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PRESSURE FIELD EXTENSION USING A PRESSURE WASHER

NEW JERSEY DEPE SPONSORED PROJECT
INNOVATIVE MITIGATION RESEARCH AWARDS

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ABSTRACT

Radon remediation is typically done with a sub-slab ventilation system. A primary cause of failure of these systems is due to an incomplete pressure field extension, which allows radon to continue to enter the building. More than half of the homes which WPB Enterprises mitigates, do not have a good gravel base under the slab. This Project investigated a technique which extends the pressure field in tight soils from a single suction point by creating sub-floor tunnels using a commonly available 3000 psi pressure washer. This technique is a possible choice for mitigators dealing with non-rocky, tight soil and limited choices for suction hole locations. Tunneling under the slab was found to be able to double the existing strength of the pressure field but not to increase the pressure field extension significantly nor to consistently produce a vacuum where none existed before. The study made a comparison between using the water jet to increase the pressure field extension versus using a high vacuum fan or adding an additional suction hole. Adding an additional suction hole compared favorable with installing a high vacuum fan and was a less expensive option. Both of these alternative options proved successful in mitigating difficult tight soil houses while the water jet approach was not successful. This paper includes a description of the Project work which was done at three of the five residential houses in Pennsylvania, each having elevated radon levels due to poor sub-slab communication.

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INITIAL INSPECTION

A visual inspection of the building and radon system was conducted. A drawing of the building, which includes the layout and components of the original radon system was made. The pressure readings between the basement and the sub-floor was recorded along with all other particulars of the site. A number of additional test holes were drilled through the concrete floor in the basement to determine the extent of the pressure field extension of the original sub-slab system. Test holes, approximately 5/16" in size, were installed at the four corners of the basements and then at varying distances towards the suction hole or holes. All pressure readings were taken with an EDM digital micromanometer and are recorded in units of inches of water. Depending on the wind conditions and/or the negative pressure induced by the house, it was necessary to occasionally open basement windows to relieve basement negative pressure in order to better determine pressure field extension. The radon system vacuum and air flow in the suction pipes was measured and recorded in units of cfm. The airflow was determined by use of the EDM and a pitot tube.

Radon measurements included duplicate measurements made in the basement. The homeowner exposed the detectors and return them by pre-paid mail to WPB. WPB is certified by PA DER to deploy E-PERMs and has been successfully mailing E-PERMs to clients with a detailed instruction sheet and return postage paid box.

PRESSURE WASHER

The initial sub-floor pressure and system flow measurements were repeated. The suction hole was opened and the pressure washer equipment set up. A Dayton gasoline powered 2900 PSI pressure washer, model # 5Z169, was used. The pressure washer was equipped with 25' of 1/4" hydraulic hose that had a cap on the end. The cap had a 1/32" hole drilled in the end. Additional holes and angles were tried in order to improve the system performance.

The hose was placed in the suction hole and held tightly. The pressure washer was turned on and the hose fed slowly away from the hole just below the slab. When the suction hole filled with water, a wet dry shop vacuum was used to suck the water out of the hole. The shop vacuum was emptied directly outdoors. The length of tunneling was determined by measuring the length of hose that has extended out from the suction point. The length of time to accomplish each stage of the work was recorded, as well as a description of the difficulties encountered.

After the tunneling had been completed as far as possible and the water in the suction hole vacuumed out, the radon system was re-connected. All sub-floor pressure and flow measurements were taken again. The rate at which the water level dropped in the hole was recorded at one site to determine if soil percolation would indicate success in extending the pressure field.

A followup radon test was done.

FOLLOW-UP PRESSURES & FLOWS

After the soil had sufficient time to dry out, the site was revisited and the sub-slab pressure and system air flow was remeasured. These measurements were compared with the previous measurements to determine the effect of the drying out of the soil.

HOUSE RESULTS AND DISCUSSION

House - WJ1

The first house, WJ1, was a two story school dormitory building. The mitigation system included nine suction holes connected to a six inch exhaust pipe that was routed through the two story building to the roof. Two fans were installed in the pipe in the attic. The first suction hole installed revealed a clay soil with some rock. After the hole was dug out by hand, only a limited pressure field was developed when an F150 fan was installed on top of the hole. It was decided that the water jet would be used to enlarge the suction hole.

The pressure washer was used with a two man crew for the first house. One man controlled the trigger and the other held the hose in the suction hole and slowly pushed the spray head through the soil. It took two hands to force the hose into the sub-slab material away from the center of the hole because of the water pressure pushing back on the hose. Occasionally the hose would get stuck as it was pushed away from the hole or in retrieving it out of the hole. The water did not drain into the soil and needed to be vacuumed out with a shop vacuum. The shop vacuum did a good job of sucking up the muck; however, caution is needed to avoid filling the vacuum. A contractor might consider using some kind of pump to remove the water directly to the outside, although this would require lengths of hose and another specialized tool.

This technique produces a substantial amount of slurry to be carried away. It would not be unusual to have thirty gallons or more of water used in each hole. Removal of the slurry from the property can be especially difficult because it is liquid and likely to spill in transport. Having a place to dump the slurry at the job site saves hauling sloshing buckets to another location.

Digging the hole out, although a muddy job, is fairly easy. Necessary protective gear includes gloves and a long sleeve work shirt because the kick of the hose, upon start up, forces ones hands and forearms against the often jagged concrete. This is especially true if there is broken wire mesh protruding from the concrete. The use of a core drill would reduce the risk of injury because the edges of the hole through the slab would be evenly cut.

We were able to get about 10 gallons of clay out of the first hole at WJ1. The pressure hose extended about five feet in several directions.

When we tested the pressure field extension after water jetting and digging out the hole, we were surprised to find that the readings were about 20% weaker than before we had used the water jet. Three days later when we rechecked the same test holes, we found that we now had approximately doubled the original vacuum readings. Two of the readings reversed from .001" and .003" positive to .001" and .002" negative. It seems that the water temporarily clogs up the pores of the soil until it has a chance to dry out.

House - WJ2

The second house in the study was a thirty year old, two-story colonial that has a partially finished basement, a small dirt floor crawl space, an attached garage, a slab-on-grade patio that has been converted into an enclosed spa room, and a front concrete entry. The heating system is oil-fired hot water with no central air handler in the basement. The foundation was block walls that were capped on top. The radon levels measured approximately 20 pCi/l in the basement before the radon system was installed.

Initial Mitigation System

An initial communication test produced a measurable vacuum across half the unfinished portion of the basement. Refer to the WJ2 Pressure & Flow Measurements Table. A radon mitigation system was designed and installed with a two hole suction system in the basement and a rubber EPDM barrier sealed on top of the dirt floor of the crawl space. Fine crushed rock was found under the concrete floor. A dampened suction pipe was installed through the crawl space barrier. The pipe was routed through a hall closet, in a single story portion of the house, into the garage attic and out the roof. An F150 fan was installed in the garage attic.

The initial vacuum after the radon system was installed in the two basement suction pipes was 1.2", and the floor vacuum ranged from .040 negative to .013 positive in the far end of the finished area. It was necessary to keep the basement to garage door open, with the outside garage doors also open, in order to neutralize the strong "stack effect" of the house. The air flow in the basement suction pipes was about 10 CFM while the crawl space suction pipe was moving 67 CFM, even with the damper partially closed.

The first follow-up radon measurements, before the high pressure water jet was tried, were 9.4 pCi/l in the finished area and 9.3 pCi/l in the unfinished area, near the crawl space entrance.

Water Jet Procedure

All of the following procedures were done with one person. The pvc pipe was removed from the center suction hole, V3, in the basement. The hole was enlarged to 6" to allow more room to work. An additional eight gallons of screenings and soil were hand dug from the hole. The pipe was then replaced and the pressure field extension test holes remeasured. Refer to the pressure readings in the table. There was no change in the pressure reading in test holes T4 and T5 in the family room, but there was about a 10 to 20% increase in test holes T6 and T7 in the boiler room, where the suction hole had been dug out. These holes are twelve and eighteen feet from the suction hole.

The suction hole was then reopened, and the water jet set up. The end cap of the hydraulic hose was modified with two additional 1/32" drilled holes that slanted to the back. This was done to reduce the back pressure of trying to push the hose through the soil, to create a larger tunnel as the hose is pushed or pulled through the dirt, and to reduce the chances of the hose getting stuck in the soil.

Six individual tunnels were created with the water jet hose in different directions from the center suction hole. Each tunnel was approximately six feet through the sub-slab screenings which were just below the slab. The screenings were only an inch or two thick, so the tunneling more than likely went through the soil. There was no accumulation of water in the suction holes as compared to House-WJ1. The water must have soaked into the sub-slab screenings. An additional four to six gallons of soil and screenings were removed from the hole. If we assume that the created tunnels traveled in a straight line under the slab, which is hard to determine, then the suction hole was actually enlarged to a diameter of over ten feet.

Initial Follow-up Measurements

The suction pipe was hooked up at V3 and the pressure field extension measurements were repeated. Once again, there seemed to be a reduction in vacuum readings of about 10% for the test holes that were relatively close to the suction pipe. The air flow and pressure measurements in the pipe did not change significantly.

Three days later there was still no change in test holes T4 and T5 at the far end of the finished area. Test hole T2, which is 30 feet from the suction hole, increased 10%. Test holes T7 and T6, in the same room as the suction hole, increased 33% and 50% respectively. Test holes T3 and T8, which are both 15 feet from the suction hole, increased 75% and 150% in negative pressure under the floor.

WJ2 Time Required to do Water Jet Tunnels

Unload tools	15 minutes
Enlarge V3 concrete opening to 6"	15 minutes
Hand dig additional eight gallons	30 minutes
Replace pipe & measure vacuum & flow	30 minutes
Water jet six tunnels, six feet out	30 minutes
Replace pipe & measure vacuum & flow	30 minutes
Clean-up and replace tools	25 minutes
Total time	175 minutes

Post Water Jet Radon Levels

Follow-up radon measurements, after the first use of the high pressure water jet did not show much additional reduction of radon levels. The radon levels measured 7.1 pCi/l in the finished area and 8.1 pCi/l in the unfinished area near the center suction hole. Because the back room measured slightly higher than the finished area, it was decided that a suction hole should be installed in the sub-floor of the slab-on-grade spa room from the basement. Although this would lessen the amount of available suction to the sub-floor, it might eliminate a major source of the remaining radon. The block suction was installed so that it would draw from the sub-slab soil and not directly from the block wall, and a damper was installed to control excessive air flow. An additional follow-up radon test was completed after this work; however, it indicated that this extra suction had little effect on the radon levels.

Additional Blockwall & Sub-Slab Suctions

It appeared that the remaining problem was still due to the lack of vacuum in the finished area, and an additional suction point would need to be added since the water jet of the center suction, V3, had not established a significant vacuum in this area. Unfortunately, there was a steel beam in the space above the drop ceiling that is set into the floor joist that effectively blocks any disguised pipe routing across the ceiling towards the area near T4. (If a pipe was routed across the ceiling it would be difficult to disguise.) The area around T4 is nicely finished into a family room and bar area. An alternative compromise was taken by adding a third suction hole in the unfinished furnace room. Refer to Phase 3, WJ2 drawing. To maintain or slightly increase the amount of sub-slab vacuum, a second fan was also added to the system. The two F150 Fan-Tech fans were stacked on top of each other in the garage.

Final Front Entry Depressurization

After the additional fan and floor suction was added and the block wall suction to the rear patio slab dampened down, the system was retested with an At-Ease monitor left in place for two months. There was a slight improvement in the system performance, but the radon levels still were consistently above four pCi/l. The monitor was moved around from one location to another to determine whether an overlooked radon source was the problem. Eventually the monitor was placed above the drop ceiling, adjacent to the front foundation wall, which has an outdoor concrete entry slab on the other side. In this location the monitor indicated the radon levels were between 30 and 40 pCi/l. An additional suction was then routed across the ceiling and through the foundation wall into the entry sub-slab area. A damper was installed in the pipe and closed down to reduce the impact on the sub-slab portion of the system. The At-Ease monitor went down below 2 pCi/l. The radon level was remeasured with an E-PERM to be 0.8 pCi/l. A long term E-PERM left in place measured 0.3 pCi/l.

Final system pressure and flows are included in the WJ2 table.

WJ2 Pressure & Flow Measurement Table

Note: All measurements done with basement to outside door OPEN. If basement to outside door is closed, with outdoor temperature at 30*, add approximately +.007" to +.012" to sub-floor pressure readings.

PHASE 1 SUB-SLAB ONLY		PHASE 1B HOLE DUG OUT		FRESH WATER JET		PHASE 2 3 DAYS LATER		PHASE 4 EX FAN & SUCTIONS	
T2	-.064	T2	-.053	T2	-.053	T2	-.059	T2	-.085
T3	-.020	T3	-.020	T3	-.016	T3	-.050	T3	-.046
T4	+.002	T4	+.001	T4	+.002	T4	+.001	T4	-.002
T5	+.000	T5	-.000	T5	+.000	T5	-.000	T5	-.007
T6	-.025	T6	-.027	T6	-.027	T6	-.041		
T7	-.038	T7	-.045	T7	-.042	T7	-.056	T7	-.051
T8	-.092	T8	-.091	T8	-.080	T8	-.159	T8	-.141

	PHASE 1		PHASE 2		PHASE 4	
V0					-.150"	139 cfm
V1		68 cfm	-.120"	52 cfm	-.120"	52 cfm
V2	- 1.2"	15 cfm	- 1.2"	13 cfm	-.970"	11 cfm
V3	- 1.2"	11 cfm	- 1.2"	11 cfm	-.730"	14 cfm
V4					-.720"	14 cfm
V5					-.720"	3 cfm
V6					-.790"	45 cfm

House - WJ3

The third house in the study, WJ-3, is a two-story colonial that was built in 1972. The house has approximately 2000 square feet of living space on the first and second floor. The basement is approximately 1000 square feet and is completely finished. It has a dropped ceiling. The panels were installed with less than 2" of clearance which makes it difficult to run any radon vent pipes perpendicular to the floor joists. The foundation walls are poured concrete but have been covered by a wooden stud wall with paneling. There is an attached garage with an attic space over the garage. The garage slab is two steps below the house floor which puts the bottom of the slab below the house sill plate. This will typically rule out the garage sub-floor contributing radon directly to the basement. A concrete patio was added to the back of the house and is open to the outdoor air. Because the back patio and the front entry are only one step down, they might be contributing radon directly to the basement. The heating system is electric baseboard heat. There is no air handling equipment or central air conditioning in the house. The basement has an outdoor entrance constructed of concrete with a metal bilco door. The basement floor is carpeted so no floor cracks are visible. The one section of exposed floor to wall joint shows only a very small perimeter crack. This was the only house in the study with well water. The radon in water level was measured and found to be low.

Summary of Initial Mitigation Systems

A single hole sub-slab suction system was installed 12/11/91 with the suction hole in the closet under the basement stairs. A standard F150 Fantech fan was used with the fan in the garage attic and the exhaust vented out the rear garage roof using 4" pvc pipe. The mitigation installer reported packed dirt under the floor and very little sub-floor vacuum. The u-tube manometer installed in the garage had a reading of almost 2" which indicates that there was almost zero air flow in the pipe. The post mitigation radon levels were 16.8 pCi/l.

On 1/3/92 a second 4" pipe was routed from the first suction hole, across the ceiling, and through a plumbing chase into the closet near test hole T4. The same packed dirt was found in the second suction hole. After the second suction hole was completed, the vacuum at test hole T9 was remeasured and found to be the same 0.004 positive reading below the floor, as before. A second post mitigation test produced a result of 45.1 pCi/l. One explanation of why the levels almost tripled compared to the first test after an additional suction hole was added, was that during the first test the dwelling was unoccupied and the heat turned down. During the second test the house was occupied and heated. Radon levels will often increase in the basement when a house is heated and occupied because of the greater negative condition of the basement caused by the stack effect from heating even though the upstairs main level is getting more ventilation.

After the owner agreed to participate in the project, duplicate E-PERM measurements were run from 1/25 to 1/27/92 and produced results of 59.4 and 56.5 pCi/l.

The water jet test at WJ3 was begun on 2/15/92. A Pylon AB5 monitor was used first to sniff out possible other sources of radon besides the basement floor. The entire basement had counts that average between 35 and 40. No significantly elevated counts were detected up at the sill plate of the foundation by the back slab on grade patio, or near where the garage slab adjoins the basement. It was discovered at this time that the well tank, near test hole T9, was sitting on cinder blocks that were open to the dirt. Sniffer measurements at this location revealed counts that averaged around 500. This indicated that the sub-soil was the main source and that possibly by sealing this large opening, some reduction in the radon levels could be achieved.

Ten new test holes, 5/16" in diameter, were drilled around the perimeter of the basement. The slab was approximately six inches thick. After all test holes were drilled they were vacuumed to remove concrete dust. No sub-floor radon measurements were made. Refer to accompanying drawing for test hole locations.

To determine the influence of stack effect on sub-slab pressures, vacuum readings were taken in test holes T8 and T9 with the basement window open versus closed. The positive readings below the floor of +.006 at T8 increased to +.007 while at T9 the readings decreased from +.004 to +.002, with the window being opened, as you would expect. It was a mild winter day of slight rain and some wind. The wind may have been responsible for this small discrepancy. All other measurements were taken with the windows closed.

The vacuum readings in the test holes before the water jet was used are listed in table WJ3. The two suction pipes produced a vacuum of -1.85" on the adjoining soil, with P1 showing no air flow and P2 showing an air flow of 13 CFM. The two suction holes produced a measurable vacuum of -.016" at 28 feet away at test hole T3. In the other direction, suction hole V2 produced a vacuum at T4 of -.386" at 11" from the hole. At four times that distance from the hole, 45", T5 measured a vacuum that was one third the strength or -.122". At ten feet, or two and one half times farther from the hole, the vacuum disappears in test hole T6 to +.002". This positive reading still indicates that a .004" change is being made in T6 at this distance, because the reading is +.002 rather than the reading of +.006", measured in test holes T7 and T8, which are not being influenced by the radon system.

Water Jet Procedure

Suction hole V2 was chosen as the hole to be water jetted first. The pressure washer was set up. The pipe was removed and the original 4 1/2" hole in the slab was not enlarged. The caulking around the hole was left in place to provide some cushion against the rough concrete during the water jetting.

The initial sub-slab size of suction hole V2 was approximately a 10" radius. The water jet is first used to enlarge the hole by using a sweeping motion with the nozzle. Unfortunately the soil turned out to have numerous rocks, which significantly reduced the effectiveness of the water jet. The water jet was still very helpful because the soil was so packed under the slab that digging without this procedure was extremely difficult. After the initial hole enlargement, some stones and dirt could be loosened enough to shove the nozzle in different directions. The hose was inserted approximately 26" in about four directions in V2. The 6 gallon shop vacuum needed to be emptied about 4 times.

Tunneling Results

The final result only created tunnels two feet long, compared to house WJ-2 where the nozzle was tunneled six feet from the center of the suction hole. There was however a measurable drainage rate of the water in the hole. After the hole filled with water from the first water jetting, the water drained down 1 1/2" in 4 minutes. After the second time the hole filled, the water drained down 3/4" in 4 minutes. After the third time the water drained down 1" in 4 minutes. After the last water jetting, the water drained 3/4" in ten minutes.

Post Water Jet Measurements

The vacuum measurements were retaken after the system was hooked up and the suction pipe resealed into V2. A small increase, from -.016" to -.018", in the vacuum reading was observed in test hole T3. Test hole T5 which is 45" from V2, doubled in its vacuum reading but then the distance to the suction hole was probably reduced in half by one of the 26" tunnels. Test hole T4 had been under tunneled so its reading was now the same as that of P2. The other test holes remained the same vacuum. Once again it appears that no significant increase in vacuum was able to be measured immediately after using the waterjet.

The cinder blocks, which were being used to hold up the well tanks, were filled with expanding urethane foam.

WJ3 Time Required to do Water Jet Tunnels

Unload tools & discuss work with Owner	30 minutes
Sniff radon entry routes with AB5 Pylon	45 minutes
Drill ten 5/16" vacuum test holes	30 minutes
Initial measurement of pressure field extension	30 minutes
Suction pipe removed & water jet set up	30 minutes
Water jet four tunnels, two feet out	45 minutes
Replace pipe & measure vacuum & flow	30 minutes
Clean-up and replace tools	60 minutes
Total time	300 minutes

Post Water Jet Radon Levels

Follow-up radon measurements were delayed 12 days in order to allow the soil sufficient time to dry out. The test was done from 2/27/92 to 3/1/92. The side by side test kits measured 21.7 and 19.1 pCi/l. This is more than a fifty percent reduction from the previous results. It is impossible, however, to determine if this reduction was due to the sealing of the cinder blocks, the water jetting of V2 or more mild weather conditions.

High Vacuum Fan

WJ3 was visited on 3/17/92. The sub-floor and pipe vacuum and flow were measured. The F150 fan was producing the same vacuum and flow readings in the soil, as measured on 2/15/92, after hole V2 was water jetted. All of the sub-floor vacuum readings on the side of the basement, farthest from the garage, were still giving positive readings. Test holes T3 and T10, near the fireplace, which are 25 feet from V2, doubled in vacuum, and T5, which is 45" from the suction hole, also doubled in vacuum. T6, which is 10 feet from V2, did not reverse from its original positive reading. Once again, it appears that after waterjetting a hole, it takes a period of time for the soil to dry out to determine how much benefit the hole enlargement produced. If there was no communication before, none was gained by water jetting the suction hole, but if some communication did exist, the increased vacuum can be measured. Keep in mind that the soil in this house was not conducive to this technique because of the excessive amount of rock.

Alternative Approach

In order to investigate the benefit of using a high pressure water hose, it is necessary to compare its performance with other alternative approaches. One of the alternatives is to use a high vacuum fan. These fans typically produce 10 to 25 times more vacuum than a typical F150 Fantech. The use of these specialized fans is limited to low flow applications. The drawback to their use is the high initial cost, $625 versus $90, and the added noise and electrical consumption. One manufacturer, Radon Away, agreed to loan one of their high vacuum fans for a trial use.

The fan is Radon Away DynaVac model HS3000B. It is capable of producing 34 inches of vacuum at 0 flow and 20" of vacuum at 26 CFM. Maximum air flow is 44 CFM. A vent muffler was also included.

In order to test the effectiveness of this fan, a communication test was done using the existing pipe system. It would be advisable that contractors always do this diagnostic step to determine before hand whether such a fan would extend the pressure field extension adequately.

Hi-Vacuum Communication Test

The F150 fan was removed from the piping in the garage attic. A shop vacuum was set up and the hose inserted into the 4" pipe leading to the two basement suction holes. The remaining opening was closed with duct tape. The vacuum was turned on and the sub-floor pressure readings repeated.

The vacuum in the pipe went from 1.8" to 27", which is a 15 fold increase. The airflow went from 11 cfm to 60 cfm, although I don't trust the air flow readings done with the pitot tube at this high pipe vacuum. Airflow readings at P1 and P2 added up to 60% more airflow than the total airflow at P0. The subfloor vacuum readings at T3 and T10 increased by a factor of 6 to 7.6 times near the fireplace. On the opposite side, near the outside cellar entrance, T7 went from +.012 to +.001. T6, T8 and T9 all went from positive readings to negative readings with the shop vacuum.

The communication test indicated that a Hi-Vac fan could possibly create a sufficient vacuum under the floor. The shop vacuum hose was removed from the pipe and the Hi-vacuum fan installed. By using couplings to change the size of the inlet and outlet on the Hi-vacuum fan, from 2" to 4", it was possible to attach the fan directly to the pipe with standard rubber couplings. This made installation quicker, because the fan comes from the factory with a plug. An electrical outlet was installed in the attic to accommodate the shop vacuum and the Hi-vacuum fan. In addition, a small muffler was installed on the exhaust side of the Hi-vacuum fan in order to minimize noise.

The sub-floor vacuum measurements were repeated. The vacuum in the pipe decreased 35%, from the shop vacuum reading of 27" to 17.5"; the airflow decreased 30%, from 60 cfm to 42 cfm. The sub-floor vacuum readings, in most cases decreased slightly from the shop vacuum readings. What was interesting was that the vacuum in T10 went down 17%, and the vacuum in T3 went up 30%. Overall the shop vacuum appeared to be an excellent emulator of the hi-vacuum fan.

Duplicate E-PERM test kits were exposed by the homeowner in the basement from 3/26/92 to 3/29/92. They measured 0.4 pCi/l and 0.2 pCi/l. This indicated that the use of a hi-vacuum would successfully mitigate the radon levels, even if test hole T8 never reversed to a vacuum. The owner indicated that the fan noise was slightly higher than before, but still acceptable. (It could be heard slightly from the bedroom through the wall between the garage and the house). The cost to operate the fan went from 80 watts to approximately 160 watts. This 80 watt increase would add an additional 700 kilowatt/hrs/year of power consumption which would cost the present homeowner approximately 70 additional dollars per year compared with the usage of the F150 fan. The homeowner was less concerned with this than the possible replacement cost of the fan, which would be around $700.

Switch Back to F150

The sub-floor measurements were repeated on 4/16/92, to determine if there had been any change in the system performance since the installation on 3/17/92. The airflow in the pipe had increased 14%, from 42 to 48 cfm. The vacuum in the pipe had decreased 16%, from 17.4" to 14.6". The sub-floor pressure readings also generally decreased from 4% to 17% with test hole T6 and T7 slightly increasing in vacuum. Overall, the fan system was performing adequately.

After some discussion with the homeowner, it was decided that an additional suction hole would be added and the original F150 fan re-installed to determine if the system could be made to operate with the smaller fan. A third suction hole was added in the well closet room. Because the space was so limited above the drop ceiling, 3" pvc pipe was routed from P2 across the ceiling to the third hole.

Once the third suction hole was installed, the performance of the whole system change significantly. With the Hi-vacuum fan still running and now drawing on three suction holes, the vacuum in the pipe decreased down to 2.0", which is only a 13 % stronger vacuum as when the less expensive F150 fan was installed. The sub-floor vacuum readings all decreased significantly, except the test holes near the new suction hole. Even though the pressure in the pipe had been decreased by a factor of seven, the overall pressure field extension was greatly enhanced. The system, however, was using the Hi-vacuum fan out on the end of its performance curve where it performs no differently than an F150 fan. To test this theory, the F150 fan was reinstalled.

With the F150 back in place, drawing on the three suction holes, the pressure reading in the pipe decreased 17% from the original F150 reading of 1.8" of water to 1.5" of water. The vacuum readings in the sub-floor test hole decreased from 22% to 42%, but were still all negative readings. T7 was now the lowest sub-floor vacuum reading at -.005", which is more than enough to hold back radon entry.

The radon levels were again measured with duplicate E-PERMs in the basement, on 4/23/92 to 4/25/92 with a result of 0.7 pCi/L. This is the result of the final installation of the F150 fan drawing on the three suction holes.

WJ3 Time Required to do Hi-Vac Communication Test

Re-measure pressure field & airflow	30 minutes
Hi Vacuum communication test	30 minutes
Switch from F150 to Hi Vacuum fan	30 minutes
Measure pressure field & airflow	30 minutes
Total time	120 minutes

WJ3 Time Required to Add Additional Suction Hole

Unload tools	15 minutes
Measure pressure field & airflow	30 minutes
Add additional suction hole & piping	165 minutes
Re-measure pressure field & airflow	30 minutes
Change Hi vacuum fan to F150	25 minutes
Re-measure pressure field & airflow	30 minutes
Clean-up and replace tools	30 minutes
Total time	315 minutes

WJ3 Conclusion

The water jetting of the suction hole, at house WJ3, gave only limited increase pressure field extension. This was due to the soil containing a large percentage of rock. The water jet tunnelling never extended more than about three feet under the floor.

The installation of a $650 fan, versus the normal $95 fan, produced a large increase in the pressure field extension. The noise associated with this fan was acceptable to the homeowner. The increased power consumption, from 80 to 160 watts, would add about $70/year to the operating cost of the system compared to using a standard fan; however, the homeowner was concerned about the replacement cost of the Hi-vacuum fan; therefore, a third suction hole was added. A typical contractor's price, for the amount of work it took to install this hole, would be about $250. The same F150 fan would power the system. The final radon results were almost the same low levels with either fan in place.

System pressure and flows are included on the WJ3 Table.

WJ3 Pressure & Flow Measurement Table

Note: All measurements done with basement to outside door CLOSED. If basement to outside door is opened, with outdoor temperature at 45°, subtract approximately .002" from sub-floor pressure readings.

	2/15/92 DISTANCE FROM V-HOLE	2/15/92 F150 FAN BEFORE/WJ	3/17/92 F150 FAN AFTER/WJ	F150 FAN LATER
T1	14"	-.638"	-.648"	-.680"
T2	30'	-.614"	-.620"	-.610"
T3	28'	-.016"	-.018"	-.035"
T4	11"	-.386"	-1.85"	-1.85"
T5	45"	-.122"	-.278"	-.530"
T6	10'	+.002"	+.002"	+.004"
T7	18'	+.006"	+.006"	+.012"
T8	30'	+.006"	+.006"	+.002"
T9	19'	+.004"	+.004"	+.006"
T10	22'	-.030"	-.033"	-.067"
P0			-1.865" 11 CFM	-1.80" 11 CFM
P1			-1.850" 0 CFM	-1.80" 0 CFM
P2			-1.850" 13 CFM	-1.80" 11 CFM

	3/17/92 VAC TEST W/2 SSS	3/17/92 HI-VAC FAN W/2 SSS	4/16/92 HI-VAC W/2 SSS	4/16/92 HI-VAC W/3 SSS	4/16/92 F150 W/3 SSS
T1		-4.47"	-4.27"	-.840"	-.615"
T2		-3.80"	-3.35"	-.713"	-.525"
T3	-.210"	-.275"	-.235"	-.056"	-.044"
T4		-17.45"	-14.50"	-2.01"	-1.39"
T5		-6.70"	-5.83"	-.978"	-.700"
T6	-.030"	-.028"	-.032"	-.023"	-.017"
T7	+.001"	-.002"	-.003"	-.007"	-.005"
T8	-.002"	+.002"	+.002"	-.024"	-.014"
T9	-.005"	-.004"	-.003"	-1.62"	-1.15"
T10	-.515"	-.430"	-.368"	-.096"	-.070"

	3/17/92 VAC TEST	3/17/92 HI/VAC FAN	4/16/92 HI/VAC FAN	4/16/92 HI/VAC/3SSS	
P0	- 27.2" 60 cfm	-17.40" 42 cfm	-14.57" 48 cfm	-2.04" 45 cfm	-1.5" 41 cfm
P1	- 26.4" 44 cfm	-17.45" 35 cfm	-14.53" 38 cfm	-2.04" 15 cfm	
P2	- 26.4" 52 cfm	- 17.45" 40 cfm	- 14.51" 36 cfm	-1.96" 11 cfm	
P4				-1.84" 15 cfm	

RECOMMENDATIONS FOR WATER JET APPLICATION

1) Overall, a water jet is not difficult to use. It can be operated by a single person and makes quick work of significantly enlarging the suction hole. The equipment cost of approximately $1,200 to $1,500 is expensive, but within the range of what a mitigator can afford. If one is careful, the job can be done neatly. The use of a second bucket with the shop vac was a significant help in this regard.

2) The initial vacuum readings in the test holes after using the water jet often showed little improvement, but after a week, they would improve as the soil had a chance to dry out.

2) The biggest obstacle to using a water jet is sub-soil rocks. Any rock larger than one and a half inches can prevent extending the hose through the soil.

3) The effectiveness of extending the pressure field is dependent upon having some initial communication. Doubling a zero reading still produces a zero. The effectiveness drops significantly at distances greater than 15 feet from the suction hole.

4) Adding a larger fan is a possible alternative choice to extend the sub-slab pressure field , although a larger fan typically needs to be a lot larger to be effective. A hi-vacuum fan, however, drops off in its power curve when it has to move a lot of air. The vacuum produced by a hi-vacuum fan can actually fall to the performance of a standard fan if it is moving too much air. An additional disadvantage of the hi-vacuum fan is the high initial and replacement cost and the additional noise level compared to a standard radon fan.

5) Adding an extra suction hole, although it takes a bit more time than water jetting, is often the best solution to extending the pressure field. It may not, however, be practical to add the extra suction hole because of a finished space or obstacles to pipe routing. The water jet, on the other hand, is limited, in how far away it can have an effect. Because of the variation in soils, the effectiveness is hard to predict. In this Project the water jet seemed to have an effect to about fifteen feet away from the suction hole.

6) Sandy soils may actually be the best soil type to use with the water jet, because of the lack of rocks and slight permeability of sand. In typical Pennsylvania rocky soils, the hose could only be extended two to six.

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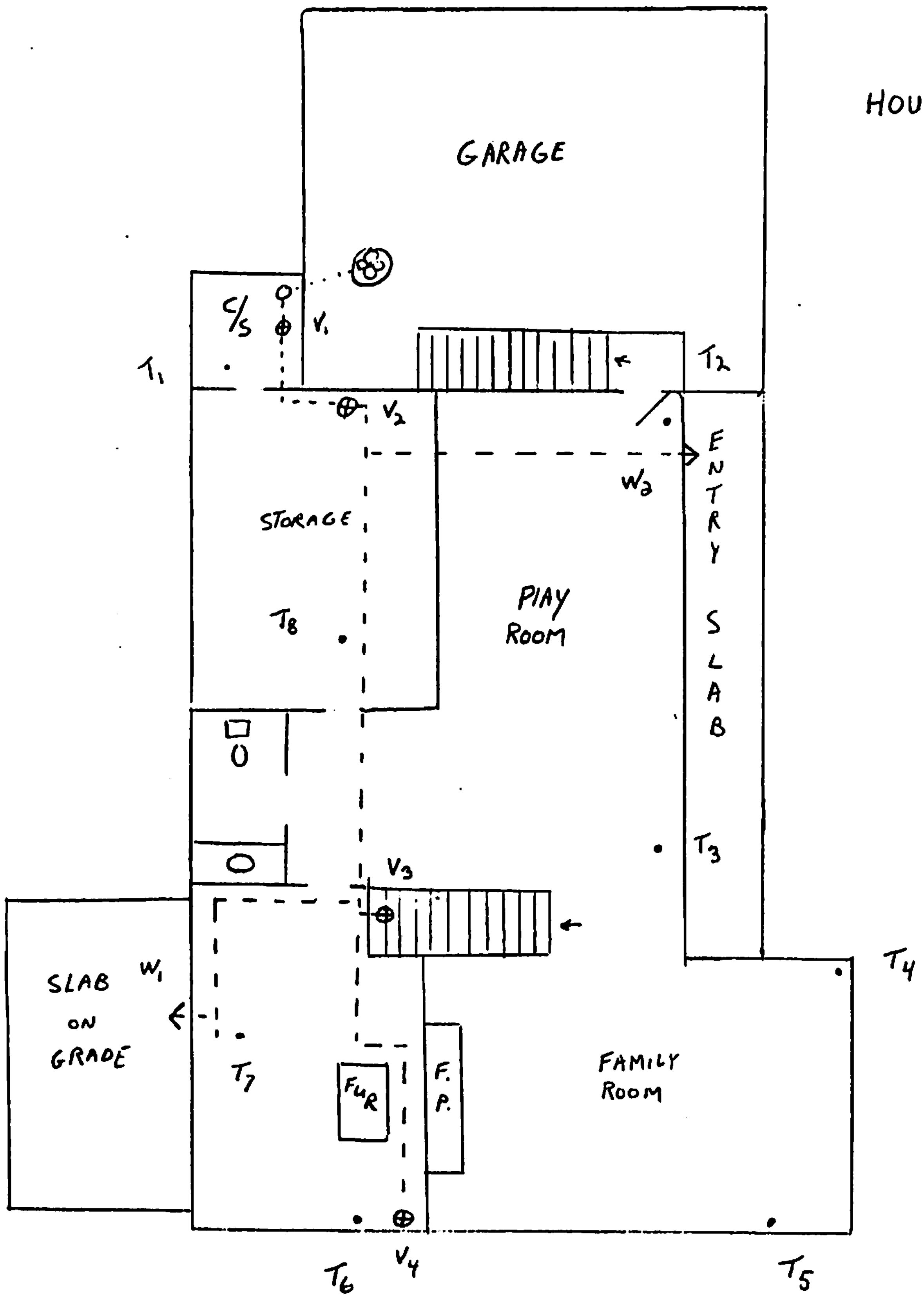
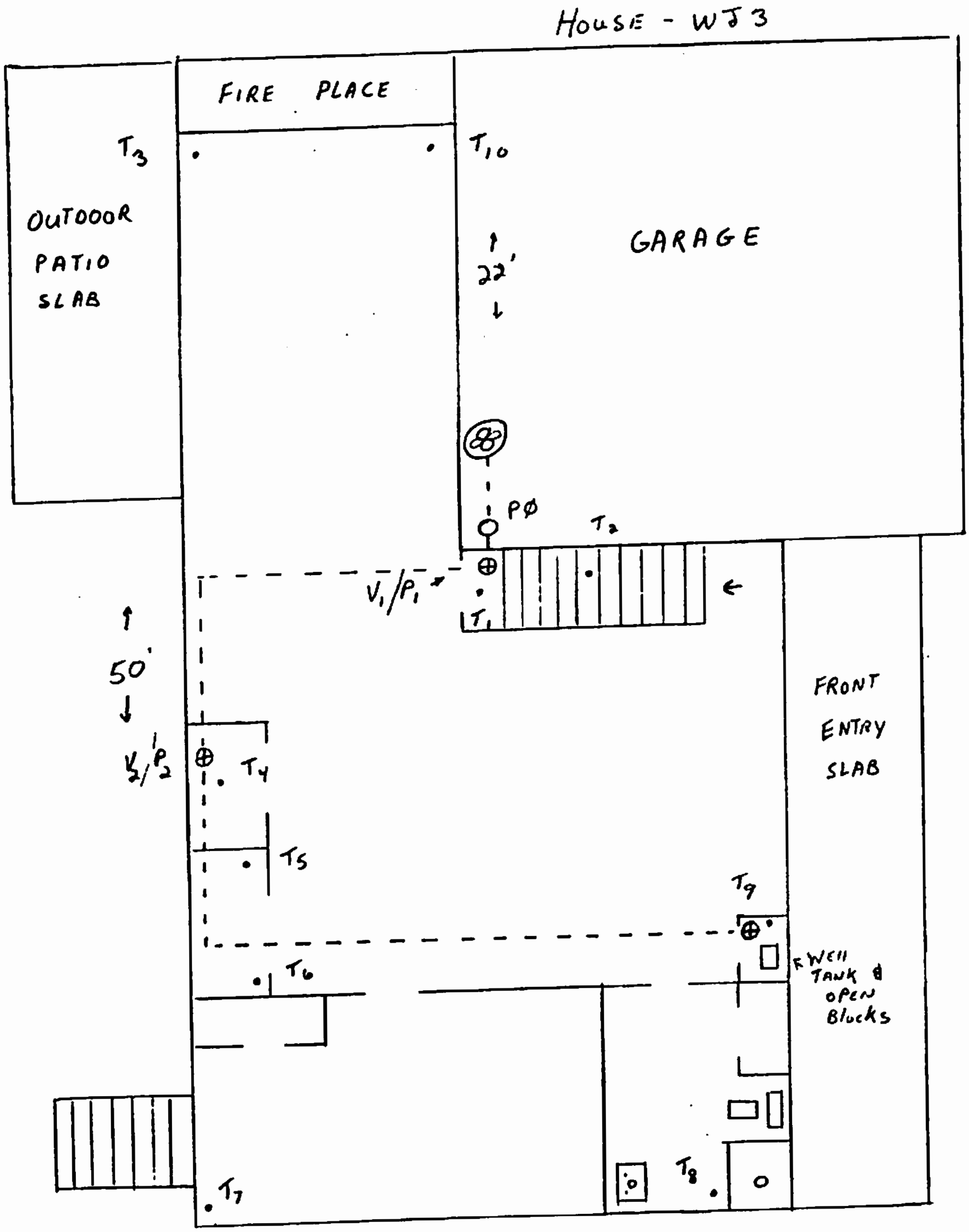
HOUSE - WJ2



GARAGE
C/S
V_1
T_1
T_2
V_2
E N T R Y
W_2
STORAGE
T_8
PlAY ROOM
S L A B
T_3
V_3
T_4
SLAB ON GRADE
W_1
T_7
FUR
F.P.
FAMILY ROOM
T_6
V_4
T_5


House - WJ3
FIRE PLACE
T3
T10
OUTDOOR PATIO SLAB
GARAGE
22'
PØ
T2
V1/P1
T1
50'
V2/P2
T4
T5
FRONT ENTRY SLAB
30
T9
Well Tank & open Blocks
T6
T7
T8