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Project Summary

Active Soil Depressurization (ASD) Demonstration in a Large Building

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The purpose of this research effort was to develop building standards for radon-resistant large buildings for the Florida Radon Research Program (FRRP) of the State of Florida. Fundamental and applied research studies of various building components (floor barriers, mitigation systems, ventilation systems, fill materials) and performance standards were conducted. Field evaluation and validation of the draft standards for residential structures have been carried out. The effectiveness of passive barriers, the modification of the heating, ventilation, and air conditioning (HVAC) system operations to ameliorate indoor radon concentration, and the use of active subslab depressurization (ASD) systems have been investigated in demonstration (new construction) houses and research structures in Florida. Current emphasis is on large scale buildings. This study evaluated the feasibility of implementing such radon-resistant construction techniques (especially ASD) in new large buildings in Florida. The techniques developed in this study for Florida large buildings focused primarily on the demonstration of passive barriers to radon entry and ASD systems as applied to large buildings. The results of this study will enable existing subslab pressure field extension (PFE) models to be expanded to include large slabs. The results of these improved models will be used to design more effective ASD systems for new buildings. In addition to an ASD system, other radon-resistant construction techniques were designed into the building, including the installation of adequate subslab membranes, sealing of all slab openings, and HVAC operation to prevent depressurization of the building interior. Implementation and installation of these features were monitored as the building was being constructed. Indoor radon concentrations and radon entry were monitored in the finished structure with the HVAC system on and the ASD system off, and with the ASD systems activated in a temporary mode. Results from this study have demonstrated that with sufficient attention to building design and construction, significant radon entry into a large building constructed on a site of high radon potential can be prevented. The effectiveness of the ASD system as a radon mitigation technique could not be realistically evaluated due to a lack of radon in the building. However, the PFE measurements suggest that the design is more than adequate to meet its purpose of pressure reversal between the building interior and the subslab regions.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Florida Radon Research Program (FRRP) was implemented by the State of Florida in 1989 to provide radon research related to the detection, control, and abatement of radon in Florida buildings. The purpose of this research effort was to develop building standards for radon-resistant buildings. Fundamental and applied research studies of various building components (floor barriers, mitigation systems, ventilation systems, fill materials) and performance standards were conducted. Field evaluation and validation of the draft standards for residential structures followed. The effectiveness of passive barriers, modification of the heating, ventilation, and air-conditioning (HVAC) system operations to ameliorate indoor radon concentration, and the use of ASD systems have been investigated in demonstration (new construction) houses and research structures in Florida. Current research includes large scale buildings.

This study evaluated the feasibility of implementing such radon-resistant construction techniques (especially ASD) in a new large building in Florida. The major specific objectives of the demonstration were:

- Work with designers/architects to design an ASD system for the building that was also broadly applicable to other similarly sized buildings in Florida;
- Test and evaluate the ASD and barrier system effectiveness in a large building built on a high radon potential site; and
- Expand existing subslab PFE models to include large slabs.

This work complements previous diagnostic and mitigation strategy development work in the FRRP. In addition to the ASD system, other radon-resistant construction techniques were designed into the building, including the installation of adequate subslab membranes, sealing all slab openings, and HVAC operation to prevent depressurization of the building interior. Implementation and installation of these features were monitored as the building was being constructed. Indoor radon concentrations and radon entry were monitored in the finished building with the HVAC system on and the ASD system off, and with the ASD systems activated in a temporary mode.

Materials and Methods

Site Selection

In 1992, Southern Research Institute (SRI) assisted in ambient radon measurements at a construction site in Polk County, FL. Polk Power Partners, L.P., were preparing to construct an industrial building on the site located on Highway 555, approximately 10 miles* southwest of Bartow, FL, for Arc Energy and Central Southwest Services, Inc. The structure was to become the Mulberry Cogeneration Facility's (MCF's) Plant Services Building. The proposed building was to be approximately 21,000 ft^2 and would consist of a metal shell on a 6 - 8 in. floating slab. The subslab area was to have five drain lines encased in concrete, below the slab running the entire length of the building, effectively separating the slab into five cells. In addition, all other subslab pipes for power, water, and other utilities were to be installed encased in concrete.

Six EPERM (High Sensitivity, Standard Chamber) canisters were deployed. They were placed at the site at ground level, at 12 ft and at 27 ft. On subsequent visits to the site, gamma measurements were made at ground level and 12 ft where the EPERMs were deployed. The results of these gamma measurements resulted in a consistent 40 µR/hr level at both ground level and 12 ft. Permeability measurements were carried out, and some radon grab samples were taken at a depth of 3 ft. Typical of reclaimed land, the results varied from 3,000 to 10,000 pCi/L. On the basis of these preliminary measurements, the MCF was identified as a candidate building for the Large Building ASD Study. The slabs for the Control Room and the Data Processing Unit (DPU) Room were poured at a recessed depth of 18 in., relative to the rest of the slabs.

A planning meeting to discuss the site was held at EPA's National Risk Management Research Laboratory, Research Triangle Park, NC, on January 20, 1993, with David Sanchez and A. B. Craig of EPA, Susan McDonough of SRI, and Tom Pugh of Florida A&M University (FAMU). A project conference was held at Black & Veatch's (B&V's) offices in Kansas City, MO, the next day. As a result of this meeting, the owner decided to incorporate both passive sealing modifications and an ASD system into the building.

ASD Matting Plan

The proposed facility and plant services building drawings were obtained from the contractors. The plans were reviewed and probable radon entry points were identified. A proposed design of an ASD system was developed at the initial planning meeting attended by EPA, FAMU and SRI researchers. Several areas of concern were identified with respect to various subslab and building design features. Subsequent to the planning meeting, a conference with B&V was attended by EPA, FAMU, and SRI. The project goals and objectives, and the overall intent/theory of radon-resistant construction were conveyed to members of the B&V design team. Drawings of the proposed ASD system, developed by the research team, and existing passive radon controls, developed by the B&V team, were discussed. The B&V team was then left to design, price out, identify schedule conflicts, and obtain owner approval to incorporate the ASD system in the final building design. Several iterations of the University of Florida residential PFE model were run to ensure that the system was capable of providing the required air flows throughout the system. The B&V design team submitted preliminary design drawings to the research team for comments on the system design. The comments were relayed to the B&V team and were ultimately included in final system design.

The current draft Florida radon standard would allow for the ASD system to consist of ventilation matting such as Enka-Vent spaced on 20-ft centers. The recommended system layout for this building utilizes ventilation strips on 15-ft centers. This is a result of several factors:

- The building utilizes a 30-ft bay spacing that lends itself to the 15-ft module;
- The performance of the mat in this configuration had not been extensively modeled, so a slightly conservative approach was considered prudent; and
- The air permeability characteristics of the soil immediately beneath the slab were not well established.

Risers R-5 and R-7 were omitted during construction, and the pipe connections to the matting were closed and sealed. These changes were necessitated by construction changes in the building after the slabs were poured. The building has unique features, most notably the encasement of all underslab plumbing and conduit in reinforced concrete. In virtually every case, the plumbing trenches were backfilled with concrete to the elevation of the bottom of the slab. The trenches were usually more than 3 ft deep. They were slightly over excavated, and 2 - 4 in. of concrete was cast over the exposed bottom of the trench to create a work surface. Piping and reinforcing were installed, and forms were set to limit the width of the concrete to approximately 20 in. After the concrete was cast and the forms stripped, the remainder of the trench was backfilled with compacted earth. This had the effect of compartmentalizing the slab into many discrete zones. As a result, the ASD matting

* Metric equivalents for nonmetric units used in this Summary are: 1 mi = 1.6 km, 1 ft^2 = 929 cm^2, 1 ft = 30.5 cm, 1 in. = 2.54 cm, 1 mil = 25.4 µm, 1 pCi/L = 37 Bq/m^3, and 1 in. WC = 249 Pa.

design might appear overly conservative, unless consideration is given to the need for intersecting each of these areas with some portion of a ventilation mat. Despite these constraints, a reasonably simple and efficient use of ventilation mat was achieved.

ASD Installation and Construction Observations

Personnel from SRI and FAMU made several visits to the job site throughout the construction period. The purpose of these visits was to monitor, but not affect, the construction process. However, the construction crews and their supervisors frequently asked advice about specific ASD installation issues, which was then freely given. Before inclusion of SRI or FAMU personnel into the project, and based on advice taken from publicly available literature, the contractor had agreed to install 6-mil polyethylene beneath the entire subslab area, including below and along the inside surface of the perimeter grade beams. Although this step exceeded current recommendations, it is not believed to have had a significant effect on the effectiveness of the barrier, since the condition of the polyethylene rapidly worsened as the beams were cast, stripped, backfilled, etc. During the installation of the ventilation mat, it became apparent that large amounts of sand would be tracked onto the mat surface by workmen, and steps were taken to have them step over, rather than walk on, the mat. Some consideration should probably be given to requiring clear polyethylene whenever an ASD system is roughed in, so that an inspector can look for sand contamination and blockage of the mat. This is true for all sizes of structures, but is especially important on large slabs where considerable time is required to install the mat and cover it with polyethylene.

Another problem that presented itself during the slab-preparation process was the cutting of the vapor barrier when reinforcing steel was dropped or dragged across it, especially if the point of contact was at the ventilation mat. This problem may be specific to this structure, but will probably occur to some degree in all buildings. Careful inspection and repair will be necessary to limit this.

The slab was cast in four sections beginning with the lowest level (the Control Room and the DPU Room). This resulted in some sections of ventilation mat being exposed to wear and tear, sand, and waste concrete that was dragged over the forms or otherwise spilled. We advised the contractor to “sleeve” the mat for a distance of approximately 6 - 7 ft at these points. This was easily accomplished by cutting a section of polyethylene approximately 6 x 6 ft and placing it at the edge of the pour immediately before installation of the mat. The polyethylene was then folded over the top of the mat and secured with tape. While this prevents the mat from communicating directly with the soil in this small section, the effect on the performance of the system is negligible. This practice did seem to effectively prevent flow along the mat at this point. It is reasonable to assume that a fully blocked mat might still exhibit some very slight flow, since the pressure field will propagate to some extent through the surrounding soil. This may be a point worth investigating in detail.

The slab had one final feature unique to the experiences of this program; several hundred twisted copper strand grounding cables were installed that penetrated the slab. Since there is considerable open space between each intersecting stand of wire (approximately 26% of the area of the cable itself that was generally 1.5 in. in diameter), these were potential entry points that were not anticipated during our earlier consultations. However, it is not difficult to imagine a variety of potential solutions to this rather unusual situation.

Despite having been heavily reinforced and cured in compliance with the current recommendations, there was some cracking visible in the slab. The effects of these cracks on radon entry are discussed elsewhere in the report.

In conclusion, it was not particularly difficult for the workmen to properly install the ASD system or to achieve a high degree of effectiveness with the slab sealing practices if they had been through a short training program. There was some learning required on their part, and this advanced most quickly through onsite demonstration rather than discussion or reference to sketches.

Diagnostic Measurements

Pressure Field Extension

Pressure field extension was measured by attaching an in-line radon mitigation fan to one of the ASD risers to produce a pressure field in the Enka-Vent mat system with the other risers capped and sealed. Subslab pressures were measured using a micromanometer attached to test holes drilled through the slab.

Slab Crack Characterization

The flow through the slab cracks and the radon concentration infiltrating through these cracks were analyzed using techniques developed for the FRRP.

Post-Construction Ventilation and Radon Entry Characteristics

Ventilation and radon entry into the building were monitored using two systems. For building ventilation, a tracer gas technique was used. For radon measurements, a Campbell Scientific, Inc. 21XL Micrologger with 40K RAM storage system was used. In the 21XL system installed in the MCF building, the following parameters were measured:

1. Δp_1 between the Electrical Equipment Room and the DPU Room.
2. Δp_2 between the DPU Room and outside the building.
3. Δp_3 between the HVAC Mechanical Room and the DPU Room.
4. Δp_4 between the Reception Area and the DPU Room.
5. Δp_5 between the subslab area and the DPU Room.
6. Temperature on the 21XL Panel located in the DPU Room.
7. Barometric pressure outside the building.
8. Radon levels under the slab using a Pylon AB5 monitor operating in the pumped mode.
9. Radon levels in the DPU Room using a Pylon AB5 with a passive radon detector (PRD) cell.
10. Radon levels outside the building using a Pylon AB5 monitor operating in the pumped mode.
11. Radon levels in the Electrical Equipment Room using a Femto-Tech ionization monitor.
12. Radon levels in the Control Room using a Femto-Tech ionization monitor.
13. Radon levels in the Water Treatment Area using a Femto-Tech ionization monitor.
14. Radon levels in the Reception Area using a Femto-Tech ionization monitor.

Data from each of these parameters was averaged (or totalized for the radon monitors) and stored every 30 min. This datalogging system was installed in the building on August 8, 1994, and was made fully operational shortly thereafter.

Results

Site Characterizations

Core samples were taken at three locations prior to pouring the slab. In each core, soil samples were recorded down to a depth of about 60 in. with separate samples every 4 - 6 in. The average soil radium content for cores one, two, and three were 5.9, 3.9, and 6.5 pCi/g, respectively, with an average for all three cores of 5.44 pCi/g. The radium content has a tendency to drop with depth, with the higher levels within 10 - 20 in. Permeability and soil gas radon were also measured prior to slab pouring. However, due to problems with the permeameter, the only reliable data were obtained in the north end of the building. The average soil gas radon concentration was approximately 9,905 pCi/L with no discernible pattern under the north end of the slab.

Pressure Field Extension Measurements

After the slab was poured, PFE was measured in the southwest corner of the slab. These measurements were undertaken not only to obtain a measure of the PFE under the slab, but also to determine the effects that deleting riser R-4 would have on the effective coverage of the ASD system. The tests were carried out with an in-line fan installed on riser R-1 and with risers R-2, R-4, R-5, and R-6 capped. Risers R-3 and R-7 were removed after the slab was poured due to changes in the building usage. The openings to the matting were closed and sealed. The subslab pressures averaged about -100 Pa (-0.4 in. WC) relative to atmospheric and, as might be expected, were generally higher (more negative) in the vicinity of the Enka-Vent matting. This subslab pressure level should be more than adequate for effective operation of the ASD system.

Slab Crack Mapping and Measurements

Three prominent slab cracks were analyzed on October 22, 1993. Based on these visible cracks, a conservative estimate of the total crack area is approximately 14 ft^2 (1.3 m^2) of a total slab area of 21,000 ft^2, a figure of less than 0.1% of the total area. In each case the flow of soil gas through the cracks (as well as the concentration of radon in the gas) was sufficiently low that it should not significantly contribute to the indoor radon levels at realistic pressure differences.

Post-Construction Ventilation and Radon Entry

Radon Entry

The data from the continuous monitoring system are plotted on a daily basis in the Appendix of the full report. These data plots cover the period 8/17/94 through 1/06/95. Operation of the building can be divided into three periods:

Period 1. From 9/08/94, when the data logger was first installed, until 10/22/94 when the ASD system was temporarily energized.

Period 2. From 10/22/94, when the ASD mitigation fan was installed and energized, until 10/28/94.

Period 3. From the time the ASD fan was turned off until 11/01/94 during that time several building operation upsets were encountered.

The radon levels for Period 1, while fluctuating somewhat, were very low overall and indeed were barely above ambient concentrations. These are shown in Table 1 where, with the exception of the subslab, the radon levels during Period 1 averaged less that 1 pCi/L.

During Period 2 an in-line radon fan was connected to riser R-5 to temporarily activate the ASD system. These results are also shown in Table 1. No significant reduction in the low radon concentrations was observed; in fact, at first inspection it would appear that the ASD operation raised the radon levels in the occupied areas of the building. However, closer inspection of the data shows that the ambient radon levels increased as well over this time period from 0.25 pCi/L in Period 1 to 0.64 pCi/L in Period 2. The increases inside the building followed the ambient levels during this same time period. In order to better understand the results of the ASD operation, the values in Table 1 were adjusted by the changes in the ambient radon levels. The resulting changes in average indoor radon, less than 0.5 pCi/L, are probably not experimentally significant. In short, the base levels of radon in the building appear to be so low that no appreciable change results from activating the ASD system. In contrast, the subslab radon levels that averaged about 13,000 pCi/L during Period 1 were noticably decreased during and shortly after ASD activation. It is seen in Table 1

***Table 1**. Average Radon Levels Measured at the Mulberry Cogeneration Facility (in pCi/L)*

Condition of the ASD System	*Subslab*	*DPU Room*	*Ambient Pumped*	*Elect. Equpt. Room*	*Control Room*	*Water Treat. Room*	*Office/ Recpt.*
ASD Off 9/08 to 10/22/94	*13043 (13043)*	*0.73 (0.21)*	*0.52*	*0.70 (0.18)*	*1.09 (0.57)*	*0.80 (0.28)*	*0.72 (0.20)*
ASD On 10/22 to 10/28/94	*9772*	*1.14 (0.34)*	*0.80*	*1.50 (0.70)*	*1.60 (0.81)*	*1.20 (0.40)*	*0.96 (0.17)*
ASD Off 10/28 to 11/01/94	*9486*	*0.71 (**)*	*1.09*	*0.74 (**)*	*1.12 (0.04)*	*1.01 (**)*	*0.70 (**)*

Notes: Numbers in parenthesis are after subtracting the ambient radon background levels. (**) indicates that the radon levels were below the lower limit of the radon monitor.

that activation of the ASD system dropped the subslab radon levels by approximately 25%.

Except for the reception area, the occupied zones were pressurized relative to the outdoors. The time traces of the pressure measurements are shown in more detail in the Appendix of the full report. These plots show a consistent pressurization of most zones with significant fluctuations that appear to be due to changes in status of some building system that was not specifically monitored, such as ventilation fans in the bay areas. It was observed that the door from the Mechanical Room to the outdoors was frequently ajar, resulting in large swings in several pressures at unpredictable times. The Office/ Reception areas fluctuated in pressure relative to the outdoors, although on the average these areas were depressurized. Also, the pressure under the slab without the ASD system running is quite positive. This is most likely due to air from the building interior being forced down under the slab through the construction joints and floating edge cracks.

Conclusions and Recommendations

In view of the low radon levels inside the building and the fact that the site has a high radon potential, it appears that either the radon barrier system installed under the slab, the overall pressurization of the HVAC systems, or some combination of the two, is very effective in preventing radon entry into the building. In either case, results from this study have demonstrated that, with sufficient attention to building design and construction, significant radon entry into a large building constructed on a site of high radon potential can be prevented.

Due to the continuous occupancy of the building, starting before completion of construction, the planned passive (HVAC off) experiments were not completed. These experiments would have better defined the relative effects of both the barriers and the HVAC operation. However, since at least part of the structure is apparently depressurized with respect to the outdoors, we assume that the primary mitigation structural element was the slab/barrier integrity rather than the HVAC system. Further measurements during an unoccupied period without HVAC operation would have been highly desirable.

The effectiveness of the ASD system as a radon mitigation technique could not be realistically evaluated due to a lack of radon in the building. However, the PFE measurements suggest that the design is more than adequate to meet its purpose of pressure reversal between the building interior and the subslab regions.

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Marc Y. Menetrez *is the EPA Project Officer (see below).*
The complete report, entitled "Active Soil Depressurization (ASD) Demonstration in a Large Building," (Order No. PB97-133805; Cost: $28.00, subject to change) will be available only from:

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