) shall reside with the PNL staff. Appropriate survey meters (including a portable alpha-particle survey meter) will be used to determine the level of alpha-particle emitting surface contamination of the area around any location that has been selected for drilling prior to the drilling of the borehole. Following the drilling operation, the area will again be surveyed. Any detected contamination with alpha-particle emitting materials will be removed until the disintegration rate at any surface location is not significantly higher than the measured disintegration rate prior to drilling.

During drilling, the ground around each hole will be covered with a plastic-coated tarp that will be used to catch the soil from the borehole. If no ^{226}Ra concentrations greater than 5 pCi/g are logged in the borehole, the soil will be replaced in the hole. However, if the average ^{226}Ra concentration is greater than 5 pCi/g, the soil will be disposed of at the uranium mill disposal site, and the hole will be filled with soil that has been determined to have ^{226}Ra concentrations below 5 pCi/g.

All residual radioactive material will be stored in metal cans or a double wall container (such as plastic bag inside of a box or drum) during transport. Tarps with detectable surface contamination will be folded and placed in plastic bags during transport. All personnel and equipment surfaces exposed to residual radioactivity will be monitored for surface alpha particle contamination before leaving the property under test. Contaminated borehole drills will be cleaned before leaving the site, and waste material will be discarded at the Silver King disposal site.

ENGINEERING ASSESSMENT PROTOCOL

INTRODUCTION

According to the proposed standards in 40 CFR 192, remedial action shall be required on a property if residual radioactivity causes (1) average annual radon daughter concentrations greater than 0.015 working levels (WL) inside a structure; (2) gamma radiation exposure rates greater than 20 μR/hr above background inside a structure; or (3) ^{226}Ra concentrations in soil greater than 5 pCi/g in any 5 cm thickness of soil within 1 ft of the surface or any 15 cm below 1 ft. Any property that the initial radiation survey has shown to have radiation levels in excess of these standards will have an engineering assessment performed to determine whether the high radiation levels are due to residual radioactivity, and, if they are, to determine the extent of the radioactive materials and the extent of the remedial action that shall be performed. No remedial action will be performed if the high radiation levels are due to natural radioactivity, although the property owner(s) will be advised as to the steps he may take to lower the levels.

AVERAGE ANNUAL RADON DAUGHTER CONCENTRATIONS >0.015 WL

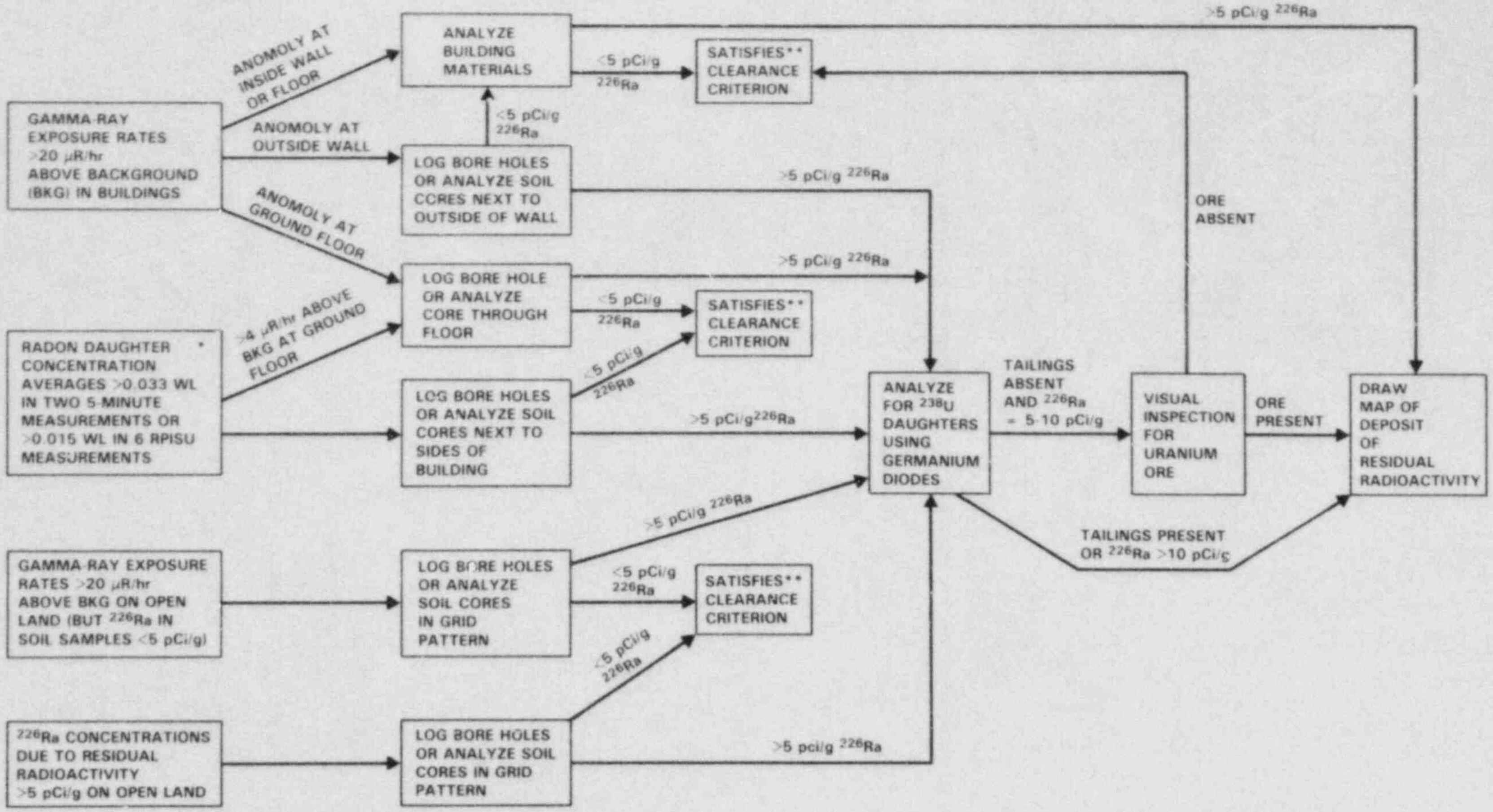
Structures that Require Engineering Assessment

Five-minute radon daughter measurements are being made in all reasonably airtight structures for which surveys have been requested. If the average of two measurements is greater than 0.033 WL, the property is scheduled for engineering assessment. If the five-minute measurement is 0.10 to 0.033 WL, or if two measurements show unacceptably short calculated turnover times, it is assumed that the five-minute measurement will not indicate with sufficient accuracy whether the annual average is greater or less than 0.015 WL. Therefore (if the structure does not already required engineering assessment because of failure of the gamma radiation and/or the ^{226}Ra criteria), a 100-hour Radon Progeny Sampling Unit (RPISU) measurement will be made every other month during the course of a year to determine the annual average in some of these structures. If the annual average is greater than 0.015 WL, the property will be scheduled for engineering assessment.

Protocols

The engineering assessments of structures that are required because of radon daughter concentrations will consist of borehole logging and soil analysis around the structures to determine the extent of any deposits of residual radioactive materials containing ^{226}Ra concentrations greater than 5 pCi/g. Very few, if any, cases have been observed where residual radioactivity in the building materials of a structure could possibly cause significantly increased radon daughter concentrations. The engineering assessment of building materials showing gamma radiation exposure rates greater tnan 20 μR/hr above background will be discussed below. A diagram of these procedures is shown in Figure A5.

One borehole will be drilled into the soil exterior to each side of the building within two meters of the building at the location showing the highest gamma radiation exposure rate, unless that location is obstructed at or below



*THIS ENGINEERING ASSESSMENT PROCEDURE ALSO FOLLOWED FOR SOME BUILDINGS HAVING RADON DAUGHTER CONCENTRATION OF 0.010-0.033 WL IN 5-MINUTE MEASUREMENT

**REMEDIAL ACTION PERFORMED UNLESS ALL CLEARANCE CRITERIA SATISFIED

FIGURE A5. Flow Diagram of Engineering Assessment Procedures the surface by an object such as a sidewalk or a sewer pipe. In that case, the hole will be drilled as close as possible to the location showing the highest exposure rates. If there is a garage, patio, or other structure attached to the side of the main building that will prevent the drilling of a hole within two meters of the main building, the hole will be drilled as close as possible to that point of attachment of the attached structure, and within two meters of the main building. Each hole will be drilled to a depth of two meters below the surface, or to the level of the foundation, whichever is deeper. If obstructions make it difficult or risky to drill the hole, it will be hand-dug instead to as great a depth as practical (generally about one meter). If residual radioactivity is measured at the bottom of this hole, another hole will be drilled nearby, avoiding the obstruction, to determine the depth to which the residual radioactivity extends. The ^{226}Ra concentrations surrounding the boreholes will be logged every 15 cm from the surface to a depth of 45 cm, and every 30 cm thereafter. The concentrations will be logged using a NaI(Tl) gamma-ray spectrometer. If the ^{226}Ra is greater than 5 pCi/g, or is increasing at a rate greater than 1 pCi/g/15 cm at the deepest level monitored, the hole will be extended in one-meter increments until the concentrations at the bottom of the hole are less than 5 pCi/g and are not increasing at a rate greater than 1 pCi/g/15 cm. A grid of contact gamma exposure rate measurements will be made around any borehole where the ^{226}Ra concentration exceeds 5 pCi/g at any depth increment or where existing measurements indicate gamma exposure rates exceed 20 μR/hr above background or ^{226}Ra concentrations in soil exceed 5 pCi/g. The grid spacing will be 2.5 feet. The grid will extend to locations where exposure rates are at background levels.

No ^{226}Ra concentrations greater than 5 pCi/g

If no ^{226}Ra concentrations greater than 5 pCi/g are measured in any borehole, it will be assumed that the radon daughter concentrations are due to natural radioactivity, so the structure will not require further radiological assessment and will be cleared from remedial action (unless gamma radiation exposure rates greater than 20 μR/hr above background or ^{226}Ra concentrations greater than 5 pCi/g were also measured at other locations during the radiation survey, in which case the engineering assessments that will be described in later sections of the protocol will be performed).

Radium-226 Concentrations Greater than 5 pCi/g

If ^{226}Ra concentrations greater than 5 pCi/g are logged in any hole, additional soil analysis or borehole logging using germanium diodes will be required to determine whether the ^{226}Ra is due to mill tailings. The soil will be analyzed at locations and depths where the ^{226}Ra concentrations are high enough to insure that reasonably accurate concentrations of the ^{238}U chain members can be obtained by germanium diode analysis. If the ^{226}Ra is due to mill tailings, the activities of ^{234}Th (24-day) should be significantly lower than the activities of the longer-lived uranium chain members, ^{230}Th, ^{226}Ra, and ^{210}Pb. However, if the ^{226}Ra is due to uranium ore or to local natural radioactivity, the activity of ^{234}Th should be similar to those of the other chain members. Samples of natural soil from the survey area will be analyzed for these radionuclides to determine the natural variabilities of the ratios of ^{234}Th to the other uranium daughters, so that soil samples containing ratios below this range can be identified as containing mill tailings. The resolution of NaI(Tl) is not good enough to measure the spectrum of ^{238}U daughters necessary to distinguish between mill tailings and unprocessed uranium ore, but NaI(Tl) is used for the original screening of boreholes because its greater sensitivity permits a much more rapid screening than would be possible using germanium diodes.

Radium-226 Concentrations >5 pCi/g Due to Natural Radioactivity

If the activity of ^{234}Th (24-day), the short-lived daughter of ^{238}U, is comparable to those of the other ^{238}U daughters, it will be concluded that the ^{226}Ra, and the radon daughter concentrations in the building are due either to uranium ore or to local natural radioactivity. Uranium ore is likely to be present in the form of yellow (sometimes green or black) rocks or flakes that have high ^{226}Ra concentrations and are generally different in appearance from the surrounding soil matrix. If no such material is present and evidence is present of native material that is naturally radioactive, it will be concluded that the high ^{226}Ra concentrations are due to local natural radioactivity. Therefore, the property will be cleared from further remedial action (unless further engineering assessment is required because high gamma exposure rates and/or ^{226}Ra concentrations had been measured at other locations on the property).

Radium Concentrations >5 pCi/g Due to Residual Radioactivity

If the concentration of the short-lived ^{238}U daughter, ^{234}Th, is significantly lower than the concentrations of the other ^{238}U daughters, or if there is physical evidence that uranium ore is present, residual radioactivity can be considered to be present, so additional gamma surveys will be carried out and boreholes drilled to determine the extent of the residual radioactive materials. The holes will be drilled in a pattern that will be modified if gamma exposure rates or visual clues provide an estimate of the size of the deposit or residual radioactivity.

When borehole logging and soil analysis has been completed, a map will be drawn showing the boundaries and the depths of the ^{226}Ra concentrations greater than 5 pCi/g. The drawing will provide an estimate of the quantity of soil that will have to be removed during remedial action.

INDOOR GAMMA RADIATION EXPOSURE RATES >20 μR/hr ABOVE BACKGROUND

Structures in which gamma radiation exposure rates greater than 20 μR/hr above background were measured during the original gamma survey will require engineering assessment to determine the extent of any residual radioactivity present (unless the gamma radiation was from an easily removable object). Elevated gamma levels in structures could be due to (1) easily removable objects such as ore samples; (2) materials used in the construction of the structure; or (3) soil containing high ^{226}Ra concentrations around the structure.

Gamma Exposure Rates Due to Removable Objects

The owners or occupants of structures have been informed about the emission rates of easily removable objects that gave gamma exposure rates greater than 20 μR/hr above background during the gamma survey. Their disposal is at the discretion of the occupant, so no engineering assessment or remedial action will be required, other than to take away items for disposal at owner's request.

Gamma Exposure Rates Due to Building Materials

In a few cases, the original gamma survey identified gamma exposure rates greater than 20 μR/hr above background that could be clearly attributed to materials used in the construction of the structure, such as rocks used in building a fireplace. A NaI(Tl) detector will be used to confirm that the gamma exposure rates are due to ^{226}Ra. If the gamma-ray spectrum is primarily that of ^{226}Ra and its short-lived daughters, the building material will be scanned with a gamma-ray detector to determine the extent of the residual radioactive material causing gamma exposure rates greater than 20 μR/hr above background. That area will be eligible for remedial action, although remedial action will obviously be performed only if it is desired by the owner. If the high gamma readings are not due to ^{226}Ra or ^{238}U decay chain members, no further engineering assessment will be performed (unless required by failure of other criteria).

Gamma Exposure Rates that Could be Due Either to Building Materials or to Surrounding Soil

Gamma exposure rates greater than 20 μR/hr above background have been observed in contact with outside walls and basement floors that could have been due to high ^{226}Ra concentrations in the soil on the other side of the wall or floor. In cases where such exposure rates were measured in contact with outside walls, soil core samples will be taken or boreholes drilled as close to the building as possible next to the location of the maximum indoor gamma reading. If the high gamma exposure rates are measured in the basement floor, a core will be drilled through the floor at the location of maximum gamma reading. Each core will be analyzed for ^{226}Ra using a NaI(Tl) detector. Boreholes will be logged using either NaI(Tl) or germanium diode detectors. If ^{226}Ra concentrations greater than 5 pCi/g are measured, additional boreholes will be logged to determine the extent of the deposit. If the ^{226}Ra is due to natural radioactivity, and is high enough to cause the measured gamma exposure rates, no further engineering assessment or remedial action will be performed (unless required by high working levels, gamma readings and/or ^{226}Ra concentrations at other locations).

If no ^{226}Ra concentrations are measured in the soil samples that could have caused the high gamma exposure rates, samples of the building material will be analyzed for ^{226}Ra. If ^{226}Ra concentrations greater than 5 pCi/g are measured, a gamma-ray detector will be used to determine the extent of the source of elevated gamma exposure rates. Sufficient detail will be provided to establish the remedial action required.

In the unlikely event that the cause of the elevated gamma readings has not yet been discovered at this point, additional soil samples and possibly samples of the wall will be analyzed for ^{226}Ra until the cause is discovered. Particular attention will be given to discovering any hot rock that could be causing the anomaly.

OUTDOOR GAMMA EXPOSURE RATES >20 μR/hr ABOVE BACKGROUND AND/OR ^{226}Ra CONCENTRATIONS >5 pCi/g IN SOIL

Locations where ^{226}Ra concentrations greater than 5 pCi/g were measured in soil samples during the radiation survey will require engineering assessment to determine whether the ^{226}Ra is due to residual radioactivity and, if it is, to determine the extent of the deposit. Engineering assessments will also be performed at outdoor locations where gamma radiation exposure rates greater than 20 μR/hr above background were observed, because it is assumed that soil or rocks containing ^{226}Ra concentrations greater than 5 pCi/g are present at these locations even if it was not measured during the survey.

A grid pattern of boreholes will be logged at these locations using NaI(Tl) detectors to determine the extent of the ^{226}Ra concentrations greater than 5 pCi/g, with one of those holes being drilled at the location of maximum gamma exposure rate. A grid of gamma exposure rate measurements in contact with the surface will be made in the vicinity of each borehole where ^{226}Ra concentrations exceed 5 pCi/g at any depth increment, or where existing measurements indicate gamma exposure rates exceed 20 μR/hr above background or ^{226}Ra concentrations in soil exceed 5 pCi/g. The grid spacing will be 2.5 feet. The grid will extend to locations where exposure rates are at background levels. The measured gamma exposure rates will be used to determine the size, shape, and density of the borehole grid. One hole will be drilled to a depth of two meters initially, but if any hole shows ^{226}Ra concentrations greater than 5 pCi/g or ^{226}Ra concentrations increasing faster than <1 pCi/g/15 cm at the bottom, that hole will be extended in one meter increments until the ^{226}Ra concentration at the bottom of the hole falls to around 5 pCi/g, or less. If the initial hole indicates that the deposit is shallow, each additional hole will only be drilled to a depth of at least 30 cm below the maximum depth at which ^{226}Ra concentrations greater than 5 pCi/g have been measured in previous holes. At least one soil sample will be analyzed, or borehole logged, with a germanium diode to help determine whether the ^{226}Ra is due to residual radioactivity. If it is, a map will be drawn showing the boundaries of the ^{226}Ra concentrations greater than 5 pCi/g and the depth of the deposit to provide an estimate of the quantity of soil that will have to be removed during remedial action.

PROTOCOL FOR DETECTING CONTAMINATION AROUND STRUCTURES WITH ELEVATED RADON DAUGHTER CONCENTRATIONS

INTRODUCTION

Protocols that were originally used at Edgemont, South Dakota required that 100-hour Radon Progeny Integrating Sampling Unit (RPISU) measurements be made every other month during the course of a year to determine the annual average radon daughter concentration in a building if the radon daughter concentration in an acceptable air filter measurement was between 0.010 and 0.033 working levels (WL). However, all of the annual average radon daughter concentrations estimated on the basis of air filter measurements in this range would be less than the final EPA 0.020 WL radon daughter standard. It was found at Edgemont that the annual average radon daughter concentrations obtained from six RPISU measurements averaged only 0.6 times the air filter measurements, because the air filter measurements were made in closed-up buildings. Therefore, the air filter measurements should be multiplied by 0.6 to obtain the best estimate of the annual average (0.33 X 0.6 = 0.0198). The average radon daughter concentration estimated in this manner is commonly referred to as the "weighted working level". The protocols used at Edgemont required RPISU measurements if the air filter measurements were between 0.010 and 0.033 WL because it was considered that air filter measurements in this range would not provide estimates of annual averages that were sufficiently precise to give adequate assurance that the annual average concentrations would be less than the 0.015 WL standard that was in force when the protocols were adopted.

There are 217 residence units that would still require year-long RPISU measurements if these protocols were followed. These measurements would require considerable time and money and would lead to a considerable delay in the completion of the remedial action program. In addition, previous measurements at Edgemont have indicated that (1) residual radioactivity would be discovered at few, if any, of these properties; (2) the probability of discovering residual radioactivity would be relatively independent of the measured radon daughter concentrations, and (3) gamma radiation and ^{226}Ra measurements would be much more useful for discovering residual radioactivity than would radon daughter measurements. Therefore, it would appear to be neither cost-effective nor necessary from a radiation protection standpoint to complete the RPISU measurement series. Gamma radiation and ^{226}Ra measurements should be used instead to locate residual radioactivity.

RESULTS OF PREVIOUS MEASUREMENTS AT EDGEMONT

During the period from July, 1981 through August, 1982, boreholes were logged close to the sides of 212 buildings during the engineering assessments of properties in Edgemont. These engineering assessments were carried out because ^{226}Ra concentrations in soil greater than 5 pCi/g, indoor or outdoor gamma radiation exposure rates greater than 20 μR/hr above background, and/or indoor radon daughter concentrations greater than 0.01 WL were measured during the radiological surveys of these properties. Residual radioactivity was discovered within a few feet of 32 (15%) of the buildings. However, residual radioactivity was discovered in only two of more than 140 cases (1.4%) in which boreholes were logged near a building solely because of elevated radon daughter concentrations. In both of these cases residual radioactivity was also discovered at other locations on the property that were some distance from the buildings. In all of the other cases indoor or outdoor gamma exposure rates greater than 20 μR/hr or ^{226}Ra concentrations greater than 5 pCi/g were measured within a few feet of the building during the radiological survey. Moreover, the probability of discovering residual radioactivity appeared to be essentially independent of the measured radon daughter concentrations. Residual radioactivity was found within a few feet of 16% of the buildings showing weighted working levels less than or equal to 0.020 WL, but was found within a few feet of only 13% of the buildings showing weighted working levels greater than 0.020 WL. Therefore, gamma radiation and ^{226}Ra measurements appeared to be much more useful for discovering residual radioactivity than did radon daughter measurements.

The gamma radiation exposure rate at the one meter elevation increased about 4 μR/hr above surrounding measurements at the locations where residual radioactivity was later discovered by borehole logging in both of the two cases where radon daughter concentrations greater than 0.010 WL, but no gamma exposure rates greater than 20 μR/hr above background or ^{226}Ra concentrations greater than 5 pCi/g were measured during the radiological surveys. Radium-226 concentrations greater than 5 pCi/g were measured in soil samples at these locations during the engineering assessments. Soil samples had not been collected at these locations during the radiological surveys because higher gamma exposure rates were measured at other locations on the properties where residual radioactivity was found to be present, and the protocols called for the collection of soil samples only at the two locations on the property showing the highest gamma radiation exposure rates. It seems likely that these cases would have been detected if their radiological survey measurements had been studied, and soil samples analyzed for ^{226}Ra at the locations within a few feet of the buildings that had gamma exposure rates at the one meter elevation that were equal to or greater than 4 μR/hr above the surrounding measurements, and that radon daughter measurements would not have been necessary to indicate the possible presence of residual radioactivity.

At Edgemont ^{226}Ra concentrations in soil greater than 5 pCi/g have been measured at only about 2% of the locations showing one meter elevation gamma exposure rates less than 4 μR/hr above background. The probability of measuring ^{226}Ra concentrations greater than 5 pCi/g increased slightly at gamma exposure rates that were 5 and 6 μR/hr above background, and then increased rapidly with increasing exposure rates to over 90% at exposure rates greater than 20 μR/hr above background. It therefore does not appear that it is necessary to analyze soil samples at locations showing gamma radiation exposure rates less than 4 μR/hr above background, but that soil samples should be analyzed at locations showing higher exposure rates.

RECOMMENDED PROCEDURES

The five-minute and RPISU radon daughter measurements that have been made up to the present time should be used to estimate the annual average radon daughter concentrations in the 217 buildings that would be required by present protocols to have year-long measurement series. The annual averages in buildings in which only five-minute measurements have been made should be estimated to be 0.6 times the measured concentrations to correct for the fact that the measurements were made in closed-up buildings. Single RPISU measurements have been made in addition to the five-minute measurements in many of the buildings. The annual averages in these buildings should be taken to equal the average of the RPISU measurement and 0.6 times the five-minute measurement. Previous measurements have shown that this average will provide a more accurate estimate of the annual average than either the five-minute or the single RPISU measurement alone.

Gamma radiation exposure rates and ^{226}Ra concentrations in soil, rather than radon daughter concentrations, should be used to determine which of the 217 buildings should require engineering assessment. The radiological survey measurements in and around the building should be inspected to determine whether there is evidence of somewhat elevated gamma radiation exposure rates. Special attention should be given to buildings that have estimated average annual radon daughter concentrations greater than 0.020 WL. If there are no locations that show gamma radiation exposure rates at contact or at the one meter elevation that are 4 μR/hr or more higher than those at surrounding locations, the building should be cleared from remedial action. If the indoor gamma exposure rates next to an outside wall, or the outdoor gamma exposure rates within a few feet of the building, show an increase of 4 μR/hr or more above surrounding areas at any location(s), a series of contact and one meter exposure rates (corrected to equivalent pressurized ionization chamber readings) should be measured around that location(s). These additional measurements should be made to confirm the elevated exposure rates, and to determine the locations of maximum exposure rates more accurately. If the additional measurements show no increases in the gamma exposure rate equal to or greater than 4 μR/hr at any location, the building should be cleared from remedial action, but if increases equal to or greater than 4 μR/hr are observed at any location(s), 0-15 cm and 15-30 cm depth soil samples should be collected outside the building as close to the locations of maximum exposure rate as possible. If no ^{226}Ra concentrations are measured that are greater than 5 pCi/g in any of the 0-15 cm or 15-30 cm samples, the building should be cleared from remedial action, but if concentrations due to residual radioactivity that are greater than this limit are measured in any of these samples, boreholes should be logged and gamma radiation measurements should be made using lead collimated detectors around the locations from which the soil samples were collected to determine the locations and dimensions of the deposits of residual radioactivity.

If the indoor gamma-radiation exposure rate either at contact or the one meter elevation shows an increase equal to or greater than 4 μR/hr at any ground-floor or basement location that is not near to an outside wall, a borehole should be logged through the floor at this location. If no ^{226}Ra concentrations due to residual radioactivity that are greater than 5 pCi/g are measured, the building should be cleared from remedial action, but any concentrations in excess of 5 pCi/g are measured, collimated contact gamma-radiation exposure rate measurements and borehole logging should be extended as necessary to determine the dimensions of the deposit.

Inspection of gamma radiation measurements around several buildings in Edgemont suggests that additional gamma exposure rate measurements would be required at about 30 of the 217 buildings at Edgemont if the above protocols were followed. The additional gamma radiation measurements would probably fail to discover exposure rates equal to or greater than 4 μR/hr above surrounding measurements at some of these locations. In addition, some of the soil samples collected at locations showing gamma exposure rates greater than 4 μR/hr above surrounding measurements would undoubtedly contain ^{226}Ra concentrations less than 5 pCi/g. Therefore the number of engineering assessments that would be required if the proposed protocols were followed would be less than 30.

APPENDIX B

MASTER LIST - PROPERTIES SURVEYED, WITH RESULTS

Explanation of the Master List

The Master List contains a list of all properties surveyed with results segregated into classes. The codes and their meanings used in each column of the Master List are given below. Asterisks are used in columns 1 through 7 to call attention to a comment in column 11 under NOTES.

PROPERTY IDENTIFIERS

Column 1 Property Type

Code	Meaning
R	Residential (i.e.- any property with an occupiable building)
CO	Commercial
I	Industrial
G	Government
S	School
CH	Church
V	Vacant Land
O	Other (e.g.-lodges, meeting halls)

Column 2	PNL Number	This is the number assigned to each property for identification purposes by Pacific Northwest Laboratory.
Column 3	EPA Number	This is the Environmental Protection Agency survey number assigned to certain properties surveyed by them.
Column 4	State Number	This number was used for identification puposes by the State of South Dakota.

SURVEY STATUS

Column 5 Results

Code	Meaning
C	1. All criteria satisfied
	2. Six failure pathways
RG	a) Failed average radon progeny grab (greater than 0.033WL)
RR	b) Failed RPISU (greater than 0.015WL)
IG	c) Failed indoor gamma (greater than 20 μR/hr + BKGD)
OG	d) Failed outdoor gamma (greater than 20 μR/hr + BKGD)
S	e) Failed Ra-226 in soil (greater than 5 pCi/gm)
RGS	f) Failed radon/gamma/soil (0.01WL-0.033WL, greater than 4μR/hr + BKGD, greater than 5pCi/gm)

Engineering Assessment

Column 6 Date

This is either the date of issuance of the engineering assessment report or the date the property was cleared by the engineering assessment.

Column 7 Results

Code	Meaning
N	1. No residual radioactive materials (RRM) discovered
	2. Four categories of contamination
HS	a) "Hot spots" or easily removed contamination
OD	b) Outdoor deposits (broken down in separate Table 4)
	c) Structural involvement (broken down in separate Table 5)
W	d) Windblown

NOTES

Column 8 Notes are comments to clarify or qualify entries in other columns. For survey purposes, a Lot is defined as a parcel of land roughly corresponding to one-half city block or less which is given a radiation survey based on a single set of grid points. Distinction is made in Table_ by capitalizing Lot when referring to a survey Lot, and using lower case when referring to a city or platted lot. A Block (capitalized) is a large parcel of land given a single survey grid as opposed to a city block (lower case).

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	1	--	250	RR	July, 1983	N	
R	2	--	341	C			
R	3	--	315	C			
R	4	--	373	RG	July, 1983	N	
R	5	--	374	RG, OG, S	April, 1983	OD	
R	6	--	345	C			
R	7	--	335	RR	July, 1983	N	
R	8	--	253	C			
R	9	--	267	OG, S	April, 1983	OD	
R*	10	--	267	*		*	*Mobile home on same Lot as State 267, see PNL 9
R*	11	7811-08	281	C			*PNL 11 and PNL 12 are on adjacent lots surveyed as 1 Lot
R*	12	--	282	C			*PNL 11 and PNL 12 are on adjacent lots surveyed as 1 Lot
R	13	7811-66	10	OG, S	June, 1980*	OD	*Engineering Assessment performed by ARIX
R	14	--	384	RR	July, 1983	N	
R	15	--	318	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	16	--	252	C			
R	17	--	383	C			
R	18	--	386	C			
R	19	--	102	C			
R	20	--	359	RG	July, 1983	N	
R	21	--	329	RR	July, 1983	N	
R	22	--	91	C			
R	23	--	336	RG, S	July, 1983	N	
R	24	--	323	RG	July, 1983	N	
R	25	--	277	RR	July, 1983	N	
V	26	--	284	C			
R	27	--	337	C			
R	28	--	395	C			
R	29	--	239	RG, IG, OG S	May, 1983	OD* SI**	*Owner refused borehole through front porch **Either the concrete slab in the porch or the material used for fill under the slab contains radioactive material
R	30	--	398	C			
P	31	--	491	C			
CH	32	7811-24	404	RR, S	June, 1983	OD	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	33	--	147	RG, S	April, 1983	OD	
R	34	7811-51	291	C			
R	35	--	259	C			
R	36	--	283	C			
R	37	7811-16	413	C			
R	38	--	409	C			
R	39	7811-06	300	C			
R	40	--	378	OG	Sept, 1982	N*	*Owner refused removal of radioactive native stone in outdoor barbecue
R	41	--	325	C			
CO	42	--	421	C			
I	43	--	420	S	June. 1983	OD	
R	44	--	143	RG	Feb, 1983	N	
R	45	--	310	C			
R	46	--	402	R*			*Owner refuseo further testing after first visit
R	47	--	301	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	48	--	220	RR, S	Feb, 1983	N	
R	49	7811-58 7811-74	17	OG, S	July, 1980*	OD	*Engineering Assessment performed by ARIX
R	50	7811-39 72-40540	32	S	Nov, 1983*	OD	*ARIX performed part of Engineering Assessment
R	51	--	425	C			
R	52	72-40540	245	RG	June, 1982	N*	*Uranium mineral samples stored in attic removed from property by owner
R	53	--	326	RR	Feb, 1983	N	
R	54	72-40558	22	RG, RR	March, 1983	N	
R	55	--	410	C			
R	56	--	184	C			
R	57	--	431	RG, IG, OG, S	May, 1983	OD SI*	*Uranium-bearing material not native to this property adjacent to the garage and uranium mill tailings beneath the rear porch were found
R	58	--	242	C			
R	59	--	330	RG	Feb, 1983	N	
R	60	--	367	RG	Feb, 1983	N	
R	61	--	363	C			
R	62	--	222	RG	Feb, 1983	N	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	63	--	364	C			
R	64	--	280	C			
R	65	7811-15	208	C			
R	66	--	192	C			
R	67	--	327	C			
R	68	--	342	C			
R	69	--	406	RG, S	Feb, 1983	N	
V*	70A	--	130	C			*1 Block
V*	70B	--	130	C			*1 Block
V	70C	--	130	C			
V	70D	--	130	C			
V	70E	--	130	C			
V	70F	--	130	C			
V	70G	--	130	C			
V	70H	--	130	C			
V	70I	--	130	C			
V	70J	--	130	S	Feb, 1983	N	
V	70K	--	130	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	70L	--	130	C			
V	70M	--	130	C			
V	70N	--	130	C			
V	70O	--	130	C			
V	70P	--	130	C			
V	70Q	--	130	C			
V	70R	--	130	C			
V	70S	--	130	C			
V	70T	--	130	C			
V	70U	--	130	C			
V	70V	--	130	C			
V	70W	--	130	C			
V	70X	--	130	C			
V	70Y	--	130	C			
V	70Z	--	130	C			
V	70AA	--	130	C			
V	70BB	--	130	C			
V	70CC	--	130	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	70DD	--	130	C			
V	70EE	--	130	C			
V	70FF	--	130	C			
V	70GG	--	130	C			
V	70HH	--	130	C			
R	71	--	441	RR	Feb, 1983	N	
R	72	--	256	C			
R	73	--	346	RR	Feb, 1983	N	
R	74	--	415	C			
R	75	--	428	C			
R*	76	--	200	RR	Feb, 1983	N	*2 units surveyed as 1 residence unit
R	77	--	439	RG	Feb, 1983	N	
R	78A	--	423	C			
R	78B	--	423	RG	Feb, 1983	N	
R	79	--	396	S	Feb, 1983	OD	
R	80	--	407	C			
R	81	--	256	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	82A	--	411	RG, OG, S	March 1983	OD SI*	*Uranium bearing material on roof of root cellar
R	82B	--	411	*	*	*	*Common outdoor contamination with PNL 82A
R	83	--	343	C			
V	84A	--	440	C			
V	84B	--	440	C			
V	84C	--	440	C			
V	84D	--	440	C			
V	84E	--	440	C			
V	84F	--	440	C			
V	84G	--	440	C			
V	84H	--	440	C			
R	85	--	372	C			
R	86	--	465	C			
R	87	--	332	C			
R	88	--	352	C			
R	89	--	103	C			
R	90A	--	437	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	90B	--	437	C			
R	90C	--	437	C			
R	91	7811-17	438	C			
R	92	7811-33	328	C			
R	93	--	348	C			
R	94	--	286	C			
R	95	--	188	C			
R	96	--	412	OG, S	April, 1983	OD	
R	97	7811-10	268	C			
R	98	--	354	RGS	May, 1984	SI*	*Tailings material used in stucco on structure addition
R	99	--	116	C			
R	100	7811-43	350	C			
R	101	--	246	S	April, 1983	OD	
R	102	--	123	RG	Feb, 1983	N	
R	103	--	247	RG	Feb, 1983	N	
CO	104	--	457	C			
CO	105A	72-42520	49	S	Feb, 1983	N*	*Radioactive soil from highway right-of-way, not property was located

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	105B	72-42520	49	*	*		**Common apparent outdoor contamination with PNL 105A
CO	106	--	433	C			
R	107	--	262	C			
R	108	72-40535	36	C			
R	109	--	232	C			
CO	110A	72-40534	37	C			
V	110B	72-40534	37	C			
CO	111	--	331	RG	Feb, 1983	N	
CO	112A	7811-13 72-40549	142	C*	*	*	*Run in conjunction with PNL 112B
CO	112B	7811-13 72-40549	142	IG*	July, 1982	N	*Box of ore samples removed by owner
CO	113	--	455	C			
CO	114	72-40550	21	C			
R	115	7811-09	461	C			
R	116	--	165	C			
R	117*	--	355	C			*This property changed hands and was rerun at owner's request; see PNL 340, State 355

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	118	--	464	C			
R	119	72-40529	42	OG, S	April, 1983	OD	
R	120	--	313	C			
CO	121	--	41	C			
CO	122	--	434	C			
R	123A	--	448	RGS	May, 1984	OD	
R	123B	--	448	*	*	*	*Common outdoor contamination with PNL 123A
R	124	--	446	C			
CO	125	--	260	OG, S	Sept, 1983	OD	
R	126	--	376	C			
R	127	--	290	C			
R	128A	7811-60 72-40542	2	S	March, 1983	OD	
R	128B	7811-60 72-40542	2	*	*	*	*Common outdoor contamination with PNL 128A
R	129	--	249	C			
CO	130A	72-40541	31	C			
CO	130B	72-40541	31	C			
R	131	--	495	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	132	--	266	C			
R	133	--	381	C			
R	134	--	382	C			
R	135	--	339	C			
R	136	--	334	RG	Feb, 1983	N	
R	137	--	475	C			
R	138	--	244	C			
R	139	--	303	C			
R	140	--	408	C			
R	$141A_1$	--	134	C			
R	$141A_2$	--	134	RG	Feb, 1983	N	
R	$141A_3$	--	134	C			
R	$141A_4$	--	134	C			
R	$141B_1$	--	134	C			
R	$141b_2$	--	134	C			
R	$141B_3$	--	134	C			
R	$141B_4$	--	134	C			
R	142	72-40521	48	RG	Feb, 1983	N	

Property Identifiers				Survey Status	Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	143A	--	129	C			
R	143B	--	129	C			
R	143C	--	129	C			
R	143D	--	129	C			
R	144	--	132	RR	Feb, 1983	N	
R	145	--	287	C			
R	146A	--	197	C			
R	146B	--	197	C			
O	147	--	459	RR, S	March, 1983	OD	
R	148	--	299	RG	Feb, 1983	M	
R	149	--	458	S	April, 1983	OD	
R	150 office	72-40524	1	IG	July, 1983	SI*	*Tailings material identified beneath floor of office living room during ARIX Engineering Assessment
R	150A	72-40524	1	C			
R	150B	72-40524	1	C			
R	150C	72-40524	1	RG	July, 1983	N	
R	150D	72-40524	1	C			
R	150E	72-40524	1	C			

Property Identifiers				Survey Status			Notes
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	150F	72-40524	1	C			
R	150G	72-40524	1	C			
R	150H	72-40524	1	OG, S	July, 1983	OD	
R	150I	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150J	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150K	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150L	72-40524	1	C			
R	150M	72-40524	1	C			
R	150N	72-40524	1	C			
R	150O	72-40524	1	C			
R	150P	72-40524	1	C			
R	150Q	72-40524	1	C			
R	150R	72-40524	1	C			
R	150S	72-40524	1	C			
R	150T	72-40524	1	C			
R	150U	72-40524	1	C			
R	150V	72-40524	1	C			
R	150W	72-40524	1	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	150X	72-40524	1	C			
R	150Y	72-40524	1	C			
R	150Z	72-40524	1	C			
R	150AA	72-40524	1	C			
R	150BB	72-40524	1	C			
R	150CC	72-40524	1	C			
R	150DD	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150EE	72-40524	1	* also RG	*	*	*Common outdoor contamination with PNL 150H
R	150FF	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150GG	72-40524	1	* also RG	*	*	*Common outdoor contamination with PNL 150H
R	150HH	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150II	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150JJ	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150KK	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150LL	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150MM	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H
R	150NN	72-40524	1	*	*	*	*Common outdoor contamination with PNL 150H

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
R	151	--	418	RG	Feb, 1983	N	
R	152	--	403	C			
R	153	--	139	C			
R	154	--	82	RG	Feb, 1983	N	
R	155	7811-41	344	RG	Feb, 1983	N	
R	156	7811-59	450	C			
R	157	7811-02	353	RG	Feb, 1983	N	
R	158	--	436	RG, S	March, 1983	OD	
R	159	--	391	C			
R	160	--	141	IG*, R**	**	R**	*Basement fireplace contains ore samples in rock work **Owner refused RPISU, Engineering Assessment
R	161	--	316	C			
R	162	--	233	RG	Feb, 1983	N	
R	163	--	442	OG, S	March, 1983	OD	
R	164	--	322	RG, S	April, 1983	OD	
R	165	--	478	RR, S*	Feb, 1983	N	*Bentonite clay lens found at depth of radioactive zone
R	166	--	369	OG, RG, S	March, 1983	OD	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	167	7811-53	477	C			
R	168	7811-14	419	RG	Feb, 1983	N	
R	169	--	416	C			
R	170	--	429	RG	Feb, 1983	N	
R	171	--	243	RG, OG, S	March, 1983	OD	
R	172	--	387	C			
R	173	72-40539	33	RG, RR, S	March, 1983	OD	
R	174	--	154	RG	Feb, 1983	N	
R	175	--	479	C			
R	176	--	279	RR	Feb, 1983	N	
R	177	--	190	RG	Feb, 1983	N	
R	178	72-40554	24	C			
R	179	--	485	OG, S	March, 1983	SI* OD**	*It appears that a stone containing a uranium mineral was used in the concrete to construct a small masonry planter wall **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	180	--	456	C			
R	181	--	379	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	182	7811-75	305	C			
R	183	--	258	C			
CH	184	--	488	C			
R	185	40-516	445	RR, S	March, 1983	N	
R	186	--	471	C			
R	187	--	370	OG, S	March, 1983	OD	
R	188	--	237	C			
R	189	--	470	C			
R	190	72-40517	50	S	Sept, 1983	OD*	*Anomaly appears to be related to highway run off
R	191	7811-22	397	C			
R	192	7811-28	273	RR	March, 1983	N	
R	193	--	482	C			
R	194	--	490	C			
R	195	7811-52	226	C*			*State residence, PNL outdoor surveys
R	196	--	109	RG	March, 1983	N	
R	197	7811-03	114	C			
R	198	--	241	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	199	--	375	C*			*Owner removed rock from back yard
R	200	--	209	C			
R	201	--	127	RR	Feb, 1983	N	
R	202	--	340	RG	Feb, 1983	N	
R	203	--	264	RG	Feb, 1983	N	
R	204	--	321	C*			*House demolished after survey
R	205	--	320	RG	Feb, 1983	N	
R	206	--	285	RG	Feb, 1983	N	
R	207	72-40553	25	RG	Feb, 1983	N	
R	208	--	493	C			
V	209A	--	443	C			
V	209B	--	443	C			
V	209C	--	443	C			
V	209D	--	443	C			
V	209E	--	443	C			
V	209F	--	443	C			
V	209G	--	443	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	209H	--	443	C			
V	209I	--	443	C			
V	209J	--	443	C			
V	209K	--	443	C			
V	209L	--	443	C			
V	209M	--	443	C			
V	209N	--	443	C			
V	209O	--	443	C			
V	209P	--	443	C			
V	209Q	--	443	C			
V	209R	--	443	C			
R	210	--	74	OG, S	Nov, 1983	OD	
R	211A	40-506	64	OG, S	July, 1983	W	
V	211B	40-506	64	OG, S	July, 1983	OD	
R*	212	40-504	68	S	June, 1983	W	*6 small lots surveyed with home
R	213	--	67	S	Oct, 1983	W	
R	214	--	385	C			

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
R	215	--	393	C			
R	216	--	394	C			
R	217	--	392	C			
R	218	--	405	RG	March, 1983	N	
R	219	--	236	OG, S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	220A	7811-54	351	RR, OG, S	March, 1983	N*	*Removal of radioactive rock and surrounding soil eliminated high readings--Owner refused borehole at spot where radioactive rocks were found
CO	220B	7811-54	351	RR*	*	*	*Common outdoor contamination with PNL 220A
R	221	--	401	RG	March, 1983	N	
R	222	--	95	OG, S	March, 1983	OD	
R	223	--	186	S	March, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	224	7811-49	496	OG, S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R*	225	7811-29	486	C			*Nonhabitable house on property
R	226	--	119	RG	March, 1983	N	
R	227	--	506	OG, S	April, 1983	OD	
R	228	7811-44	481	RG	March, 1983	N	

Property Identifiers				Survey Status	Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	229	--	480	C			
R	230	7811-48	505	C			
R	231	--	347	S	July, 1983	W	
R	232	--	297	C			
R	233	--	494	C			
R	234	--	270	C			
R	235	--	292	RG	March, 1983	N	
R	236	--	361	RG	March, 1983	N	
R	237	--	500	C			
R	238	7811-01	503	C			
R	239	--	502	C			
R	240	--	497	C			
R	241	--	293	C			
R	242	--	113	C			
R	243	72-40519	234	RG, RR, OG, S	Oct, 1983	W	
R	244	--	257	OG, S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	245	--	254	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	246	--	126	C			
R	247	7811-47	101	C			
R	248	--	513	C			
R	249	--	498	C			
R	250	--	358	OG	June, 1983	SI*	*Contaminated sewer vent pipe
R	251	--	272	C			
R	252	--	314	C			
V	253	--	453	C			
R	254	--	311	C			
R	255	--	99	C			
R	256	--	466	C			
R	257	--	432	RG	March, 1983	N	
R	258	--	274	RR	March, 1983	N	
V	259A	--	520	C			
V	259B	--	520	C			
V	259C	--	520	C			
R	260	--	333	RG	March, 1983	N	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	261	--	86	OG, S	March, 1983	OD SI*	*Garage built on uranium mill tailings
R	262	--	248	RR	March, 1983	N	
V	263A	--	117	C			
V	263B	-	117	C			
V*	264A	7811-63 7811-83	52	OG, S	*	OD	*1 Block
S	264B	7811-63 7811-83	52	IG*	July, 1983	HS**	*Sample of uranium oxide in chemistry laboratory **Common outdoor contamination with PNL 264A
S	264C	7811-63 7811-83	52	*	*	*	*Common outdoor contamination with PNL 264A
S	264D	7811-63 7811-83	52	*	*	*	*Common outdoor contamination with PNL 264A
S	264E	7811-63 7811-83	52	RG*	*	*	*Common outdoor contamination with PNL 264A
S	264F	7811-63 7811-83	52	OG, S*	*	*	*Common outdoor contamination with PNL 264A
S	264G	7811-63 7811-83	52	RG*	*	*	*Common outdoor contamination with PNL 264A
CH	265A	7811-50	228	C			
R	265B	7811-50	228	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	FNL Number	EPA Number	State Number	Results	Date	Results	Notes
O	265C	7811-50	228	C			
O	266	72-40552	231	RR	March, 1983	N	
O	267	--	535	C			
R	268	--	518	OG, S	July, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	269	--	577	C			
R	270	7811-72	19	S	June, 1983	OD	
R	271A	--	585	C			
R	271B	--	585	C			
R	272A	--	578	C			
R	272B	--	578	RG	March, 1983	N	
R	273	--	536	C			
V	274	--	594	C			
V	275	--	546	C			
V	276	--	380	C			
G	277	72-40551	5	S	Feb, 1983	N	
CO	278	--	474	C			
CO	279	--	162	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	280	--	278	C			
CO	281	--	447	C			
CO	282	72-40550	105	C			
CO	283	--	539	RR	March, 1983	N	
R	284N	--	526	S	Sept, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	284S	--	526	*	*		**Common outdoor contamination with PNL 284N
R	285	--	556	C			
R	286	--	606	C			
R	287	--	476	RR	March, 1983	N	
R	288	--	83	C			
R	289	--	93	C			
R	290	--	135	RG	March, 1983	N	
R	291	--	44	RG, OG, S	March, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	292	--	524	RG	March, 1983	N	
G	293A	--	368	C			
V*	293B	--	368	C			*1 block

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	293C	--	368	C			*1 Block
R	294	--	529	C			
R	295	--	530	C			
CO	296	--	487	RR	March, 1983	N	
CO	297	--	599	C			
CO	298A	--	579	C			
R	298B	--	579	C			
R	299	--	158	OG, S	July, 1983	OD HS*	*Chunks of uranium bearing stone were present when surveyed, but were gone when engineering assessment was done.
CO	300	--	472	OG, S	April, 1983	OD* HS**	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area **Chunks of uranium bearing stone used as stepping stones and in wall
CO	301	--	563	C			
V	302	--	512	C			
CO	303	--	613	OG, S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
CO	304	--	582	OG, S	Sept, 1983	OD	
V*	305A	--	29	C			*1 Block vacant land
I	305B	--	29	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	306	--	161	C			
V	307A	72-40537	34	C			
V	307B	72-40537	34	C			
V	308A	72-40532	39	C			
V	308B	72-40532	39	C			
V	308C	72-40532	39	C			
V*	309A	--	473	C			*1/2 lot surveyed as 1 Lot
V	309B	--	473	C			
R	310	--	469	C			
R	311E	--	521	C			
R	311W	--	521	C			
R	312	--	574	C			
R	313	--	611	C			
V*	314	--	605	OG, S	April, 1983	OD	*Commercial garage on property
V	315	--	365	C			
CH	316	--	537	S	June, 1983	N*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	317	--	302	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	318	--	523	S	March, 1983	N	
R	319*	--	581E	OG	April, 1983	SI**	*See PNL 328 also **Radioactive rocks in concrete foundation and sidewalk
R	320	--	603	C			
R	321	--	534	C			
R	322	--	525	C			
R	323	7811-18	468	S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	324	--	377	S	April, 1983	OD	
R	325N	--	551	OG, S	Oct, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	325S	--	551	*	*	*	*Common outdoor contamination with PNL 325N
R	326	--	550	C			
R*	327	--	549	IG, OG	March, 1982	N**	*Mobile home removed before engineering assessment **Hot rock removed
R	328*	--	581W	*	*	*	*Same as PNL 319
R	329	--	592	C			
R*	330	--	517	C			*Nonhabitable house on property
R	331	--	312	S	R*	*	*Refused engineering assessment

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	332	--	604	C			
R	333	--	596	C			
R	334	--	133	RG	March, 1983	N*	*Bentonite clay at 4 ft to 6 ft depth
V	335	--	462	C			
R	336	--	587	RG	March, 1983	N	
R	337	--	131	C			
R	338	--	616	C			
R	339	--	636	OG, S	April, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
*	340*	--	355	C			*Resurvey of residential property PNL 117, State 355 at new owner's request
R	341	--	507	C			
R	342	--	516	RG	March, 1983	N	
CH	343	--	538	C			
R	344E	--	614	RG	March, 1983	N	
R	344M	--	614	C			
R	344W	--	614	RG	March, 1983	N	
O	345	--	183	C			
R	346	--	238	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	347	--	510	C			
R	348	--	53	C			
R*	349	--	349	C			*Also used commercially
R	350	--	533	OG, S	June, 1983	OD	
V	351	--	608	C			
V	352	--	414	C			
V	353	--	399	C			
V	354	--	557	C			
V	355	--	615	C			
V*	356	--	435	OG, S	March, 1983	OD	*1 Block (outlot)
CO	357WW	--	602	C			
CO	357SS	--	602	C			
V*	358	--	601	S	June, 1983	W	*Tank farm area
CO	359	--	430	OG, S	May, 1983	OD	
V	360	--	508	C			
V	361	--	508	C			
CO	362	--	600	C			

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
CO	363	--	584	S	Sept, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
CO	364	--	572	OG, S	Sept, 1983	OD*	*Also chunks of ore scattered on ground
R	365	--	467	C			
R	366	--	467	RGS	May, 1984	SI*	*Radioactive material under disintegrating concrete basement floor in vicinity of sewer line
V	367	--	559	C			
V	368	--	388	S	July, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V*	369	--	593	S	July, 1983	OD**	*3 lots surveyed as 1 Lot **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V*	370N	72-40547	27	S	June, 1983	N	*1 Block
V*	370S	72-40547	27	C			*1 Block
R	371	--	454	C			
R	372A	--	357	C			
V*	372B	--	357	C			*1 Block
R	373	--	489	C			
R	374	--	483	C*			*Radioactive plastic tubing source in house removed at owner's request. No elevated gamma after source removed

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	375	--	598	S	June, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V	376	--	547	C			
V*	377	72-40525	46	S	March, 1983	N**	*13 lots surveyed as 1 Block **Deposit buried by City of Edgemont during park construction. Can no longer locate elevated gamma nor radium
V*	378	--	597	C			*2 lots surveyed as 1 Lot
V*	379A	--	444	OG, S	June, 1983	OD	*1 Block
V*	379B	--	444	C			*1 Block
R	380	--	543	RG	March, 1983	N	
R	381	--	214	RG	March, 1983	N	
V	382	--	554	OG, S	May 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V	383	--	555	C			
R	384	--	515	RG, OG, S	Nov, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V	385	--	610	C			
V	386	--	463	C			
V	387	--	212	S	June, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	388A	--	553	OG, S	May, 1983	OD	*2 lots surveyed as 1 Lot
V*	388B	--	553	C			*2 lots surveyed as 1 Lot
V	389	--	519	C			
R	390	--	552	C			
R	391E	--	511	C			
R	391W	--	511	C			
R	392A	--	449	C			
V*	392B	--	449	C			*10 lots surveyed as 1 Block
R	393A	--	504	S	Sept, 1982	N	
V*	393B	--	504	C			*5 lots surveyed as 1 Lot
R	394A	--	362	C			
V	394B	--	362	C			
R	395A	--	389	C			
V*	395B	--	389	S	June, 1983	W	*1 Block
V	396	--	528	C			
V*	397	--	565	C			*2 lots surveyed as 1 Lot
R	398	--	564	OG, S	May, 1983	OD	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	399	--	168	OG	June, 1983	HS*	*Two sections of white 6 in. plastic pipe stored on ground were radioactive
V*	400A	--	417	C			*8 lots surveyed as 1 Block
R	400B	--	417	C			
R	401	7811-62	308	C*			*Radioactive rocks in garage were removed by owner
R	402	--	619	RG	March, 1983	N	
R	403	--	251	OG, S	Nov, 1983	SI* OD	*Radioactive material beneath three-quarters of the garage concrete floor
V*	404	--	620	C			*Nonhabitable house on lot not surveyed
R	405	--	460	C			
R	406	--	298	C			
V	407	--	548	C			
R	408A	--	118	C			
V*	408B	--	118	OG, S	July, 1983	OD	*1 Block
G	409	--	366	S	May, 1983	OD	
R	410A	72-40531 7811-84	40	S	Sept, 1982	N	
V*	410B	72-40531 7811-84	40	C			*22 acres surveyed as 1 Block

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	411A	--	633	C			
V*	411B	--	633	C			*415 ft x 450 ft surveyed as 1 Block - parts of large farm
R	412A	72-40555 7811-79	23	C			
R	412B	--	23	C			
R	412C	--	23	C			
R	412D	--	23	C			
R	412E	--	23	C			
R	412F	--	23	C			
R	412G	--	23	C			
R	412H	--	23	C			
R	412I	--	23	C			
R	412J	72-40555 7811-79	23	C			
R	412K	72-40555 7811-79	23	C			
R	412L	72-40555 7811-79	23	C			
R	412M	72-40555 7811-79	23	RG	March, 1983	N	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	412N	72-40555 7811-79	23	C			
R	412O	72-40555 7811-79	23	C			
R	412P	72-40555 7811-79	23	C			
R	412Q	72-40555 7811-79	23	C			
R	412R	72-40555 7811-79	23	RG	March, 1983	N	
R	412S	72-40555 7811-79	23	C			
R	412T	72-40555 7811-79	23	C			
R	412U	72-40555 7811-79	23	C			
R	412V	72-40555 7811-79	23	C			
R	412W	72-40555 7811-79	23	C			
R	412X	72-40555 7811-79	23	C			
R	412Y	72-40555 7811-79	23	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	413	--	527	C			*1 Block
V	414	--	218	C			
R	415	--	627	RG	March, 1983	N	
R	416	--	501	C			
R	417	--	155	C			
R	418	--	609	C			
R	419	40-523	306	OG, S	June, 1983	W	
V	420	--	304	C			
V	421	--	588	C			
R	422	40-505	94	OG, S	June, 1983	W	
R	423	--	70	OG, S	Nov, 1983	OD	
V*	424	--	561	C			*2 nonhabitable buildings + 6 lots surveyed as 1 Lot
V*	425	--	567	C			*1 nonhabitable building on Lot
V*	426	--	562	C			*1 nonhabitable structure + 3-1/2 lots surveyed as 1 Lot
V*	427	--	560	OG, S	March, 1983	N**	*9 lots surveyed as 1 Lot **Radioactive rock removed
CO	428A	--	590	C			

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
V*	428B	--	589 590 591	S	Oct, 1982	N**	*11 lots 16 lots 41 lots surveyed as 1 Block 14 lots stockyards **City excavated after survey-resampling found no residue
V*	429A	40-514	626	OG, S	July, 1983	W	*6 lots surveyed as 1 Block
R*	429B	40-514	626	**	**	**	*See also PNL 724, State 56 **Common outdoor contamination with PNL 429A
R	430	--	63	C*			*PNL inside survey only, state did remainder
R	431	--	65	RG, OG, S	June, 1983	W	
V*	432	--	580	C			*3 lots surveys as 1 Lot
V*	433	--	595	C			*21 lots surveyed as 1 Block
R	434	--	618	C			
R	435	--	124	S	July, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	436	--	240	RG	March, 1983	N	
R	437A	--	558	OG	Sept, 1983	HS*	*Radioactive rock in rock pile on property
V*	437B	--	558	C			*3 lots surveys as 1 Lot
V*	438	--	452	C			*130 ft x 300 ft = 1 Block
V*	439	--	623	C			*7 lots surveyed as 1 Lot

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	440	--	632	C			
CO	441	--	319	C			
R	442	--	566	C			
R	443	--	360	C			
R	444	--	499	C			
V	445	--	612	C			
*	446	--	338	*			*Void see State 562, PNL 426
V*	447A	--	422	C			*9 lots surveyed as 1 Block
R	447B	--	422	S	Oct, 1982	N	
V*	448	--	371	C			*1-1/2 lots surveyed as 1 Lot
V	449	--	540	C			
V*	450	--	317	C			*2 lots surveyed as 1 Lot
V*	451	--	622	S	March, 1983	OD	*5 lots surveyed as 1 Lot
R	452	--	621	C			
R	453A	--	571	OG, S	May, 1983	OD* SI**	*A rock wall also contained contaminated stones **Uranium bearing materials were used in a concrete patio slab
V*	453B	--	571	C			*6 lots surveyed as 1 Lot

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	454	--	617	C			*1 Lot - mobile home not surveyed
R	455	--	390	OG, S	Sept, 1983	OD* W	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V*	456	--	583	C			*1/2 of 2 lots surveyed as 1 Lot
CO	457	--	400	S	July, 1983	W	
R	458	--	451	C			
R	459	--	628	C			
V*	460	--	288	C			*Parts of 4 lots + 6 acres = 1 Block
R	461	--	108	S	July, 1983	W	
V*	462A	--	573	C			*4 lots surveyed as 1 Lot
R	462B	--	573	C			
R	463	--	484	C			
R	464A	--	324	C			
R	464B	--	324	C			
R	465	--	629	S	July, 1983		
V*	466E	--	426	C			*Approximately 15.5 acres = 1 Block
V*	466W	--	426	C			*10 acres = 1 Block
V*	467A	7811-77	356	C			*6 lots surveyed as 1 Block

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	467B	7811-77	356	C			
V*	468-1	--	541	C			*3 acre Block
V*	468-2	--	541	C			*3 acre Block
V*	468-3	--	541	C			*3 acre Block
V*	468-4	--	541	C			*3 acre Block
V*	468-5	--	541	C			*3 acre Block
V*	468-6	--	541	C			*3 acre Block
V*	468-7	--	541	C			*3 acre Block
V*	468-8	--	541	C			*3 acre Block
R	468-9R	--	541	C			
V*	468-9	--	541	C			*3 acre Block
V*	468-15	--	541	C			*3 acre Block
V*	468-16	--	541	C			*3 acre Block
V*	469	--	631	C			*10.4 acre Block
I	470	--	295	C			
V*	471	40-515 72-40536	294	OG, S	Nov, 1983	OD	*1 Block railroad right of way within Edgemont
R	472	--	152	RG	March, 1983	N	

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
CO	473	72-40522	630	OG, S	July, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
CO	474E	72-40548	26	RG, IG	March, 1983	N*	*Gamma reading from large bag of rocks. When rocks were removed, no contamination measured
R	474W	72-40548	26	C			
R	475	--	522	C			
R	476	--	570	C			
R	477	--	79	RG	March, 1983*	N	*Engineering assessment performed by ARIX
V	478	--	635	C			
R	479	--	634	OG	June, 1983	HS*	*Radioactive rocks in garden rock collection
V*	480	--	638	C			*About 5.7 acres surveyed as 1 Block
V*	481A	--	637	C			*About 5.5 acres surrounding shop-office surveyed as 1 Block
G	481B	--	637	C			
R	482	--	639	OG, S	March, 1983	N	*Small contaminated area removed while boreholing
R	483	--	640	C			
R	484	--	569	C			
V*	485	--	531	OG, S	July, 1983	W	*3 lots surveyed as 1 Lot

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
*	486	--	544	*			*VOID - see PNL 591, State 737
*	487	--	545	*			*VOID - see PNL 578, State 724
V*	488	--	625	OG, S	July, 1983	W	*14 lots surveyed as 1 Block, nonhabitable residence on property
V	489	--	576	OG, S	June, 1983	W	
V*	490	40-512	509	OG, S	Oct, 1983	OD	*4 lots surveyed as 1 Lot
V*	491	--	568	OG, S	Oct, 1983	W	*2 lots surveyed as 1 Lot
*	492	--	624	*			*VOID - see PNL 585, State 731
V*	493	--	71	OG, S	July, 1983	W	*1 Block
V*	494	--	575	S	Sept, 1983	W	*17 lots surveyed as 1 Block
R	495	--	641	C			
R	496	--	642	C			
R	497	--	643	C			
R	498	--	644	S	June, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	499	7811-61	645	S	May, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	500	--	646	OG, S	June, 1983	OD	
R	501	--	647	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	502	--	648	C			
R	503	--	649	S	Sept, 1983	OD	
R	504	--	650	C			
R	505	72-40526	651	C			
V	506	--	652	OG	April, 1982	N*	*2 radioactive sandstone rocks in garage on a shelf
V	507	--	653	S	May, 1983	OD	
V	508	--	654	C			
V*	509	--	655	C			*1 Block
V*	510	--	656	C			*1 Block
V	511	--	657	C			
V	512	--	658	C			
V*	513	--	659	C			*Commercial garage on property
V	514	--	660	C			
V*	515	72-40546	661	C			*4 lots surveyed as 1 Lot
V	516	--	662	OG, S	July, 1983	W	
V	517	--	663	C			
V	518	--	664	OG, S	Sept, 1983	OD	

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	519	--	665	OG, S	June, 1983	W	
V*	520	--	666	C			*2 lots surveyed as 1 Lot
V*	521	--	667	C			*Boarded-up house not surveyed at owner's request
V*	522	--	668	C			*1 Block
V	523	--	669	C			
V	524	--	670	OG, S	June, 1983	W	
V	525	--	671	C			
R	526	--	672	S	[illegible]e, 1983	W	
R	527	--	673	C			
CO	528	--	674	C			
R	529	--	675	C			
V	530	--	676	C			
V	531	--	677	C			
V	532A	--	678	OG, S	July, 1983	W	
R	532B	--	678	OG, S	July, 1983	W	
V*	533	--	679	C			*2 lots surveyed as 1 Lot
V	534	--	680	C			

Property Identifiers				Survey Status	Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	535	--	681	OG, S	July, 1983	OD**	*6 lots surveyed as 1 Lot **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
V*	536	--	682	C			*5 lots surveyed as 1 Lot
R	537	--	683	C			
R	538	--	684	C			
R	539	--	685	C			
R	540	--	686	C			
R	541	--	687	C			
CO	542	72-40533	688	C			
CO	543A	--	689	*	*	*	*Common outdoor contamination with PNL 543B
CO	543B	--	689	S	July, 1983	OD	
R	544	--	690	C			
R	545	--	691	C			
R	546	--	692	RG, OG, S	July, 1983	HS* W	*Radioactive stepping stones and wind blown
R	547	7811-21	693	S	July, 1983	OD W	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	548	--	694	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	549	--	695	C			
V	550	--	696	C			
V	551	--	697	C			
V	552	--	698	C			
V*	553	--	699	C			*2 lots surveyed as 1 Lot
V*	554A	--	700	C			*1 Block
R	554B	--	700	C			
R	555	--	701	OG, S	June, 1983	OD	
R	556	--	702	C			
R	557E	--	703	RG	March, 1983	N	
R	557M	--	703	RG	March, 1983	N	
R	557W	--	703	RG	March, 1983	N	
R	558	--	704	R*			*Refused testing - residential
CO	559	--	705	C			
CO	560	--	706	C			
V	561	72-40516	707	R*			*Refused testing, mobile home on lot
R	562	--	708	R*			*Refused testing

Property Identifiers				Survey Status	Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	563	--	709	R*			*Refused testing, no signed refusal, mobile home on lot
V	564	--	710	C			
V	565	--	711	C			
V	566	--	712	C			
R	567	--	713	C			
R	568	--	714	C			
R	569	--	715	R*			*Refused testing
V	570	--	716	R*			*Refused testing - vacant Block
V	571	--	717	R*			*Refused Testing - vacant Block
V	572	--	718	C			
V	573	--	719	C			
V	574	--	720	C			
R	575	--	721	C			
V	576	--	722	R*			*Refused testing
V*	577	--	723	C			*Commercial garage on property
V	578	--	724	C			
R	579A	--	725	R*			*Refused testing

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	579B	--	725	R*			*Refused testing
CO	580	--	726	R*			*Refused testing
CO	581	--	727	C			
R	582	--	728	C			
R	583	--	729	S	Nov, 1982	N	
R	584	--	730	OG, S	Nov, 1983	OD	
V	585	--	731	OG, S	July, 1983	W	
R	586	--	732	C			
R	587	--	733	S	Nov, 1982	N	
R	588	--	734	C			
V*	589A	--	735	C			*18 city blocks surveyed as 1 Block
R	589B	--	735	R*			*Refused further testing, unsigned refusal
R	590	--	736	R*			*Refused testing
R	591	--	737	R*			*Refused testing
V	592	--	738	OG, S	Sept, 1983	W	
R	593	--	739	OG	Sept, 1983	HS*	*Stepping stone in walkway - owner refused removal
V	594	--	740	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	595	--	741	C			
V	596	--	742	OG, S	July, 1983	W	
V	597	--	743	R*			*Refused testing
V	598	--	744	R*			*Refused testing
CO	599	--	745	S	July, 1983	OD*	*Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	600	--	746	C			
R	601	--	747	R*			*Refused testing
R	602	--	748	R*			*Refused testing, nonhabitable residence on property
V	603	--	749	C			
V	604	72-40527 72-40528	750	R*			*Refused testing, no signed refusal
R	605	7811-80	751	R*			*Refused testing, no signed refusal
R	606	7811-69	752	R*			*Refused testing, no signed refusal
V	607	40-510	753	OG, S	July, 1983	W	
R	608	--	754	C			
CO	609	--	755	R*			*Refused testing

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	610A	--	756	*	*	*	*Common outdoor contamination with PNL 610B
R	610B	--	756	OG	July, 1983	CD	
V	611	--	757	C			
R	612	--	758	RGS	May, 1984	HS*	*Uranium minerals
R	613	--	759	C			
V*	614A	7811-56	760	R*			*Refused testing - vacant Block
R	614B	7811-56	760	R*			*Refused testing
V	615	--	761	C			
V*	616	--	762	S	Nov, 1982	N	*1 Block
V	617	--	763	C			
V	618	--	764	C			
R*	619	--	765	C			*Also a business present
V	620	--	766	NR*			*No response
V	621	--	767	NR*			*No response
V	622	--	768	NR*			*No response
R	623	--	769	NR*			*No response
CO	624	--	770	NR*			*No response
R	625	--	771	NR*			*No response

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V	626	--	772	NR*			*No response
R	627	72-40557	773	OG, S*	June, 1980*	OD SI**	*Engineering Assessment performed by ARIX **Tailings mixed in basement wall plaster
R	628A	--	774	C			
V*	628B	--	774	C			*1 Block
CO	629	--	775	OG, S	Oct, 1983	OD	
V*	630	--	776	C			*1 Block
V*	631	--	777	S	Aug, 1982	N**	*1 Block **Natural bentonite clay deposit
R	632	40-509	69	OG, S*	April, 1983	OD W	*PNL outdoor only, State indoor survey
V*	633A	--	62	OG, S	Sept, 1983	W	*1 Block
R	633B	--	62	OG, S**	Sept, 1983	W	**PNL outdoor only, State indoor survey
V*	634	--	778	C			*1 Block
V	635	--	779	C			
V	636	--	780	C			
V*	637	--	781	C			*1 Block
V	638	--	782	C			

Property Identifiers				Survey Status			
Property Type	PNL Number	EPA Number	State Number	Results	Engineering Assessment Date	Engineering Assessment Results	Notes
V	639	--	783	C			
R	640	--	159	C*			*State residence, PNL outdoor surveys
R	641	7811-11	122	S*	April, 1983	OD	*State residence, PNL outdoor surveys
R	642	--	136	OG, S*	June, 1983	OD	*State residence, PNL outdoor surveys
R	643	--	153	C*			*State residence, PNL outdoor surveys
R	644	7811-35	199	C*			*State residence, PNL outdoor surveys
R	645	--	202	OG, S*	May, 1983	OD	*State residence, PNL outdoor surveys
V	646	--	225	C*			*State residence, PNL outdoor surveys
V	647	--	289	C*			*State residence, PNL outdoor surveys
R	648	--	169	C*			*State residence, PNL outdoor surveys
R	649	--	61	IG, OG, S*	Nov, 1983	SI** OD W	*State and PNL residence, PNL outdoor surveys **Soil under the residence floor was contaminated
R	650	--	60	OG, S*	Oct, 1983	W	*State residence, PNL outdoor surveys
R	651	--	59	OG, S*	July, 1983	W	*State residence, PNL outdoor surveys
V	652A	--	57	OG, S*	Sept, 1983	OD W	*State residence, PNL outdoor surveys
R	652B	--	57	OG, S*	Sept, 1983	W	*State residence, PNL outdoor surveys

Property Identifiers				Survey Status			Notes
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
V*	653A	40-507	55	OG, S**	Nov, 1983	W	*1 Block **State residence, PNL outdoor surveys
R	653B	40-507	55	OG, S*	Nov, 1983	W	*State residence, PNL outdoor surveys
R	654	--	66	OG, S*	Oct, 1983	W	*State residence, PNL outdoor surveys
R	655	--	174	OG, S*	July, 1983	OD**	*State residence, PNL outdoor surveys **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	656	--	84	C*			*State residence, PNL outdoor surveys
R	657	7811-36	92	C*			*State residence, PNL outdoor surveys
R	658	--	97	OG, S*	June, 1983	OD**	*State residence, PNL outdoor surveys **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	659	--	167	R*			*Owner refused testing
R	660	--	87	S*	June, 1983	OD**	*State residence, PNL outdoor surveys **Positive ^{226}Ra, but less than EPA standard based on 100 m^2 area
R	661A	--	138	C*			*State residence, PNL outdoor surveys
R	661B	--	138	C*			*State residence, PNL outdoor surveys
R	662	--	191	R*			*Refused testing
R	663	--	181	C*			*State residence, PNL outdoor surveys
R	664	--	137	C			

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
CO	665	--	88	OG, S*	July, 1983	OD	*State residence, PNL outdoor surveys
R	666	--	80	C*			*State residence, PNL outdoor surveys
V	667	--	784	C*			*State residence, PNL outdoor surveys
R	668	--	78	OG, S*	Sept, 1983	W	*State residence, PNL outdoor surveys
R	669	--	81	C*			*State residence, PNL outdoor surveys
R	670	--	115	RG, S*	Sept, 1983	OD	*State residence, PNL outdoor surveys
R	671	--	150	C*			*State residence, PNL outdoor surveys
R	672	--	179	C*			*State residence, PNL outdoor surveys
R	673	--	189	RR*	March, 1983	N	*State residence, PNL outdoor surveys
V*	674	--	785	OG, S	Nov, 1983	OD*	*Ore truck spill
R	675	--	786	C*			*Outdoor survey done in conjunction with PNL 17 and 19
R	676	7811-65	20	C*			*State survey
R	677	--	96	C*			*State survey
R	678	--	112	C*			*State survey
CO	679	--	120	C*			*State survey
R	680	--	128	C*			*State survey
R	681	--	145	C*			*State survey

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	682	--	146	C*			*State survey
R	683	--	151	C*			*State survey
R	684A	--	160	C*			*State survey
R	684B	--	160	C*			*State survey
R	685	--	166	C*			*State survey
R	686	--	172	C*			*State survey
R	687	--	176	C*			*State survey
R	688	--	180	C*			*State survey
R	689	--	185	C*			*State survey
R	690	7811-23	187	C*			*State survey
R	691	7811-07	195	C*			*State survey
CO	692	--	196	C*			*State survey
R	693	7811-19	205	C*			*State survey
R	694	--	211	C*			*State survey
R	695	--	215	C*			*State survey
R	696	--	221	C*			*State survey
R	697	7811-04	227	C*			*State survey
R	698	--	229	C*			*State survey

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	699	--	235	C*			*State survey
R	700	--	269	C*			*State survey
R	701	--	271	C*			*State survey
R	702	--	275	C*			*State survey
R	703	7811-74 72-40538	3	RG, OG, S*	June, 1980*	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were identified under and around east enclosed porch
R	704	72-40543	4	OG, S*	June, 1980*	OD	*State survey, engineering assessment performed by ARIX
R	705	72-40556	6	RG, IG, OG, S*	July, 1980*	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were found under the basement floor slab and beneath the crawl space
R	706	72-40557	7	*	*	*	*VOID - same as PNL 627, State 773
R	707	72-40559	8	OG, S*	July, 1980*	OD	*State survey, engineering assessment performed by ARIX
R	708	7811-64	9	C*			*State survey
R	709	7811-71	13	OG, S*	July, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings were mixed into basement wall plaster
R	710	7811-82	14	RG, OG, S*	July, 1980	OD	*State survey, engineering assessment performed by ARIX

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	711	7811-68	16	RG, S*	July, 1980	OD	*State survey, engineering assessment performed by ARIX
CH*	712	7811-73	18	C**			*Church on several lots **State survey
R	713	72-40544	30	OG, S*	July, 1980	OD	*State survey, engineering assessment performed by ARIX
R	714	7811-37	54	RG*	July, 1980	OD	*State survey, engineering assessment performed by ARIX
R	715	7811-26	85	C*			*State survey
R	716	7811-40	89	RG*	July, 1980	N	*State survey, engineering assessment performed by ARIX
R	717	--	90	C*	July, 1980	N	*State survey, engineering assessment performed by ARIX
R	718	--	100	C*			*State survey
R	719	--	104	C*			*State survey
R	720	--	106	C*			*State survey
R	721	7811-20	107	C*			*State survey
R	722	--	110	C*			*State survey
R	723	--	111	C*			*State survey
R	724	--	125	C*			*State survey
R	725	--	140	C*			*State survey

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	726	--	144	C*			*State survey
R	727	--	148	C*			*State survey
R	728	--	149	C*			*State survey
R	729	--	156	C*			*State survey
R	730	--	157	C*			*State survey
R	731	--	163	C*			*State survey
R	732	--	164	C*			*State survey
R	733A	--	170	C*			*State survey
R	733B	--	170	C*			*State survey
R	733C	--	170	C*			*State survey
R	733D	--	170	C*			*State survey
R	733E	--	170	C*			*State survey
R	734	--	173	C*			*State survey
R	735	--	175	RG, OG, S*	July, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Tailings identified beneath north wooden porch and decks
R	736	--	177	C*			*State survey

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	737	7811-27	178	C*			*State survey
R	738	--	182	C*			*State survey
R	739	--	193	C*			*State survey
R	740	--	198	C*			*State survey
R	741	--	201	C*			*State survey
R	742	7811-05	203	C*			*State survey
R	743	--	204	C*			*State survey
R	744	--	206	C*			*State survey
R	745	--	207	C*			*State survey
R	746	--	210	C*			*State survey
R	747	--	213	C*			*State survey
R	748	--	216	C*			*State survey
R	749	--	217	C*			*State survey
R	750	--	219	C*			*State survey
R	751	--	223	C*			*State survey
R	752	--	224	C*			*State survey
R	753	--	265	C*			*State survey

Property Identifiers				Survey Status			
					Engineering Assessment		
Property Type	PNL Number	EPA Number	State Number	Results	Date	Results	Notes
R	1021	7811-67	15	OG, S*	June, 1980	OD SI**	*State survey, engineering assessment performed by ARIX **Radioactive material beneath southeast stoop

APPENDIX C

SPECIAL STUDIES

INDEX PAGE

APPENDIX C

DIFFERENTIATION OF WINDBLOWN AREAS AND DEPOSITS IN COTTONWOOD

NRC requested that PNL locate those properties where the deposits of residual radioactive material were present from causes other than being transported there by wind and water erosion of the mill waste storage areas. Therefore, differentiation between windblown and deposits from other means was necessary. It is not technically feasible to discriminate between naturally transported deposits and those transported by other agencies, except by their thickness and location. The EPA, in its 1980 report about Edgemont (Thrall, Hans, Kallemeyn, 1980), identified numerous properties in the eastern part of Edgemont near to the mill which, in their opinion, had been contaminated by windblown tailings. In PNL surveys, many of the deposits in all parts of town were found to be relatively thin, although the absence of such deposits in neighboring properties made a windblown hypothesis unlikely in many of these cases.

PNL evaluated survey techniques for discriminating between radiation from the mill itself, naturally transported residual radioactive material, and material brought in by people at properties close to the uranium mill storage areas in Edgemont. When making gamma surveys, as one approached the mill storage areas, the gamma radiation field from the storage areas became an ever larger proportion of the total that was measured. When this background was very high, locating local deposits of residual radioactive materials by means of gamma radiation measurements became a very insensitive technique. To reduce the background, a lead collimating shield was attached to our normal micro-R-meters (Figure C1). This shield was found to reduce the background by about a factor of 2-3, depending on the location.

For evaluation purposes, readings with this instrument were taken at most of those properties near the mill. In addition, soil samples were collected at 4-5 sites on each property to compare the ^{226}Ra concentrations with gamma exposure rate measurements. In practice, exposure rates were measured following the normal grid survey protocols with the following modifications:

1. Since the collimated micro-R-meter readings could not be related to the free field exposure rate readings measured with a pressurized ionization chamber, no attempt was made to apply correction factors to the micro-R-meter readings.

2. Two readings at one meter above the ground were taken at each grid location--one taken only with the collimator in place, the second with the bottom window of the collimator (and therefore the bottom of the detector) shielded with a one-half inch thick plate of lead.

3. At each location where a 5 cm thick soil sample was collected, a reading was taken with the collimated micro-R-meter held in contact with the soil, in addition to the two exposure rate readings made at a height of one meter.

The difference (delta) between the two readings taken at one meter at each grid point would be expected to emphasize photons coming from beneath and a short distance to each side of the detector. Local sources would also

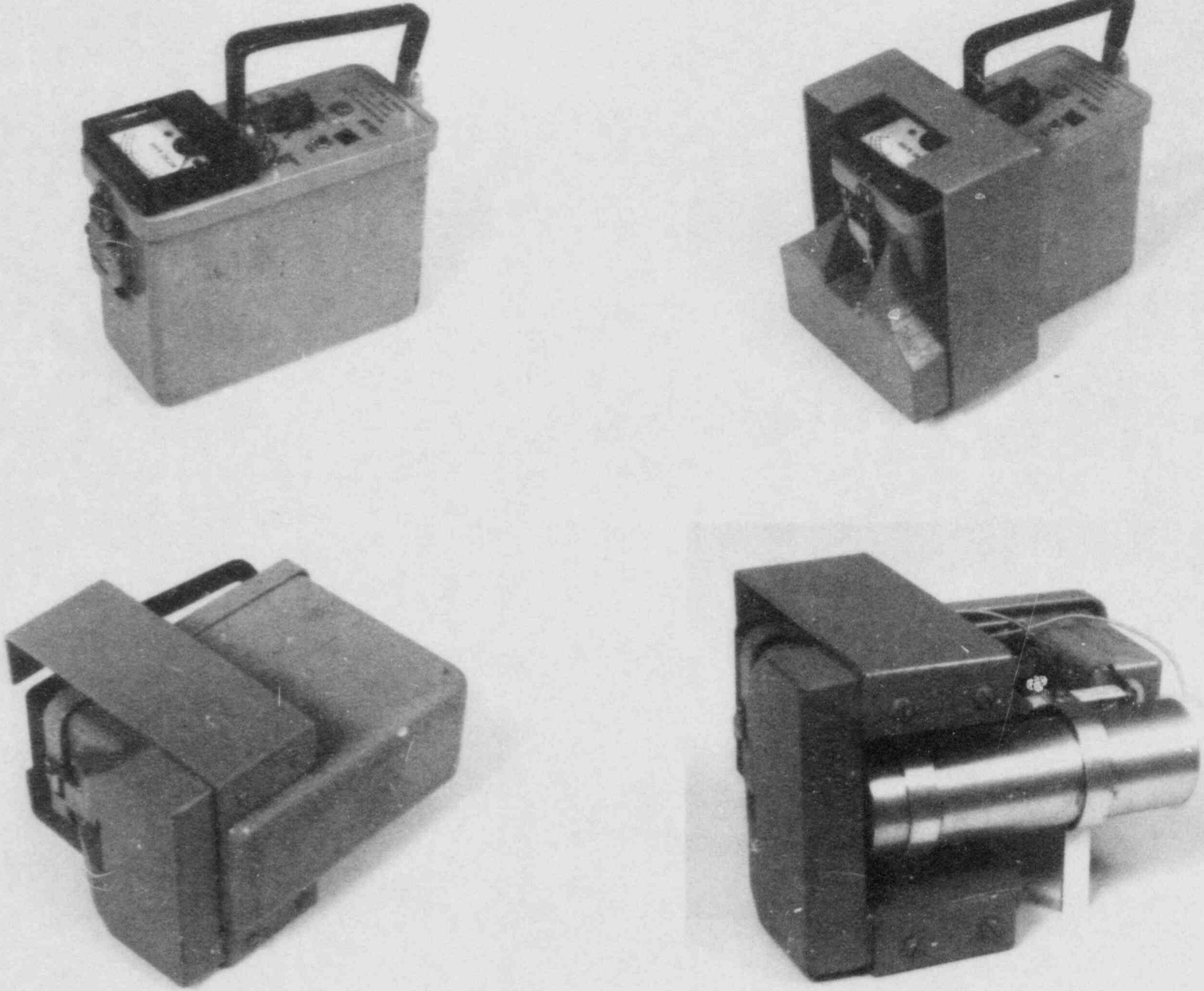


FIGURE C1. Views of a Lead Collimator for Use with a Portable Micro-R-Meter be expected to be largely responsible for the collimated exposure rate readings made in contact with the ground. To test these hypotheses, a linear regression analysis was applied to the 52 comparison measurements completed at that time. The linear dependence of delta readings on ^{226}Ra concentrations gave a correlation coefficient squared (R^2) of only 0.049, hardly better than the value of 0.048 obtained for measurements taken with the collimator window open. The correlation was only slightly better for the contact exposure rate measurements, for which R^2 was equal to 0.14. An examination of the plotted delta versus ^{226}Ra concentrations showed that in many cases the dose rate was much higher than would be predicted from the local ^{226}Ra content of the soil. All of those higher dose rate measurements were from properties adjacent to the mill and within the distance of a city block. At other properties where the local exposure source terms were a higher percentage of the total gamma exposure rate, the correlation was much better (R^2 of the delta values from ^{226}Ra concentrations was 0.61). For the same data set, the linear dependence of the readings with the collimator window open on ^{226}Ra concentrations was almost the same ($R^2 = 0.60$), indicating that at the one meter height, the added effort of taking delta readings was not justified. Window open reading greater than 17 micro-R/hr were normally from those parts of properties with abnormally high dose rates adjacent to the mill. Readings below 9 micro-R/hr indicated that the ^{226}Ra content of 2-inch thick soil cores was less than 5 pCi/g.

Thus, although the collimated micro-R-meter technique could provide an evaluation of the presence of absence or residual radioactive material at all but those properties closest to the mill, it was necessary to use another technique for the latter. Further discussion of the collimated meter and measurements was reported in NUREG/CR-3479 (Thomas and Kinnison, 1983). A larger number of soil samples taken using a grid sampling pattern on those properties could define contaminated areas. However, we had already found that soil from the top 5 cm of many of the properties contained ^{226}Ra concentrations slightly in excess of 5 pCi/g, presumably from windblown tailings. Since soil samples from only about one-third of the properties in that locale had concentrations in excess of 15 pCi of ^{226}Ra/g in the top 5 cm, a test based on the average concentration in the top 15 cm of soil would probably not have exceeded the EPA final standard for cleanup of uranium mill tailings (40 CFR 192) if the material was indeed windblown and on the surface.

At that time, we proposed that 15 cm deep cores be taken at those grid sites where ^{226}Ra concentrations of the 5 cm thick samples were between 5 pCi/g and 15 pCi/g to determine which of them exceeded the standard. In addition, a method of using collimated micro-R-meters in selecting soil sampling locations was proposed as a part of the survey technique, although all criteria for establishing the need for engineering assessments would still be based on the concentration of ^{226}Ra in the soil. During engineering assessments, the borehole logging technique could define the depth of significant deposits in this locale when they were deeper than 15 cm because the shielding effect of the local soil on gamma photons from nearby tailings areas when the detector was underground reduced its sensitivity to the aboveground radiation field. Thinner deposits which were more difficult to define by this technique would be detected using the soil cores. Based on the above evaluations, PNL proposed the following draft, supplementary protocol for use in areas that were too close to the mill for the application of existing protocols:

1. When the source of the elevated background reading can be ascribed to nearby uranium processing sites, and a gamma survey using uncollimated micro-R-meters indicates that a gamma field reading is present which is in excess of 14.5 micro-R/hr, micro-R-meters that are collimated to emphasize radiation from beneath them shall be used or soil sampling grids shall be required at that property or portion of the property.

2. When a collimated micro-R-meter grid survey is performed at one meter height, and any reading exceeds 17 micro-R/hr, it will be necessary to collect a 15 cm thick surface soil sample at that grid location. A maximum of twelve soil samples will be used to characterize such properties. Soil samples will be collected at uniformly positioned grid sites when the total number of survey readings greater than 17 micro-R/hr exceeds twelve.

3. At properties where no collimated grid dose rate measurement exceeds 17 micro-R/hr, two 15-cm deep soil samples will be collected at grid locations where the collimated micro-R-meter readings show the highest gamma exposure rates.

4. Whenever the measured ^{226}Ra concentration of a 15-cm thick soil sample exceeds 5 pCi/g, that property will require an engineering assessment to determine the extent and depth of residual radioactive material.

5. If 5 cores from the top 5 cm have already been taken at properties within 3 city blocks of the mill waste storage areas, the ^{226}Ra content of those samples can be used as an alternative screening mechanism. If the concentration of ^{226}Ra in any top 5 cm soil core is greater than 15 pCi/g, that property will be given an engineering assessment. That assessment can use cores from the top 15 cm to define areas that exceed the standard because of windblown tailings. If ^{226}Ra concentrations in the top 5-cm samples are less than 5 pCi/g, no engineering assessment will be required if two of the samples were collected at the grid locations where the highest gamma exposure rates were measured. At those properties where the top 5 cm cores show concentrations greater than 5 pCi/g but less than 15 pCi/g, additional soil cores from the top 15 cm will be taken to determine the average concentration of ^{226}Ra. If the average concentration exceeds 5 pCi/g, an engineering assessment will be required.

An evaluation of the above suggested supplementary survey procedures for Cottonwood, based on about two or three times as many measurements as were available in the initial tests reported above, found that the use of gamma dose rates as an indicator of local ^{226}Ra concentrations gave a correlation coefficient (R^2) of 0.73 when only properties which were more than one block from the mill were considered. However, the original conclusion that closer properties could also be screened on the basis of the maximum gamma exposure rate (protocol steps 2 and 3) was not proven to be acceptable. Low exposure rates were present in some areas close to the mill which had soil with significantly more than 5 pCi of ^{226}Ra/g. This phenomenon combined with properties where cores were essentially background soil, but had readings of 15 to 20 micro-R/hr (from shine), caused R^2 to decrease from 0.73 to only 0.34 when the data set was limited to properties where the maximum dose rate was 17 micro-R/hr instead of those more than a block from the mill. Thus, it was not possible to use gamma exposure rates to assure that the concentration was less than 15 pCi/g at locations in the vicinity of the mill.

Because of these limitations of the gamma exposure rate measurements, we began using a combination of shallow cores taken from 0 to 5 cm, 0 to 15 cm and 15 to 30 cm depths, along with dose rate measurements to define the perimeter and depth of shallow deposits. Borehole logging was used for deeper deposits when doing engineering assessments in Cottonwood. A large number of soil core samples were collected throughout the Cottonwood area and other Edgemont locations near the uranium mill in the process of performing radiological surveys and engineering assessments. Most of them were samples of the top 15 cm of soil. Where the radium concentration in the top 15 cm exceeded 5 pCi/g, cores from the 15-30 cm depth were taken. When the deposit was confined to the top 15 cm and was from an area close to the mill tailings pile, it was presumed to be windblown tailings. Deeper deposits were assumed to be possibly transported by human agencies.

In conclusion, at those properties where gamma-ray measurements could be made without being unduly influenced by the gamma shine from the uranium mill tailings storage piles, a combination of gamma dose rate measurements, shallow soil core samples and borehole logging was used to differentiate between shallow widespread deposits of uranium mill tailings which were attributed to windblown causes and more localized deeper deposits which were attributed to other causes. However, in those areas near the mill tailings piles where gamma radiation shine unduly influenced the gamma-ray measurements, making them unreliable, a regular grid of core samples from 0-15 cm and 15-30 cm in depth were analyzed for ^{226}Ra concentration, and these measurements were used in conjunction with borehole logging to differentiate between windblown and local deposits.

CORRELATION OF GAMMA MEASUREMENTS AND ^{226}RA IN SOIL

Surface soil samples were collected at Edgemont properties to determine whether ^{226}Ra concentrations greater than 5 pCi/g were present, and to determine from the ratios of the ^{238}U concentration (actually estimated from the measured concentration of ^{234}Th) to the concentrations of other radionuclides in the ^{238}U decay chain, whether the ^{226}Ra was due to naturally deposited radioactivity or to uranium mill tailings. Soil samples were collected at two locations on each property containing habitable buildings and at a single location on each property having no habitable building. Samples were also taken at locations having gamma-ray exposure rates greater than 20 μR/hr above background. Although the final EPA Standards for radium concentrations in soil were based on concentrations above background, the criteria for the Edgemont surveys were based on the total radium concentration specified on the interim EPA standards.

The percentage of 951 surface soil samples containing greater than 5 pCi/g ^{226}Ra (including background) as a function of contact gamma-ray exposure rate is shown in Figure C2. From 8 to 20 μR/hr, each point represents the percentage for each one μR/hr exposure-rate increment from 8 to 20 μR/hr, but for exposure rates greater than 20 μR/hr, each point represents the percentage for a range of exposure rates.

The ^{226}Ra concentrations were greater than 5 pCi/g only about 2% of the time if the exposure rate was less than 15 μR/hr (<4 μR/hr above the average Edgemont background of 10.9 μR/hr). Most of this 2% of the samples contained only 5 to 6 pCi/g ^{226}Ra, and all of this 2% contained less than 9 pCi/g. The ratios of the measured concentrations of ^{226}Ra to uranium (^{234}Th) in this small fraction of the samples indicated that the source of the ^{226}Ra was not uranium mill tailings. When concentrations as high as 5-9 pCi/g produced exposure rates less than 15 μR/hr, the size of the deposits tended to be much smaller than 100 m^2.

The percentage of soil samples containing ^{226}Ra concentrations greater than 5 pCi/g increased very little from 15 to 17 μR/hr, but increased rapidly from 17 to 30 μR/hr, reaching 90% at 30 μR/hr.

During gamma-ray surveys at Edgemont, a waist-level gamma dose-rate measurement of greater than 14.5 μR/hr dictated that a contact survey search of the immediate area be made to locate the source of the elevated gamma radiation. The relationship described in the last two paragraphs indicates that the decision level of 14.5 μR/hr was valid in that the probability of finding elevated levels of ^{226}Ra did increase significantly just above the decision level.

Ninety percent of the soil samples collected at locations showing gamma-ray exposure rates greater than 20 μR/hr above background contained ^{226}Ra concentrations greater than 5 pCi/g. Seventy-five percent had ^{226}Ra concentrations greater than 15 pCi/g.

The measured gamma exposure rate depends not only on the concentration of ^{226}Ra present, but on the dimensions of the deposit, and also upon its thickness and the thickness of any uncontaminated cover material. A higher exposure rate was expected from a given concentration of radium as the area

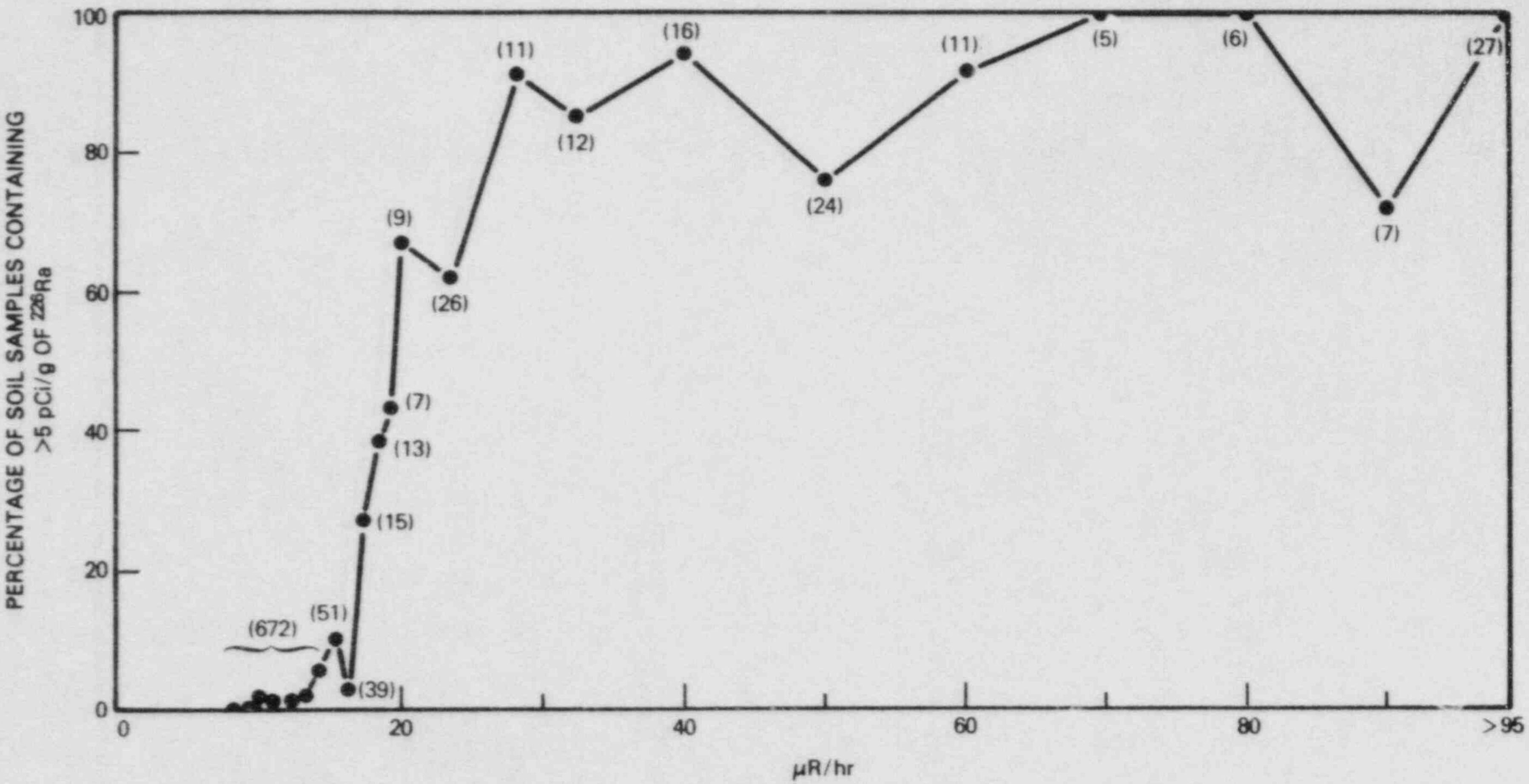


FIGURE C2. Percentage of Soil Samples Containing >5 pCi/g of ^{226}Ra as a Function of Gamma-ray Exposure Rate (Numbers in Parentheses Represent the Numbers of Samples the Percentages are Based Upon).

of the deposit increased. However, it was not possible to derive a functional relationship between the areas of deposits and the exposure rate produced by a given radium concentration from the Edgemont data. In addition to the other factors affecting the relationship, the lack of uniformity of most deposits made it impossible to define the areas that corresponded with given concentrations and exposure rates.

INTERCOMPARISON OF EDGEMONT RADIOLOGICAL ASSESSMENT RESULTS WITH MOBILE SCANNING VAN RESULTS

In late 1983, the Department of Energy (DOE) sent to Edgemont the mobile scanning van designed and operated by Oak Ridge National Laboratory in 1979 (Myrick et al. 1982) and used in support of DOE's UMTRCA, Title I radiological surveys. The survey of Edgemont was conducted as a test of the van capabilities because of the extensive radiological surveys that had been conducted there by PNL and the State of South Dakota. The van survey was conducted prior to the availability of the results of those surveys to assure that the normal operational procedures would be tested in an unbiased manner.

DOE conducted a series of workshops where a committee reviewed and evaluated the results of an intercomparison of the van data and PNL data. The initial comparison showed that of 96 properties where the State or PNL had found measurements exceeding 20 μR/hr, the van had discovered 46. This gave a discovery rate of 48%. Of 62 properties defined as having a deposit of ^{226}Ra exceeding the EPA's final standards for vicinity properties (40 CFR 192), 38 were discovered by the van, for a discovery rate of 61%. In addition, based on initial interpretations by DOE contractors, the van had given indications of 52 new discoveries not previously found or reported by PNL. It was not clear whether or not the new discoveries were measurements of undiscovered deposits of residual radioactive materials or false positives caused by the variability of background radium sources in Edgemont.

After review of the scanning van results, it was suggested by PNL that the statistical test criteria used for evaluating results might be biased so as to reduce the van sensitivity unnecessarily. Subsequent testing of new criteria demonstrated that a higher fraction of the properties could be located by the truck, but the number of false positives greatly increased.

PNL staff reviewed the 52 cases of new van discoveries presented at the workshops. Very few of these could be considered as valid new discoveries of residual radioactive material deposits that contained an average of 5 pCi ^{226}Rn/gram of soil over an area of 100 m^2. Most of the cases could be considered as having detected something, but not something new or significant. The details of that comparison are presented in Table C1 at the end of this special study.

Some of the properties that had been included as new discoveries were properties on which PNL had found no deposit, but were next door to a property that PNL had identified previously as being contaminated. Although they may have been valid, they were not new discoveries that can be added to those previously reported by PNL. In others, the maximum gamma dose rate measured by PNL or the State of South Dakota on the property precluded the existence of a significant radium deposit as defined above. The measured dose rates for these properties are shown in Table C1.

A correlative study (Young, Jackson, Thomas, 1983) on 951 Edgemont soil samples taken from the top 5 cm of soil showed that only 2% of samples taken where dose rates were below 15 μR/hr contained more than 5 pCi/g including background radium. No sample contained more than 9 pCi/g. It is virtually certain that no deposit containing 5 pCi/g above background in the top 15 cm would read as little as 15 μR/hr if the area were significant. Thus, that

TABLE C1. Evaluation of "New Discovery (Hit)" List Properties Identified in Mobile Van Surveys of Edgemont, South Dakota

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
28		395		X	Next door to PNL No. 29 which has reported contaminated. Max Ra = 2.0; Max γ = 11.
41		325		X	From location, possible surface windblown but Ra <5 pCi/g, (0-5 cm); (probably (0-15 cm) <<5 pCi/g).
66		192		X	Found 2 hot rocks stored in garage - Not a significant deposit.
97		268	X		Max γ = 12, Max Ra = 2.5 next door to newly discovered contaminated property not yet reported by PNL.
99		116		X	Max γ = 12, Max Ra = 2.3; next door to contaminated property previously reported by PNL.
110		37		X	Max γ = 11 no exposed soil - brick bldg. is naturally more radioactive.
229	116	480		X	Wrong PNL No.; No. 229 is 209 4th; 116 is 306 C St.; near contaminated street area; for either one Max γ = 12, Max Ra = 2.0.
118		464		X	Max γ = 12; Max Ra <2; average γ = 10.4
154		82		X	Max Ra - 6.3 including bkg. (0-5 cm) but Ra <5 (0-15 cm) high W.L.
181		379		X	Max γ = 12; Max Ra 2.5. Rock garden present but no hot rocks found
182		305		X	Max γ = 14; Max Ra 3.5, average γ = 12.1

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
185		445		X	Max Ra 7.4 (0-5 cm), Max Ra <5 (0-15 cm), no significant deposit. Possible windblown.
192		273		X	Max γ = 13; Max Ra 4.1 (0-5 cm). Next door to PNL reported contamination
194		490		X	Max γ = 15; Max Ra 2.6, average γ = 12
206		285		X	Max γ = 14; Max Ra 5.0 (0-5 cm), <5 (0-15 cm) including bkg.; high W.L.
207		25	X Possible		Wrong address PNL No. 207 is 207 4th, no house on 205th. One borehole indicated possible Max Ra = 6.4 (0-15 cm) not confirmed by repetitive soil analyses there. Street contaminated under asphalt but area is $\sim 2\ m^2$. Max dose in street was $\sim$21 μR/hr at contact. EPA previously reported 100 μR/hr on contact. Consider this a remotely possible hit but very unlikely to be significant.
229		480		X	Address wrong, should be 209 4th Avenue. Max γ on lot = 11 μR/hr, average γ = 9.4; Max Ra = 1.9. No elevated γ found on street here. Don't give multiple hit credits for one street deposit.
238		503		X	Max γ = 14, average γ = 12; Max Ra = 2.5. Area with 14 γ and Ra = 2.3 is small - possible false hit on natural bentonite seam.
248	249	513		X	Property on 112 Second Avenue is PNL 248. Max outdoor γ = 14 (Max γ of PNL 249 also 14) Max Ra = 4.5. Similar to 238. Apparent false hit.

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
313		611		X	Max γ = 11; Max Ra = 3.9. Small deposits were present on neighboring property, but were less than 5 pCi/g/100 m^2 there too.
318		529		X	Max γ = 14, Max Ra = 5.3 (0-5 cm) but repeated samples taken at site of that sample were all <5.0 and area <100 m^2. Borehole showed no buried deposit.
320		603		X	Max γ = 13, Max Ra = 2.1. Radiological survey completed except owner refused RPISU.
331		312		X	Max γ screening survey = 20, Max Ra = 8.9; owner refused engineering assessment. However, area was at most 10' x 25' (23 m^2). Estimate 0.23 x 8.9 = <5 pCi/g above bkg. on 100 m^2 basis.
333		596		X	Max outdoor γ = 13; Max Ra = 3.5 outdoor (10 m^2). Max indoor γ = 16, in basement area ≤ 10' x 10' not significant deposit. Max borehole Ra = 6.1 top 5 cm. Top 15 cm Ra <5 pCi/g above bkg.
334		133		X	Max γ = 16, Max Ra = 3.8. Max borehole Ra = 5.5 inc. bkg. Not >5 pCi/g above bkg. Apparent shale deposit - not residual radioactive material.
358		601		X	Previously reported engineering assessment case by PNL found ^{226}Ra >5 pCi/g top 5 cm but no deposit >5 pCi/g in the top 15 cm.
383		555		X	Max γ = 10, Max Ra = 2.4. Next door to a previously reported

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
					engineering assessment case by PNL. Not a new hit.
410		40		X	Max γ = 14, average γ = 12, Max Ra 2.3. Recheck of area indicated by van found no deposit.
428		591		X	Max γ = 20, average γ = 13, Max Ra = 7.4 (0-5 cm). Borehole <5 top 15 cm. Actual location of indicated van hit is on railroad right-of-way not surveyed. Van indicates Th (shale) present. Deposit is near known outcrop of bentonite. This appears to be a natural deposit.
285	496	556		X	Vacant lot E. of 1005 E. Street is actually a part of P285. Survey of 285 shows Max γ of 14, Max Ra = 2.5. Hillside with shale behind property. False hit.
497		643		X	Max outdoor γ = 12; Max indoor γ = 14 in basement. Max Ra = 2.3. No γ detected in street check. Next door to P207 where street showed a deposit $\sim$2 m^2 from surface check. Not a new hit. Already credited street hit to P207.
542		588		X	Max γ = 16, Max Ra = 4.6 (0-5 cm). Possible trace of windblown but will be <5 top 15 cm.
561			X Possible		Never surveyed by State or PNL because of refusal. Possible hit. Neaby properties had windblown tailings . Some nearer to mill had >5 top 5 cm but not in top 15 cm.
571		717 (173)	X Possible		Truck survey location unclear. State survey of lot 173 closest to description had Max γ of 13 (corrected). PNL 571 West of intersection not surveyed because of refusal. Potential hit

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
					but not likely use of tailings because it is an unimproved lot.
582		728		X	Max γ = 13, Max Ra = 2.2. No reason for van hits other than possible natural deposit.
605		751	X Possible		No data - Refusal
606		752		X	Van did not actually indicate a hit on this property. Credit given for hit under PNL No. 662 below, where owner refused survey. 662 is adjacent to this property. Owner of 606 also refused survey.
631		777		X	Max γ = 22 on bentonite outcrop (natural). Max Ra top 5 cm = 7.2 including bkg. Not residual radioactive material.
662		191	X Possible		Refusal - Not surveyed by PNL. Potential hit. State survey Max γ = 17 corrected.
	912	219		X	Not surveyed by PNL. State survey Max γ = 13. Recheck found homemade bricks potentially contaminated, but area is only $\sim$3-4 ft.^{2} or $\sim$0.3 m^2. From γ exposure rate, ^{226}Ra is much less than 200 pCi/g. Thus, deposit per 100 m^2 is less than 200 x .3/100 = 0.6 pCi/g, thus insignificant.
	913	227		X	Not surveyed by PNL. State survey Max γ = 13 corrected. Not enough to be >5 pCi/g above bkg. in top 15 cm.
	914	177		X	Not surveyed by PNL. State survey Max γ = 12 corrected. Not enough to be >5 pCi/g in top 15 cm.

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
	915	217		X	Not surveyed by PNL. State survey Max γ = 14 corrected. Not enough to be >5 pCi/g in top 15 cm.
	916		X Possible		Refusal - not previously surveyed. Investigator observed a pile of rubble that may have contained pieces of uranium bearing minerals. Potential hit.
	917	195		X	Not surveyed by PNL. State survey Max γ = 15. Not high enough to be >5 pCi/g in top 15 cm. May have seen granite on property or next door.
	918	100		X	Not surveyed by PNL. State Max γ = 14 corrected. Not enough to be >5 Pci/g top 15 cm.
	919			X	Not originally surveyed by PNL. No elevated γ dose rates along edge of roadway. Trace of residual radioactive material may have washed to the edge from windblown or ore trucks, but won't be >5 pCi/g in top 15 cm on 100 m^2 basis.
571	920			X	Description of property identical with PNL 571 already credited as a possible hit above. State No. 173 (adjacent) survey indicates Max γ there of 13 corrected. Not an additional hit.
	921	216		X	Not surveyed by PNL. State Max γ = 14 corrected. Not enough to be >5 pCi/g in top 15 cm. Next to PNL 219 a reported engineering assessment case.

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

TABLE C1 (continued)

Site			Significant Deposit?*		
PNL No.	Other No.	State No.	Yes	No	Comments
	922	221		X	Not surveyed by PNL. State Max γ = 13 corrected. Possible shale from hill behind. Not enough to be >5 pCi/g in top 15 cm.
	923		X Possible		Not previously surveyed - beyond PNL survey perimeter. Contamination verified. Probable uranium mine equipment maintenance shop. Area involved was <100 $ft.^2$ or <10 m^2 but possible Ra contamination >50 pCi/g. Consider this potential hit.
	929	216		X	Same description as No. 921. State Max γ = 14 corrected. Property is next to PNL 219. A reported engineering assessment case with <5 pCi/g/100 m^2 deposit.

*Significant deposits are defined as having a deposit of residual radioactive material that averages 5 pCi ^{226}Ra/gram in the top 15 cm of soil averaged over an area of 100 m^2 or 15 pCi ^{226}Ra/gram for deeper 15 cm layers.

Note: Units of results shown as γ in comments are μR/hr of exposure rate corrected to the equivalent pressurized ionization chamber reading. Units of results shown as Ra are pCi ^{226}Ra/gram for soil weight as sampled.

cutoff was used as a criterion to eliminate those properties where State of South Dakota gamma survey information indicated no dose rate exceeded 15 μR/hr. Where PNL had performed a survey and soil analysis and no significant deposit, as defined above, was located on the properties, we also eliminated them as being valid new discoveries even if there were natural or small deposits present.

There is a deposit in the street on 4th Avenue, which PNL had previously noted on a survey report, and a case of contaminated building materials which was not found at the time of the van survey comparison. The only other locations that could not be eliminated from the totals of new discoveries made by the van were those which were not surveyed because the owner refused permission or because they were in open areas more than 50 feet from the perimeter of the Edgemont and Dudley city limits, that marked the normal boundary of our survey area. Some of the refusal cases may contain significant deposits, and since there is no information on the others, they are retained on the table as potentially significant new discoveries.

Thus, for the purposes of evaluating the ability of the van to discover new deposits averaging 5 pCi/g on a 100 m^2 area basis, there were eight possible new van discoveries, all of which were either not a surveyable property or were discovered in PNL surveys made after the van intercomparison.

CORRELATION OF RADON PROGENY CONCENTRATIONS WITH PRESENCE OF RESIDUAL RADIOACTIVE MATERIALS

At the request of NRC, a brief study of the correlations between measured radon progeny concentrations and other parameters indicating the presence of residual radioactive material was conducted. The data set selected was from a group of properties where working levels and indoor and outdoor gamma exposure rates had been measured. At a portion of the properties, surface soil samples had been collected near the foundation, or borehole logs of the depth profile of radium contaminations had been measured. As shown in the following results, there were no significant linear correlations between grab working level measurements and the following selected parameters:

- 80 average indoor gamma dose rate measurements - correlation coefficient (R^2) <0.1
- 214 average outdoor gamma dose rate measurements - R^2 <0.1
- 273 maximum indoor gamma dose rate measurements - R^2 = 0.12
- 73 average measured soil radium concentrations - R^2 <0.1
- 73 average borehole logging measurements adjacent to the structures - R^2 <0.1

These low correlations confirm the observations that elevated radon daughter measurements at a property were not useful for discovering residual radioactive material. Our correlative studies indicated that a high average gamma dose rate or ^{226}Ra concentration does not necessarily correspond with elevated working level measurements; however, these analyses are affected by extreme values among results (i.e., the cases when large deposits of residual radioactive material produced little, if any, increase in the working levels or conversely, the cases where high working levels were accompanied by low radium concentrations or gamma exposure rates).

We have also performed a linear correlation analysis of the maximum detected ^{226}Ra concentration at any depth on all sides of each structure measured during abbreviated engineering assessments with the grab working level measurements made in the structures. There was essentially no linear correlation between the maximum ^{226}Ra content detected and the working level measurements either at all 102 locations sampled (R^2 = 0.11) or at those where soil radium concentrations did not exceed 10 pCi/g (R^2 = 0.04). This means that one could not predict the radon progeny exposure level in a structure from the radium content of soil surrounding it. Many factors such as the porosity of the soil, the existence of convective flow paths from the soil into the structure, the degree of contact between the soil and the structure, and the presence or absence of physical barriers between the soil and the basement must be as important as the ^{226}Ra content of the soil in determining radon daughter concentrations.

CORRELATION OF RADON PROGENY GRAB MEASUREMENT RESULTS WITH RADON PROGENY INTEGRATING SAMPLING UNIT (RPISU) RESULTS

Buildings that should not require long-term radon daughter measurements were identified by screening radon-daughter concentrations measured in five-minute air filter samples using the Thomas modification of the Tsivoglou method (Thomas 1972). The samples were collected by the procedure given in the protocol (see Appendix A). The screening decisions are also described in the protocol. In short, if the wind speed and turnover/plate-out rate of the radon daughters were within prescribed limits, the measurement was accepted as a valid estimate of the working level.

Invalid air filter measurements were repeated at later dates until a valid measurement was obtained or until the staff decided a valid measurement was impractical to obtain. The latter buildings were also scheduled for long-term measurements using Radon Progeny Integrating Sampling Units (RPISU).

If the valid WL estimate was greater than 0.033 WL (based on the average of measurements made on two different days), the building was scheduled for engineering assessment to locate the cause of the elevated radon daughter concentration. If the estimate was less than 0.010 WL, the building was cleared from engineering assessment and remedial action unless required for other reasons. In those buildings where the air filter WL measurements ranged from 0.010 to 0.033 WL, long-term WL measurements were scheduled to be made using RPISU. Measurements in this range were not considered to provide a sufficiently reliable indication of whether the building average annual WL would exceed the proposed EPA limit.

Radon daughter concentrations expressed as working levels were determined by both short-term air filter measurements and by six 100-hour RPISU measurements on the same floor in several buildings. Figure C3 shows a linear regression analysis of 84 pairs of such measurements. There was a small correlation between radon daughter concentrations as determined by single 5-minute air filter measurements and RPISU average annual radon daughter concentration measurements. The linear correlation coefficient, r, between the two techniques was only 0.61. This indicates that only 38% (r^2) of the variation in the air filter measurements could be linearly correlated to the RPISU measurements, assuming the RPISU measurements to be the independent variables.

The scatter of the data about the regression line increased as the radon daughter concentrations increased, and the air filter measurements averaged considerably higher than the RPISU annual averages. The average ratio of the RPISU annual average to the air filter measurements was estimated to be 0.63 (Young, Jackson and Thomas 1983). Air filter measurements were made in closed-up buildings and presumably this was the cause of the higher air filter measurement values. The estimated portion of the time residential buildings are open in Edgemont used by the EPA (Giedt 1980; Lloyd 1981) for HUD radiological surveys was 40%, yielding 60% of the time closed up. When the buildings are open to flushing with ambient air, radon daughter concentrations should be negligible. Thus, the annual average should be about 0.6 times the concentration measured in a closed building. This average factor was confirmed by measurements made in Edgemont.

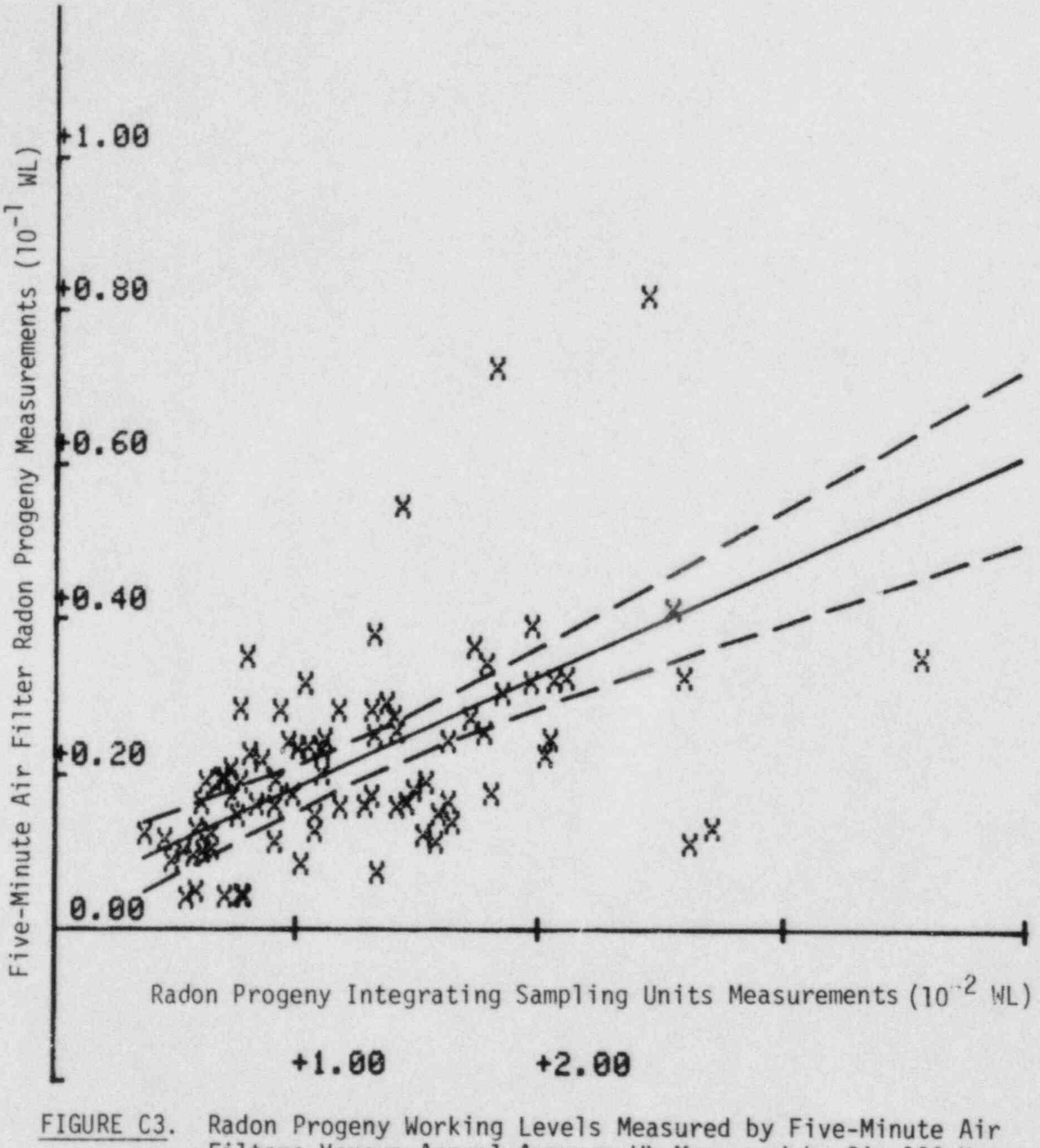


FIGURE C3. Radon Progeny Working Levels Measured by Five-Minute Air Filters Versus Annual Average WL Measured by Six 100-Hour Radon Progeny Integrating Sampling Units

These data were made available for use in a research task being performed for the Office of Nuclear Regulatory Research evaluating and comparing short- and long-term methods of measuring radon and radon daughters (Young, Jackson and Thomas 1983). Analysis of this data set during that study indicated that the decisions based on five-minute air filter measurement estimates of average annual working levels were reasonable.

THE IDENTIFICATION OF RESIDUAL RADIOACTIVE MATERIALS BY USING HIGH USING HIGH RESOLUTION GAMMA-RAY SPECTROSCOPY

Before initiating field sampling in Edgemont, a protocol was established for the purpose of identifying properties potentially contaminated with residual radioactive material (RRM). A portion of this protocol addressed soil sampling and analyses. At least two surface soil samples were collected at each lot with a habitable structure, and at least one soil sample was collected on vacant land parcels. More surface or core samples were taken as necessary if gamma-ray exposure rates indicated the possible presence of RRM. Initially, those samples were weighed as collected, and were hermetically sealed in metal cans. The ^{226}Ra content of the soil was measured using a 23 cm tall X 23 cm diameter NaI(Tl) well counter. After allowing at least 10 days time for the ingrowth of ^{222}Rn and its short-lived daughters (from ^{226}Ra), concentrations of ^{214}Bi above 1 pCi/g were easily measured using 10-minute counts. Thus, this technique was useful for making large numbers of screening survey measurements in the field.

To evaluate the possible presence of uranium mill tailings in the deposits, the concentrations of ^{238}U and its long-lived decay chain progeny were measured using an intrinsic germanium detector. This instrument has sufficient resolution to measure the low energy photons of ^{230}Th, ^{226}Ra, ^{210}Pb, and ^{238}U (by measuring its daughter ^{234}Th which has a half-life of 24.1 days and may be expected to be in secular equilibrium in soil samples).

To expeditiously determine which samples should be analyzed, the results of screening counts were compared with the interim EPA standard for soil. Any samples measuring greater than 5 pCi ^{226}Ra/gram in the screening surveys were initially presumed to possibly contain RRM and were scheduled for high resolution spectroscopy counting. Those samples were shipped to PNL in Richland, Washington, where the cans were opened and the weight of soil was determined before and after drying. The dried soil was placed in a mortar and ground with a pestle. Sixty grams of ground soil (from a total of about 500 grams collected) were mixed with 9 grams of cellulose powder and formed into a pellet about 1.5-2 cm thick X 5.1 cm in diameter using a forming die in a 30-ton press (the thickness of pellets varied with the soil density). After wrapping the soil pellets with polyvinyl-chloride film, their photon emissions were routinely counted using a planar intrinsic germanium detector.

The detector was calibrated using sources made by blending standard solutions of ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb with blank sand, drying and quantitatively pressing into pellets as done with the samples. Instrument control counts were periodically made using an International Atomic Energy Agency (IAEA) uranium ore standard, blended with blank soil.

This technique is capable of providing sufficient sensitivity for radionuclide determinations at 5 pCi/g if counting intervals of 500-1000 minutes are used. However, since most samples contained in excess of that concentration, they were routinely counted for 60-200 minutes, and only those with a large statistical uncertainty were recounted for longer intervals.

In practice, the ratio of ^{226}Ra to ^{238}U has proven to be the most reliable indicator of the presence of uranium mill tailings. Since uranium has been extracted from the native ore, the tailings must show a ^{226}Ra to

^{238}U ratio significantly greater than one. Thorium-230 could be used instead of ^{226}Ra, but is much less precisely measured than ^{226}Ra because of its relatively small photon emission rate per disintegration. Lead-210 appears to be measured with about the same sensitivity as or better than ^{226}Ra, but it was not used because of concern for the possible enhancement of ^{210}Pb by fallout from the decay of atmospheric ^{222}Rn.

The decision level for determining when a ratio indicated a significant disequilibrium was based on ^{226}Ra and ^{238}U concentration variations observed in native minerals for the area. In Table C2, are tabulated analyses of several native materials from Edgemont identified by the program field staff geologists. These minerals are Quaternary alluvium (coded QA), Quaternary windblown material (QW), Tertiary-terrace gravel (TG), Cretaceous-Belle Fourche shale (KBF), Cretaceous-Mowry shale (KM), and the inclusive materials, bentonite clay (KBFB), and manganosiderite concretions (KBFMN).

The standard deviations based on counting statistics for these native material samples were used to obtain approximate upper bounds for the ratio

$^{226}Ra/^{238}U$. The formula for the upper limit of the ratio is:

$$\left(\frac{\text{pCi } ^{226}\text{Ra/g}}{\text{pCi } ^{238}\text{U/g}}\right)_{\text{Maximum}} = \frac{(\text{pCi } ^{226}\text{Ra/g}) + \text{standard deviation of } ^{226}\text{Ra}}{(\text{pCi } ^{238}\text{U/g}) - 1 \text{ standard deviation of } ^{238}\text{U}} \quad (1)$$

which has a confidence limit of about: 100 1 $-(.16)^2$ = 97%. The maximum upper-limit ratio obtained for the tabulated native materials was 2.2 for manganosiderite concretions in Belle Fourche shale. Thus, PNL arbitrarily selected as decision levels a ratio of 2.5 for the minimum that can be considered evidence of a "probably significant disequilibrium", and 5.0 as a "highly significant disequilibrium."

After initial testing during the early portion of the program, two arbitrary screening tests were adopted to improve the probability of detecting a significant disequilibrium while minimizing the chance that a natural material would be misidentified as being mill tailings. First, the ratio of the concentration of ^{226}Ra to ^{238}U was compared with the decision levels above (2.5 and 5.0). If it exceeded either limit, the precision of the measurement was examined. Only if the relative standard deviation of the measured ratio was less than 0.17, was the result flagged as having a "possibly significant" or "highly significant" disequilibrium depending on the decision level that was exceeded. This test reduced false positives caused by imprecise measurements of ratios that could have come from background materials. However, with this test, there is the possibility of missing a very significant disequilibrium measured imprecisely.

To detect the latter cases, the second test was also used. The ratio of ^{226}Ra to ^{238}U for each sample was adjusted using the propagated precision estimate of each measurement in a similar manner as was done for background samples. In the case of samples, the numerator was reduced and the denominator increased. The modification is as follows:

TABLE C2. Uranium Decay Chain Measurements for Background and Source Residual Radioactive Materials

		^{238}U		^{230}Th		^{226}Ra		^{210}Pb	
Sample	Date Counted	pCi/g	Std.Dev.	pCi/g	Std.Dev.	pCi/g	Std.Dev.	pCi/g	Std.Dev.
BLK SAND 1	5-May-82	1.5	0.20	4.1	2.0	0.41	0.46	0.62	0.24
BLK SAND 2	5-May-82	0.81	0.21	2.2	2.1	1.6	0.57	1.2	0.27
KM 1	13-Nov-81	0.86	0.091	1.6	0.84	0.86	0.21	0.56	0.11
KM 2	6-May-82	2.5	0.32	0.78	3.1	4.3	0.83	2.7	0.45
QW 3	4-Mar-82	0.45	0.068	2.1	0.73	0.71	0.18	0.75	0.11
KBF 1	13-Nov-81	2.3	0.24	0.98	2.1	2.4	0.55	1.7	0.30
KBF 2	22-May-82	2.6	0.19	2.0	1.1	2.0	0.29	2.0	0.21
KBF	6-Aug-81	2.5	0.30	2.9	2.5	3.6	0.84	1.6	0.34
KBFB	14-Nov-81	4.4	0.41	2.7	3.4	4.1	0.84	3.5	0.51
KBFMAN	25-Sep-81	0.99	0.19	4.0	1.7	1.4	0.59	0.74	0.24
QAL 1A	24-May-82	0.78	0.084	0.58	0.77	0.85	0.20	0.71	0.12
QAL 1B	23-May-82	0.66	0.14	1.2	1.5	1.3	0.36	0.40	0.17
QAL 2	14-Nov-81	2.3	0.212	0.47	1.8	2.2	0.48	1.7	0.26
SOIL 3	16-Jan-81	1.3	0.16	4.0	1.6	2.0	0.41	1.5	0.24
QW	25-Sep-81	0.48	0.15	0.45	1.8	0.13	0.43	1.1	0.25
QW 3	4-Mar-82	0.45	0.068	2.1	0.73	0.71	0.18	0.75	0.11
TG	5-Aug-81	2.4	0.26	0.37	2.2	3.1	0.64	2.0	0.32
TGB	23-May-82	2.2	0.20	0.73	1.6	2.9	0.46	1.7	0.25
ORE SPILL A	23-May-82	0.73	0.11	0.58	1.2	1.6	0.32	1.7	0.22
ORE SPILL B	2-May-82	150	9.6	160	15	150	13	130	12
ORE SPILL C	23-May-82	210	13	220	20	180	16	200	18
ORE SPILL D	23-May-82	0.75	0.097	1.4	1.1	1.2	0.24	0.93	0.14
ORE SPILL E	28-Aug-81	110	7.1	95	16	100	10	96	8.9

TABLE C2. (continued)

Sample	Date Counted	^{238}U pCi/g	^{238}U Std.Dev.	^{230}Th pCi/g	^{230}Th Std.Dev.	^{226}Ra pCi/g	^{226}Ra Std.Dev.	^{210}Pb pCi/g	^{210}Pb Std.Dev.
**SKMA	10-Jan-81	2.9	1.0	58	15	220	20	230	21
**SKMB	10-Jan-81	3.7	0.97	56	13	150	13	140	13
**SKMC	20-Jan-81	7.7	1.0	41	13	140	13	170	15
**SKMD	11-Jan-81	4.2	0.88	24	12	94	9.0	120	11
**SKME	12-Jan-81	1.5	0.93	40	13	130	12	160	15
SKMF	11-Jan-81	950	61	1200	120	940	85	640	58

* Possibly significant disequilibrium.
** Highly significant disequilibrium.

$$\text{Ratio A} = \frac{(\text{pCi } ^{226}\text{Ra/g}) - 2 \times \text{standard deviation of } ^{226}\text{Ra}}{(\text{pCi } ^{238}\text{U/g}) + 2 \times \text{standard deviation of } ^{238}\text{U}} \qquad (2)$$

When ratio A exceeded the decision levels, the sample was also flagged as having a "possibly" or "highly" significant disequilibrium. The latter test permitted decisions when the measurements were relatively imprecise but the disequilibrium was significant relative to the measurement error. These tests and arbitrary limits were chosen from among several options because they did not yield positive indications for a set of samples known to contain ore or native material. For another large block of samples they also tended to "catch" most cases which had been judged to have significant disequilibrium by a careful examination of the results for all radionuclides in the decay chain.

Also included in Table C2 of the test results for native soil samples are results from samples collected at the local mill which were identified as ore (SKMF) or tailings (SKMA-SKME) and samples collected at the site of a reported spill from an ore truck. The precision estimates are based on the propagation of counting statistics with an additional error of 9% included for the limiting error in excess of counting statistic errors determined for replicate sample pellets.

As previously mentioned, this test was normally applied only to samples which had been initially screened as having concentrations of ^{226}Ra above 5 pCi/g. Although it might be presumed that those samples not found to have a significant disequilibrium probably contain uranium ore, the concentrations of ^{226}Ra measured in samples identified by physical characteristics to be bentonite clay were found during screening measurements to be as high as 6.2 pCi/g at one location in Edgemont. In practice, at some locations field geologists working on the program could identify the characteristic "popcorn" or "expanded-mica" like appearance and the grey/white color of bentonite clay. Such obvious deposits were noted on the outdoor gamma survey maps for properties.

When the only soil samples from a property containing more than 5 pCi ^{226}Ra/gram were from such identified deposits, the property was classified as not contaminated with residual radioactive materials in the engineering assessment screening. Although the physical characteristics of uranium mineralization could be detected in some samples, it was not possible to physically detect small quantities of uranium minerals at low levels in all cases. Even though positive physical evidence of uranium mineralization was lacking, samples were assumed to contain uranium minerals which had been transported to the property unless there was a positive identification of bentonite clay.

BOREHOLE LOGGING IN EDGEMONT

An engineering assessment protocol was developed for Edgemont in 1981. To evaluate the depth profile of underground deposits containing ^{226}Ra, the protocol specified the use of a borehole logging technique. Gamma-rays from the decay of the short-lived daughters of ^{222}Rn resulting from ^{226}Ra can be measured through a significant thickness of contaminated soil by a probe lowered into the borehole. A detection probe for this purpose was constructed at PNL in Richland. This probe used an integrally canned NaI(Tl) gamma scintillation crystal and photomultiplier tube obtained from the Harshaw Chemical Co. To maximize the sensitivity of the probe, a crystal nominally 7.6 cm in diameter by 7.6 cm tall was used. For this detector size, the probe diameter was 8.9 cm. The detector crystal was collimated front and rear with at least 1.3 cm of lead. The probe was 53 cm long. It could be lowered into an uncased 10.2 cm diameter borehole, which was about as large a diameter as could be drilled to the necessary depths with a portable power auger. The sensitivity was sufficient to provide that counting errors of less than 11% relative standard deviation at 5 pCi/g when a 100 second count was used for measurements.

The calibration of the detector was based on three kinds of assumed deposits. The first was a uniform deposit that was large enough so that the counting rate from 609 keV photons reaching the detector would not increase if the deposit were made larger. A source of these dimensions is equivalent to an infinite planer source. The second source was a planer source 15 cm thick and large enough in diameter to be equivalent to an infinite planer source. The third was a similar source 5 cm thick. A laboratory facility was designed to simulate these characteristics.

The use of these kinds of deposits was based on the requirements of the proposed EPA standards for concentrations at properties in the vicinity of uranium processing facilities. Those standards required measurements at 5 cm intervals for the first foot of depth, and 15 cm intervals below that depth. We intended to simulate the 5 cm and 15 cm layers. The 609 keV photopeak of the ^{214}Bi daughter of ^{222}Rn formed in the decay of ^{226}Ra was selected because of its abundance and relative freedom from interference caused by gamma-rays from other naturally radioactive species. The use of a relatively low energy gamma-ray also limited its range in soil. Thus, the detector response would give more precise information about the depth of a deposit of residual radioactive material than could be obtained if the higher energy photons from ^{214}Bi were used.

The efficiency for counting of a uniform infinite source increases with depth because of the geometric relationship of the source and detector. At the surface, the geometry approximates a hemisphere. The efficiency will increase with depth until the detector is deep enough that the range of gamma rays in the soil prevents those rays from the surface reaching the detector. Thus, the appropriate efficiency factor is depth dependent, until that limiting depth is reached.

For layers of contaminated material in background soil, the geometry effect is different. The counting efficiency is maximum when the detector is centered in the layer, but the detector will continue to respond to gamma-rays from the layer when it is positioned at nearby depths. Thus, the relatively thin layered source produces a gamma field, the intensity of which decreases with distance from the layer. To determine the position and intensity of the source layer, the response of the detector must be transformed to conform to the original concentration profile with depth.

For the Edgemont program, an iterative calculational process was used. First, all deposits were assumed to be uniform in concentration. Appropriate efficiency factors for each depth were used to convert borehole logging gamma counts taken at various depths to the equivalent concentration for a uniform deposit. Then each concentration was compared to the concentration of the next deeper layer. If a non-uniform deposit was present, the computed concentrations would show a change even though the appropriate efficiency correction had not been used. When a layer was found to contain more ^{226}Ra than the next deeper layer, its thickness was determined. If the thickness was greater than 30 cm, it was assumed that the efficiency for measurement of 609 keV gamma-rays from the layer would be similar to that for uniform deposits and no recalculation would be needed. If the thickness was between 15 and 30 cm, a correction factor, based on the calibration taken with the 15 cm thick layer, was used to correct the excess ^{226}Ra activity of the layer. If the layer was less than 15 cm thick, the excess ^{226}Ra activity was redetermined using the calibration based on the 5 cm thick layer.

For calibration purposes, a cylindrical tank (102 cm in diameter X 86 cm tall) was constructed of 1/16 in. thick aluminum. The tank was equipped with a 4 in. diameter concentric aluminum tube, down which the probe could be lowered. When this tank is filled with soil, the center will receive about 92% of the 609 keV photon emissions of ^{214}Bi from an infinite sphere of the same soil, neglecting the potential loss of ^{222}Rn from the tank. For thin layers, the photon emission at the center of the tank will approach 100% of an infinite planer source. The thickness of the center tube walls would attenuate the photons by less than five percent.

The detector was calibrated with 5-cm and 15-cm thick layers of uranium mill tailings, and with layers of uranium mill tailings diluted with blank sand to a total average ^{226}Ra concentration of about 5 pCi/g.

In the calibrations for 5 cm thick layers and 15 cm thick layers, the detector response for each 5 or 15 cm interval was entered into the computational program, and the efficiency factor was adjusted to yield the known calibrated ^{226}Ra concentration of the layer for the measurement taken with the detector positioned in its center.

The laboratory facility could give only a preliminary calibration for the case of an infinitely thick layer of uniform concentration because of the dimensions of the tank size that were used. Later, one Edgemont property was chosen for a field calibration because it had relatively uniform gamma exposure rates, and surface samples contained similar ^{226}Ra concentrations. In addition, based on the preliminary calibrations, the borehole logging data indicated that the soil on that property was a layer of shale approximately 5 feet thick, having a relatively uniform ^{226}Ra concentration. Soil cores were taken at three locations on the property to a depth of 6 feet. The ^{226}Ra concentrations were determined from the soil core samples for each 5 cm increment for the first 30-cm and each 15-cm soil increment thereafter. Then these data were compared with borehole logs made in the same holes. Efficiency factors were adjusted so that the average concentration measured for the three holes by borehole logging at each depth increment was the same as the average concentration measured in the soil cores. Counts for borehole logging were taken at 5-cm increments for the first 30 cm and at 15-cm increments thereafter, to depths of 120 or 180 cm. The probe was inserted into a borehole until the surface of the ground was aligned with an index mark corresponding to the center of the sodium iodide crystal. A 100 second count was taken at that depth using a multi-channel analyzer. The spectrum was stored in the first 1/16th for the analyzer memory. Then the probe was lowered to the position of the next depth increment and another 100 second count was stored in the next 1/16th of the memory. This process was repeated until each depth was measured. Then, the analyzer was adjusted to integrate the channels corresponding to the 609 keV photopeak of ^{214}Bi and also another energy band at 690 keV. The higher energy band was immediately above the photopeak spectral region and was used to estimate the approximate background and the compton-scatter corrections from radionuclides emitting higher energy gamma-rays than ^{214}Bi.

The field personnel recorded both integral counts for each depth increment on a survey sheet for the borehole. Later, the depths and the corresponding counts were entered into a programmable calculator. The computational programs determined the net counts for each depth and stored the results and depths in register arrays prior to computing the ^{226}Ra concentrations. At the calibration site, as the depth increased to 75 cm, the geometry and counting efficiency increased. Thereafter, the geometry was relatively constant, and only random variations of the count-rate were observed from the inherent scatter in measurements. Thus, the average efficiency for all depths greater than 75 cm was computed and used in subsequent calculations.

The borehole logging technique and program were field tested at several residences in Edgemont. Soil cores were taken at several locations and cut into five or 15 cm increments. The ^{226}Ra concentration was measured using the large volume sodium iodide well counter and the procedure normally used for soil samples collected at Edgemont. After cores were removed, the coring holes were enlarged from 7.3 cm to 10.2 cm in diameter using a portable power auger. Then the boreholes were monitored using the logging procedures.

A comparison of the results of this test is shown in Table C3. The results demonstrate the approximate nature of the borehole logging and soil core measurements. Soil cores give the concentrations present in the borehole soil at each depth, whereas the borehole logger detects the gamma-rays emitted from soil surrounding the boreholes, mostly from a radius of about 15 cm. However, a large, intense source could be detected more than 30 cm from the borehole. The layers contaminated by residual radioactive material tended to be detected by either technique. However, the comparisons of actual concentrations at any given depth in a borehole showed a scatter of about ±50% relative standard deviation. The overall average ratio of borehole concentration measurements to soil core measurements was about 1.2. When only those measurements greater than 5 pCi ^{226}Ra/g were included, the average ratio was about 1.0, and when only concentrations greater than 15 pCi ^{226}Ra/g were included, it was about 0.7. These ratios do not demonstrate a bias of one method from the other since the two techniques were not measuring the same source. For example, it might be concluded that the computational program caused the concentrations measured at the 20-30 cm increments of borehole 166-32 to be biased low relative to the soil core measurements

TABLE C3. Comparison of ^{226}Ra Concentrations Determined by Analysis of Soil Cores and by Borehole Logging

Identification Code:	261-15			261-16		
Depth Increment (cm)	Core (C)*	Borehole (B)*	B/C Ratio	Core (C)	Borehole (B)	B/C Ratio
0-5	2.2	3.5	1.6	7.8	4.2	0.5
5-10	1.9	4.0	2.1	4.2	3.8	0.9
10-15	1.8	4.0	2.2	3.2	3.6	1.1
15-20	1.6	4.4	2.8	2.5	3.0	1.2
20-25	1.8	6.5	3.6	2.6	3.1	1.2
25-30	7.0	10.3	1.5	3.5	2.9	0.8
30-45	41.4	28.6	0.7	2.6	2.7	1.0
45-60	36.8	11.4	0.3	2.4	2.4	1.0
60-75	5.3	4.0	0.8	2.6	2.7	1.0
75-90	3.0	3.3	1.1	2.4	2.6	1.1
90-105	2.0	2.9	1.5	2.5	2.6	1.0
105-120	2.3	2.4	1.0	2.4	2.4	1.0
120-135	2.2	2.5	1.1	--	--	--
135-150	2.1	2.5	1.2	--	--	--
150-165	2.2	2.3	1.0	--	--	--
165-180	--	2.6	--	--	--	--

Identification Code:	261-17			166-32		
0-5	10.0	11.8	1.2	50.4	57.1	1.1
5-10	10.3	10.4	1.0	56.6	67.3	1.2
10-15	3.7	4.4	1.2	87.1	63.8	0.7
15-20	3.1	3.8	1.2	87.9	47.1	0.5
20-25	2.8	3.6	1.3	83.5	22.9	0.3
25-30	2.9	3.4	1.2	19.2	12.4	0.6
30-45	2.4	3.0	1.2	3.0	5.2	1.7
45-60	2.5	2.5	1.0	3.4	4.0	1.2
60-75	2.6	2.6	1.0	3.5	3.6	1.0
75-90	2.3	2.6	1.1	3.6	3.4	0.9
90-105	2.6	2.8	1.1	3.2	4.4	1.2
105-120	2.5	2.7	1.1	6.9	4.8	0.7
120-135	--	--	--	3.9	4.8	1.2
135-150	--	--	--	--	5.4	--
150-165	--	--	--	--	--	--
165-180	--	--	--	--	--	--

*All concentration results are pCi ^{226}Ra/gram of soil on a wet weight basis.

TABLE C3 (continued)

Identification Code:	166-33			166-34		
Depth Increment (cm)	Core (C)	Borehole (B)	B/C Ratio	Core (C)	Borehole (B)	B/C Ratio
0-5	9.7	5.2	0.5	2.6	3.7	1.4
5-10	11.1	5.3	0.5	lost	4.2	--
10-15	3.0	4.9	1.6	2.6	4.0	1.5
15-20	2.9	3.5	1.2	2.6	2.6	1.0
20-25	3.2	3.4	1.1	2.6	2.5	1.0
25-30	3.3	3.3	1.0	2.7	2.4	0.9
30-45	3.1	3.3	1.1	2.0	2.5	1.3
45-60	3.0	3.1	1.0	2.3	2.2	0.7
60-75	2.4	2.4	1.0	2.1	2.0	1.0
75-90	1.2	1.7	1.4	1.7	1.7	1.0
90-105	1.3	2.2	1.7	2.1	2.3	1.1
105-120	2.1	2.3	1.1	1.8	2.3	1.3
120-135	--	--	--	--	--	--
135-150	--	--	--	--	--	--
150-165	--	--	--	--	--	--
165-180	--	--	--	--	--	--
Identification Code:	222-10			222-11		
0.5	6.8	8.5	1.3	12.9	16.8	1.3
5-10	7.0	8.4	1.2	8.4	15.7	1.9
10-15	13.2	8.7	0.7	8.8	13.2	1.5
15-20	5.4	6.8	1.3	7.0	10.9	1.6
20-25	2.0	5.8	2.9	3.4	9.6	2.8
25-30	2.0	4.4	2.2	2.1	6.0	2.9
30-45	1.8	2.6	1.4	1.7	2.7	1.6
45-60	2.1	2.4	0.9	2.0	2.3	1.2
60-75	2.9	2.0	0.7	1.9	2.2	1.2
75-90	1.9	1.8	0.9	1.9	2.1	1.1
90-105	1.7	1.7	1.0	1.7	2.0	1.2
105-120	1.5	1.7	1.1	1.9	2.0	1.1
120-135	--	--	--	--	--	--
135-150	--	--	--	--	--	--
150-165	--	--	--	--	--	--
165-180	--	--	--	--	--	--

TABLE C3 (continued)

Identification Code:	205-5**		205-6**		205-7**	
Depth Increment (cm)	Core (C)	Borehole (B)	Core (C)	Borehole (B)	Core (C)	Borehole (B)
0-5	2.7	2.6	2.1	2.6	2.7	2.6
5-10	2.5	2.4	2.5	2.7	2.6	2.8
10-15	2.3	2.7	2.6	2.7	2.8	2.7
15-20	2.5	2.7	2.6	2.4	2.6	2.9
20-25	2.9	3.0	2.3	2.7	2.7	2.6
25-30	2.9	2.7	2.9	3.0	2.6	2.7
30-45	2.7	2.9	3.0	3.1	3.4	2.8
45-60	2.6	3.0	2.8	2.7	2.7	2.7
60-75	2.5	2.9	2.5	2.7	3.4	2.5
75-90	2.0	2.5	2.7	2.6	3.1	2.5
90-105	2.2	2.3	2.6	2.9	2.7	2.5
105-120	2.4	2.4	2.6	2.6	2.9	2.7
120-135	2.2	2.5	2.7	--	--	--
135-150	2.4	2.7	2.6	--	--	--
150-165	2.3	2.4	2.8	--	--	--
165-180	2.5	--	2.6	--	--	--

Overall average ratio ± standard deviation = 1.2 ± 0.5
Average ratio for cores containing >5 pCi/g ± standard deviation = 1.0 ± 0.5
Average ratio for cores containing >15 pCi/g ± standard deviation = 0.7 ± 0.3

**Results from boreholes at property 205 were not used in determining average ratios because those boreholes had been used to determine the calibration factors for uniform layers.

in those increments. However, an examination of the raw counts from the photopeak area recorded during the borehole logging process showed that the net counts fell by almost a factor of three between the count taken 15 cm below the surface and the one taken 25 cm below the surface. Thus, the relatively constant radium concentration measured in borehole soil for those increments was not present on the average in the soil surrounding the borehole.

The principal difficultly experienced in using this method was associated with measurement of thin surface deposits characteristic of windblown tailings. These kinds of deposits were detected having ^{226}Ra concentrations between 5-10 pCi/g adjacent to structures at distances as far as several city blocks from the uranium mill. Apparently, in those cases, the windblown material was first deposited on the roofs of the structure and later washed from the roofs to the surface soil adjacent to the foundation. A similar effect was noted along the edges of some of the streets. However, in Cottonwood, where extensive deposits of windblown tailings were present and gamma fields were relatively intense from nearby tailings piles, the borehole logging was supplemented by soil cores taken from the 0-15 cm and the 15-30 cm depth increments. The need for supplementary sampling was partially based on the cost of performing extensive arrays of boreholes when soil cores could demonstrate that the residual radioactive material was confined to the surface, and could permit the estimation of its areal profile.

It is possible that a bias could exist in the logging technique that could not be demonstrated by field testing. Since the logging technique used only three alternate geometry configurations, it could not accommodate every potential spatial distribution of ^{226}Ra in soil. However, one purpose of borehole logging was to demonstrate the depth and extent of deposits of residual radioactive material. Table C3 shows that both borehole logging and soil core analyses techniques gave approximately the same depth profiles at each borehole. It will always be necessary to perform test measurements after any remediation process to determine that the ^{226}Ra concentrations in soil below the remediation depth is within the applicable standards. If the borehole logging process gives a reasonably good estimate of the extent and depth of the deposit, it serves the purpose of providing information necessary to estimate the cost and complexity of the remediation.

Since the detection sensitivity is theoretically capable of measuring 5 pCi ^{226}Ra/g with a relative standard deviation of 11% even in layers that are 5 cm thick, it is unlikely that significant deposits of residual radioactive material would not be detected in this borehole logging procedure. Many boreholes throughout Edgemont detected the different layers of shale and sand characteristic of the local geology. Radium concentration changes from 2 pCi/g to 4 pCi/g were often detectable. Thus, the use of borehole logging results as a criterion for selecting sites for remedial actions is justified on the basis of these experiences.

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Argonne National Laboratory
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Argonne, IL 60439

G. Lane
Council of Energy Resource Tribes
5660 South Syracuse Circle
Englewood, CO 80111

J. R. Durey
Bendix Project Manager
U.S. Department of Energy
Technical Measurements Center
Grand Junction, CO 81502

H. Langner
Bendix
U. S. Department of Energy
Technical Measurements Center
Grand Junction, CO 81502

C. McIntyre
State Planning Bureau
Capitol Building
Pierre, SD 57501

R. Overmeyer
Ford, Bacon and Davis
P.O. Box 8009
Salt Lake City, UT 84108

R. P. Powers
Tennessee Valley Authority
P.O. Box 2957
Casper, WY 82602

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Sandia Area Office
U.S. Department of Energy
P.O. Box 5400
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This document is the final report for radiological surveys conducted in the community of Edgemont, South Dakota for the purpose of locating residual radioactive materials from the uranium processing industry. It contains a discussion of the historical justification for the surveys, and a summary of activities during the survey, from September 1980 through November 1984. The survey protocols are presented and discussed. The results of several studies of relevance to the surveys are also included. The results of the survey are presented in tabular form.

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