AEERL-P-329

RADON DIAGNOSIS AND ABATEMENT

IN

RESIDENTIAL DWELLINGS

BY

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EPA - ORD

INDOOR RADON REDUCTION DEVELOPMENT/DEMONSTRATION PROJECT

OBJECTIVE: TO DEVELOP AND DEMONSTRATE LOW-COST RADON REDUCTION MEASURES

- EXISTING HOMES (FIRST PRIORITY) AND NEW CONSTRUCTION
- CONSIDER ALL SUBSTRUCTURE TYPES, NATIONAL IN SCOPE

DRIVING FORCE FOR SOIL GAS ENTRY

- HOUSES NATURALLY TEND TO BE AT A LOWER PRESSURE THAN THE SURROUNDING SOIL, SO RADON-CONTAINING SOIL GAS IS SUCKED INTO THE HOUSE

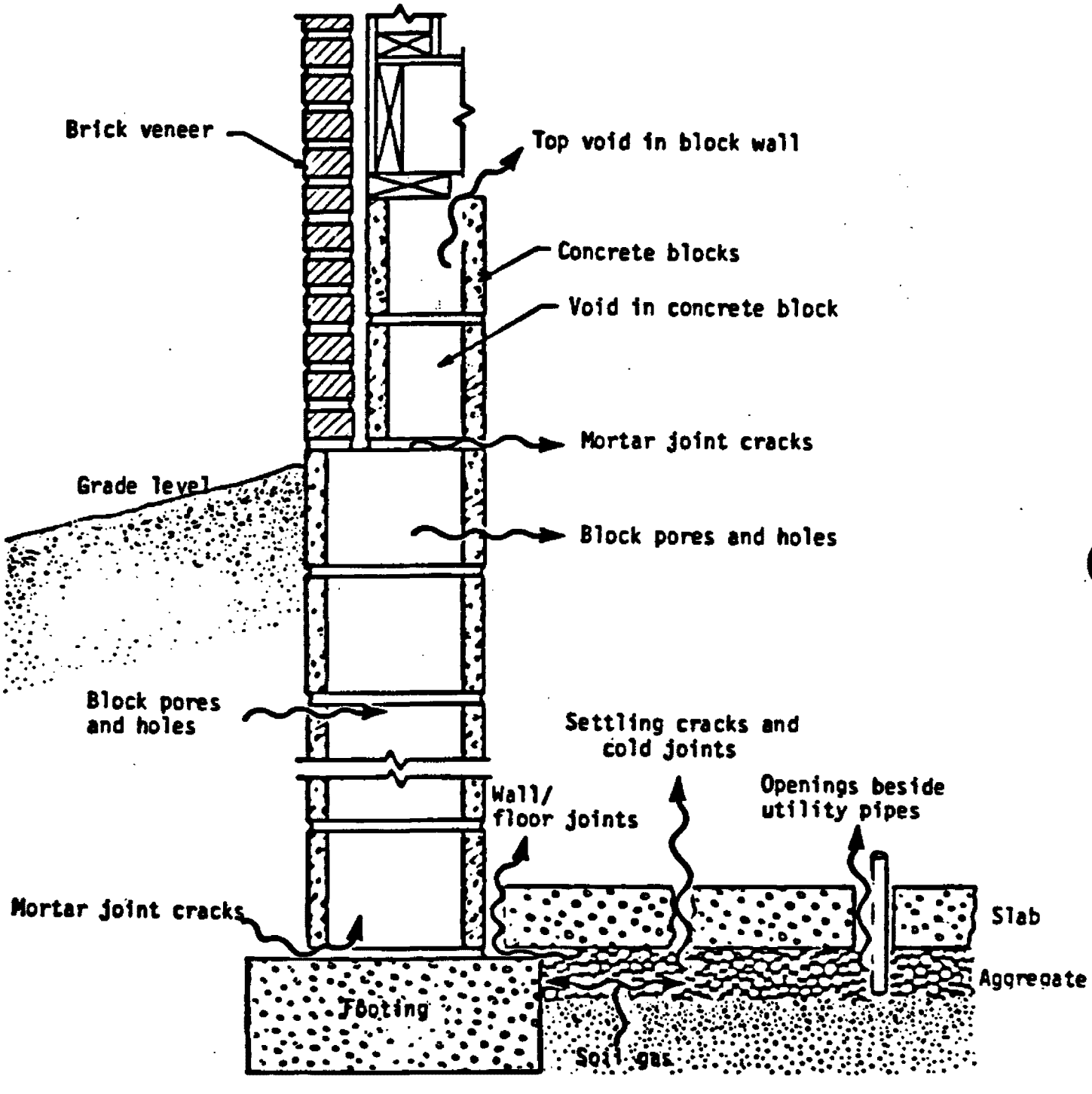
- FLOW OF SOIL GAS INTO HOUSE IS INCREASED BY ANY ADDITIONAL DEPRESSURIZATION OF THE HOUSE (OR BASEMENT), WHICH CAN BE CAUSED BY:

  - NATURAL THERMAL STACK EFFECT (MOST PRONOUNCED IN COLD WEATHER)

  - THERMAL BYPASSING (FACILITATES THE STACK EFFECT)

  - APPLIANCES WHICH DRAW AIR OUT OF THE BASEMENT OR HOUSE (FIREPLACES, FURNACES, CLOTHES DRIERS, EXHAUST FANS)

  - OPEN WINDOWS ON JUST THE DOWNWIND SIDE OF THE HOUSE



Entry routes for soil gas into a concrete block basement home

CHECKLIST OF POSSIBLE RADON ENTRY ROUTES

A. SOIL GAS ENTRY THROUGH FOUNDATION WALL (BASEMENT HOUSES)

1. UNCLOSED VOIDS IN THE TOP COURSE OF HOLLOW BLOCKS
2. CRACKS IN BLOCKS, AND IN MORTAR JOINTS BETWEEN BLOCKS; CRACKS IN POURED CONCRETE WALLS
3. OPENINGS IN WALLS AROUND UTILITY PENETRATIONS (WATER, SEWER, FUEL OIL, ETC.)
4. OTHER HOLES IN WALLS (E.G., DEFECTS IN BLOCKS)
5. PORES IN HOLLOW BLOCKS (CINDER BLOCK GENERALLY MORE POROUS THAN CONCRETE BLOCK)
6. JOINT BETWEEN THE WALL OF THE LOWER LEVEL AND THE SLAB OF AN ADJOINING HIGHER LEVEL IN A SPLIT LEVEL HOUSE
7. FIREPLACE STRUCTURES BUILT INTO WALLS

NOTE: FOR HOLLOW BLOCK WALLS, THE ABOVE LIST APPLIES NOT ONLY TO EXTERIOR PERIMETER WALLS, BUT ALSO TO ANY INTERIOR WALLS WHICH PENETRATE THE SLAB AND REST ON FOOTINGS.

B. SOIL GAS ENTRY THROUGH SLABS AND FLOORS

1. SETTLING CRACKS IN SLABS
2. COLD JOINTS IN SLABS
3. JOINT BETWEEN THE SLAB AND THE WALLS (INCLUDING INTERIOR AS WELL AS EXTERIOR WALLS)
4. OPENINGS IN SLAB AROUND ANY UTILITY PENETRATIONS (WATER, SEWER, ETC.)
5. JOINT BETWEEN THE SLAB AND ANY OTHER INDIVIDUAL PENETRATIONS THROUGH THE SLAB
6. ANY HOLLOW OBJECTS PENETRATING THE SLAB AND OPEN TO THE HOUSE

7. Other holes in slab exposing earth

8. Holes in flooring over crawl spaces

9. Untrapped floor drains which connect to drain tiles (or trapped floor drains with rodding eye missing)

10. Sumps (generally connected to drain tiles beneath the slab or around the exterior of the footings)

C. Soil gas entry through other routes

1. Leakage of crawl space air into circulating house air in central HVAC system

D. Radon entry with well water

1. Any water usage appliance in houses having wells with elevated radon concentrations in the water

RADON MITIGATION ALTERNATIVES (EXISTING HOUSES)

A. HOUSE VENTILATION

- o PRINCIPLE: REMOVE THE RADON ONCE IT HAS ENTERED THE HOUSE (BY DILUTION WITH OUTDOOR AIR)
- o SPECIFIC TECHNIQUES:
  - NATURAL VENTILATION
  - FORCED VENTILATION (USING FAN)
  - HEAT RECOVERY VENTILATOR (HRV, OR AIR-TO-AIR HEAT EXCHANGER)
- o EFFECTIVENESS DEPENDS UPON INCREASE IN VENTILATION RATE ACHIEVED; REDUCTIONS UP TO 90% HAVE BEEN REPORTED.
- o ADVANTAGES
  - NATURAL, FORCED VENTILATION EASY TO IMPLEMENT, NO (OR LIMITED) INSTALLATION COST
  - "CONVENTIONAL" TECHNOLOGY
  - AT LEAST MODERATE REDUCTIONS REASONABLY ASSURED
- o DISADVANTAGES
  - NATURAL, FORCED VENTILATION MIGHT NOT BE PRACTICALLY APPLICABLE (AND WOULD CAUSE SIGNIFICANT ENERGY PENALTIES) DURING SOME MONTHS IN COLD AND HOT CLIMATES
  - SOME ENEGY PENALTY, EVEN WITH A HRV
  - MECHANISMS BY WHICH HRV'S ACHIEVE REDUCTIONS NOT YET FULLY UNDERSTOOD (MIGHT BE MORE THAN SIMPLE DILUTION); NOT CLEAR THAT VERY HIGH REDUCTIONS CAN ALWAYS BE ASSURED.
- o PRACTICAL CONSIDERATIONS
  - ASSURANCE OF HIGH LEVELS OF REDUCTION WOULD REQUIRE A HRV (FIXED, HIGH INCREASE IN VENTILATION RATE); PRACTICAL ABILITY OF OPERATE YEAR-AROUND WOULD ALSO REQUIRE A HRV
  - MUST ASSURE THAT HRV'S REMAIN BALANCED OVER TIME (FRESH AIR INTAKE/HOUSE AIR EXHAUST)

RADON MITIGATION ALTERNATIVES

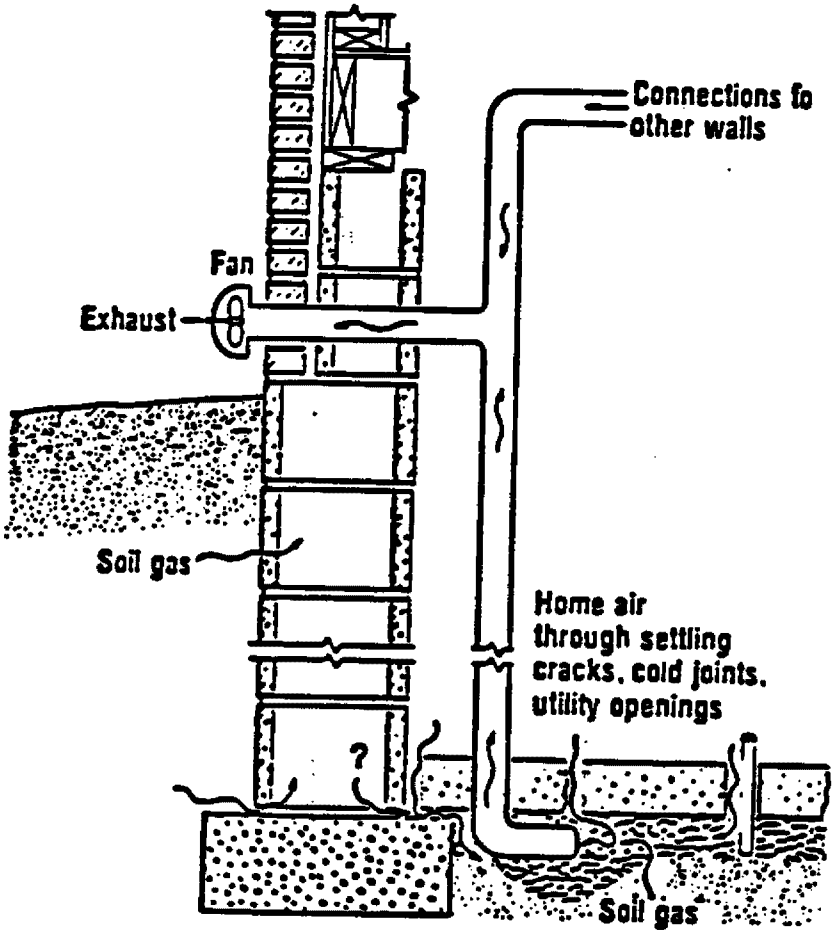
B. SEALING OF SOIL GAS ENTRY ROUTES

- o PRINCIPLE: PREVENT SOIL GAS FROM GETTING INTO HOUSE
- o SPECIFIC TECHNIQUE: PERMANENTLY SEAL ALL OPENINGS BETWEEN THE SLAB (OR FLOOR) AND THE SOIL, AND BETWEEN THE FOUNDATION WALL AND THE SOIL (E.G., USING SEALANTS, COATINGS, MEMBRANES). COVER SUMPS. REMOVABLE PLUG IN UNTRAPPED FLOOR DRAINS.
- o EFFECTIVENESS DEPENDS UPON COMPLETENESS OF SEALING JOB, IMPORTANCE OF THE ENTRY ROUTES SEALED; REDUCTIONS UP TO 90% HAVE BEEN REPORTED.
- o ADVANTAGES
  - TOTALLY PASSIVE, IDEALLY NO OPERATING COST
  - POTENTIALLY THE MOST AESTHETIC APPROACH
- o DISADVANTAGES
  - ENTRY ROUTES TYPICALLY NUMEROUS AND INACCESSIBLE; IT WOULD BE TECHNICALLY VERY DIFFICULT, AND VERY EXPENSIVE, TO COMPLETELY SEAL AN EXISTING HOME
  - CRACKS IN THE SEAL CAN RE-OCCUR AS HOUSE SHIFTS OVER THE YEARS
- o - PRACTICAL CONSIDERATIONS
  - MAJOR, REASONABLY ACCESSIBLE OPENINGS SHOULD ALWAYS BE SEALED; SOME HIGHLY SITE-SPECIFIC REDUCTION WILL LIKELY BE ACHIEVED
  - SEALING WILL OFTEN BE A NECESSARY PART OF OTHER MITIGATION APPROACHES
  - SEALING OF MAJOR OPENINGS MIGHT SOMETIMES BE SUFFICIENT, BY ITSELF, TO REDUCE SLIGHTLY-ELEVATED HOUSES DOWN TO "SAFE" LEVELS; SEALING WILL PROBABLY RARELY, IF EVER, BE A COST-EFFECTIVE MEASURE BY ITSELF FOR REDUCING HIGH-LEVEL HOMES DOWN TO "SAFE" LEVELS.

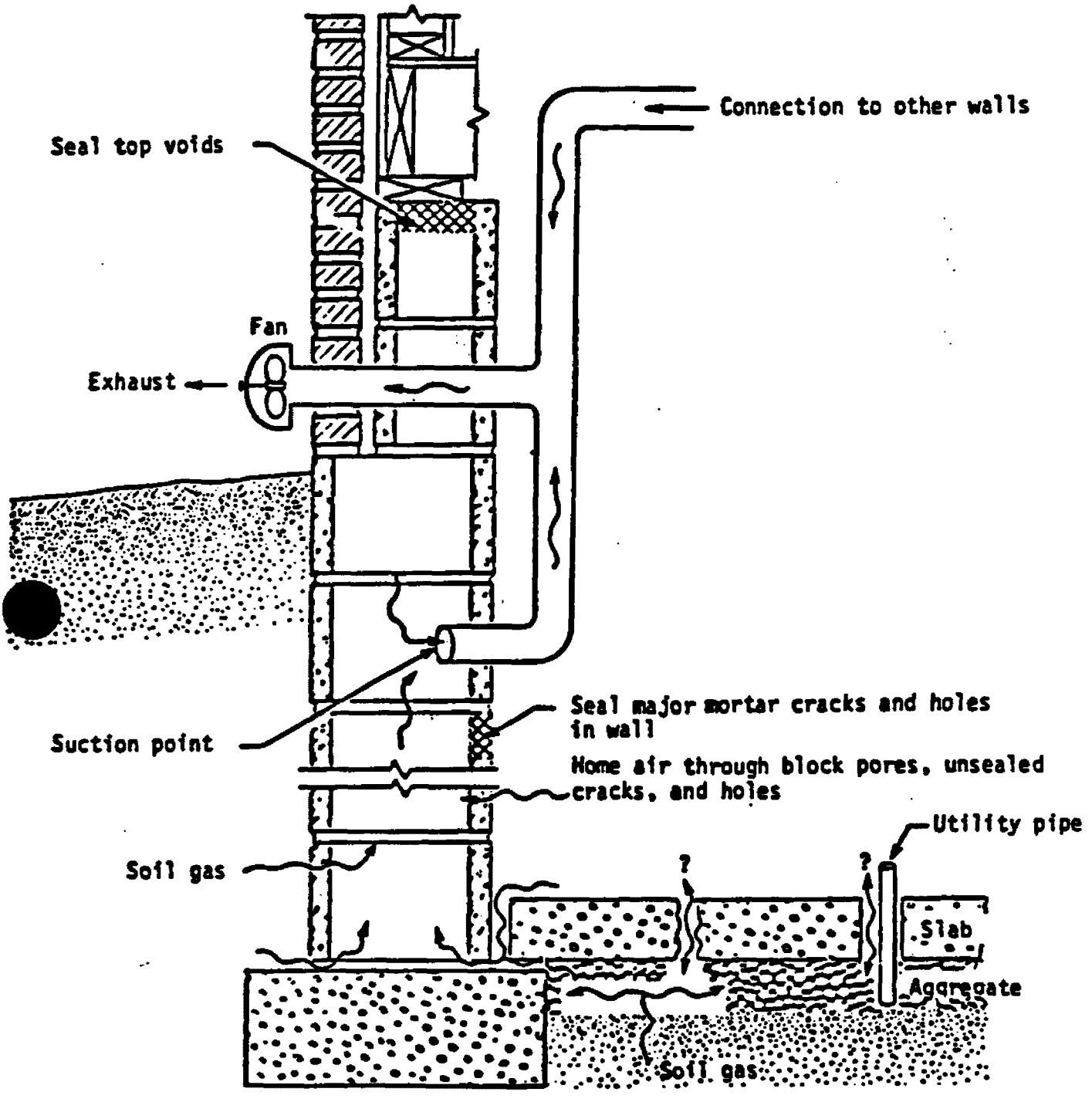
RADON MITIGATION ALTERNATIVES

C. ACTIVE SOIL VENTILATION

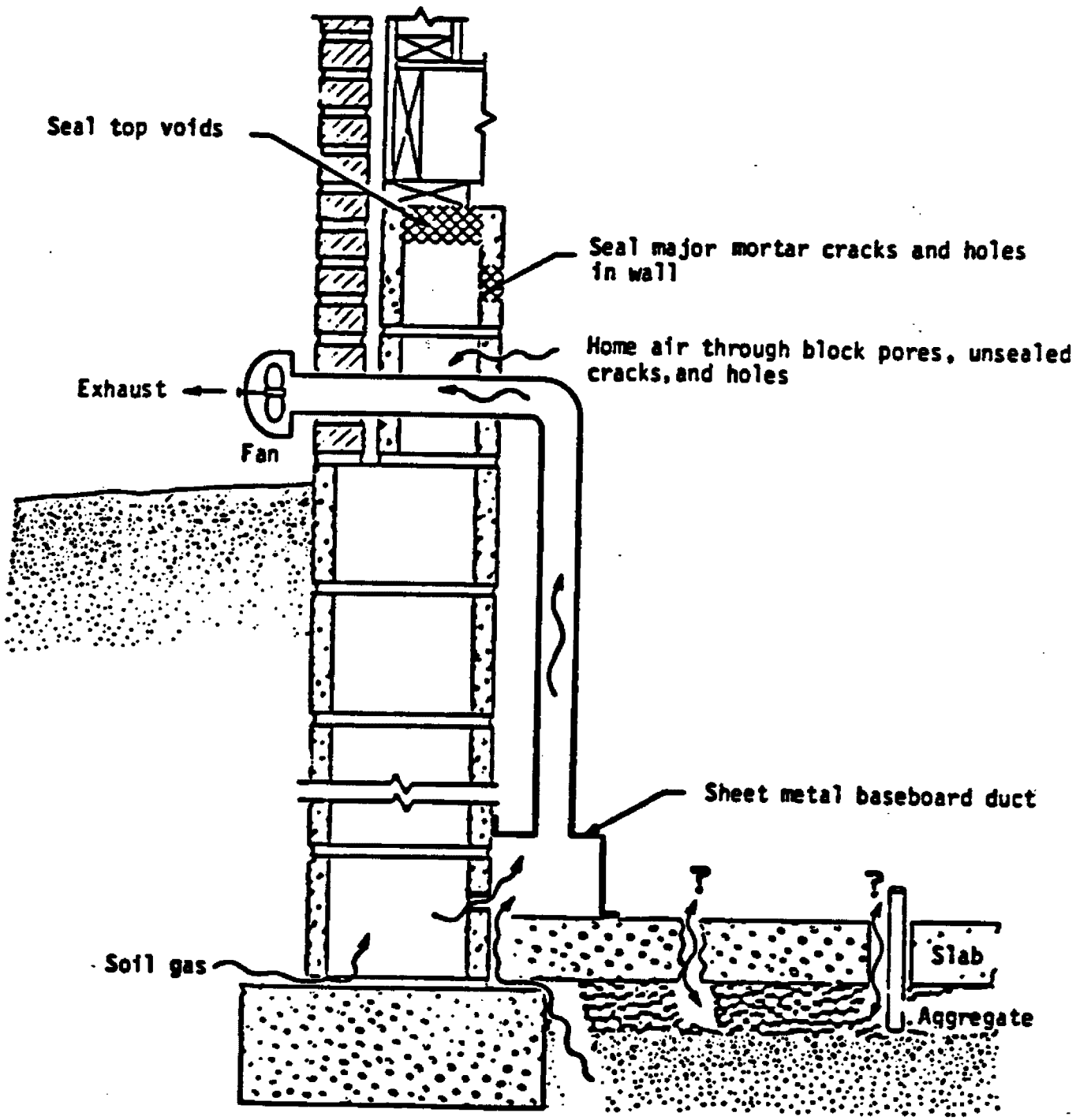
- o PRINCIPLE: USE FANS TO DRAW OR FORCE SOIL GAS AWAY FROM THE VICINITY OF THE HOUSE BEFORE IT CAN ENTER. CAUSE THE SOIL (OR, E.G., THE HOLLOW BLOCK VOID NETWORK) TO BE AT A PRESSURE LOWER THAN THAT IN THE HOUSE, SO THAT ANY GAS MOVEMENT IS FROM THE HOUSE OUTWARD INTO THE SOIL.
- o SPECIFIC TECHNIQUES:
  - HOLLOW BLOCK WALL VENTILATION
  - SUB-SLAB VENTILATION
  - WALL VENTILATION PLUS SUB-SLAB VENTILATION
  - DRAIN TILE SUCTION
    - -- TAP INTO LINE TO EXTERNAL SOAK-AWAY
    - -- COVER AND VENT INTERNAL SUMP
- o REDUCTIONS WELL ABOVE 90% (TO 99+%) CAN GENERALLY BE ACHIEVED, ALTHOUGH THE INSTALLATION COST FOR ACHIEVING SUCH HIGH REDUCTIONS CAN VARY SIGNIFICANTLY DEPENDING UPON SITE-SPECIFIC FACTORS.
- o ADVANTAGES:
  - POTENTIAL FOR HIGH LEVEL OF REDUCTION IN MOST CASES
  - POTENTIAL FOR MODERATE COST IN MANY CASES
- o DISADVANTAGES:
  - CAN BE DIFFICULT/EXPENSIVE TO ADEQUATELY VENTILATE ALL SOIL GAS ENTRY ROUTES IN SOME CASES
  - IS DEVELOPMENTAL (NOT "CONVENTIONAL")
  - SOME ACTIVE SOIL VENTILATION TECHNIQUES CAN BE DIFFICULT/EXPENSIVE TO INSTALL IN FINISHED BASEMENTS
  - WILL BE SOME CONTINUING OPERATING AND MAINTENANCE COSTS
- o PRACTICAL CONSIDERATIONS
  - WILL LIKELY ALWAYS HAVE TO BE CONSIDERED FOR HIGH-LEVEL HOUSES



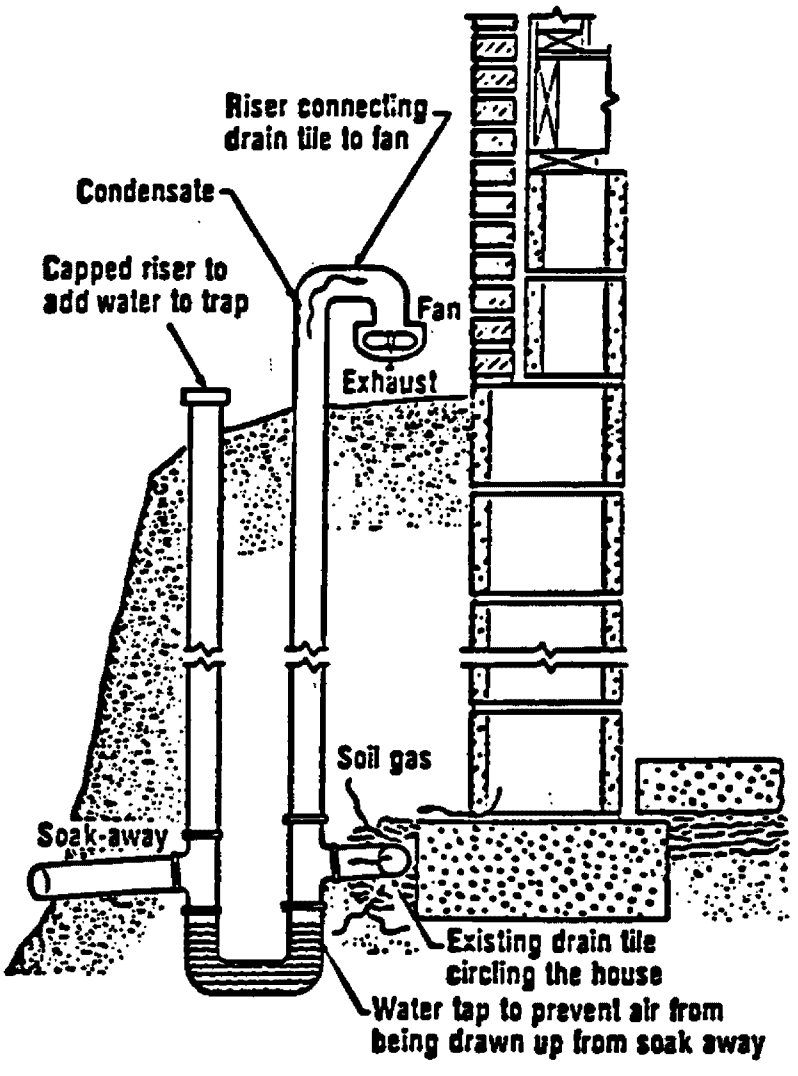
Sub-slab ventilation



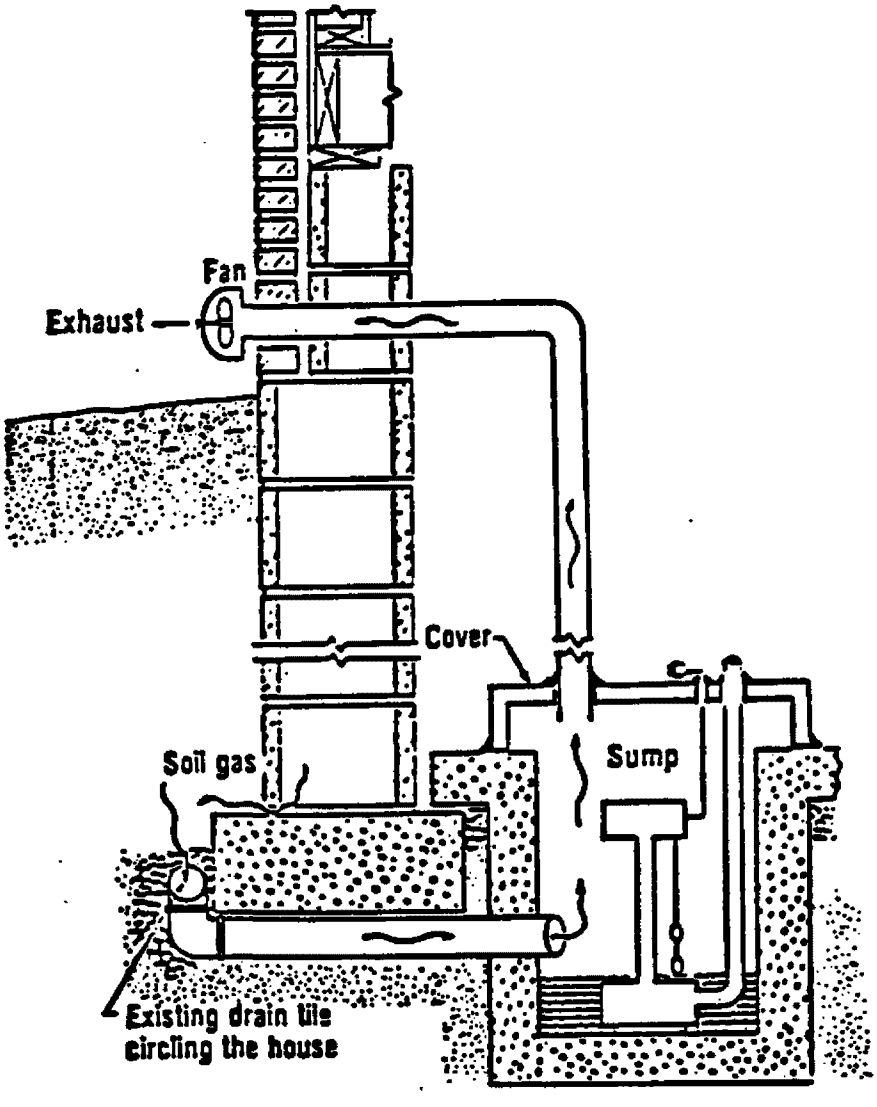
Block wall suction system



Baseboard suction system

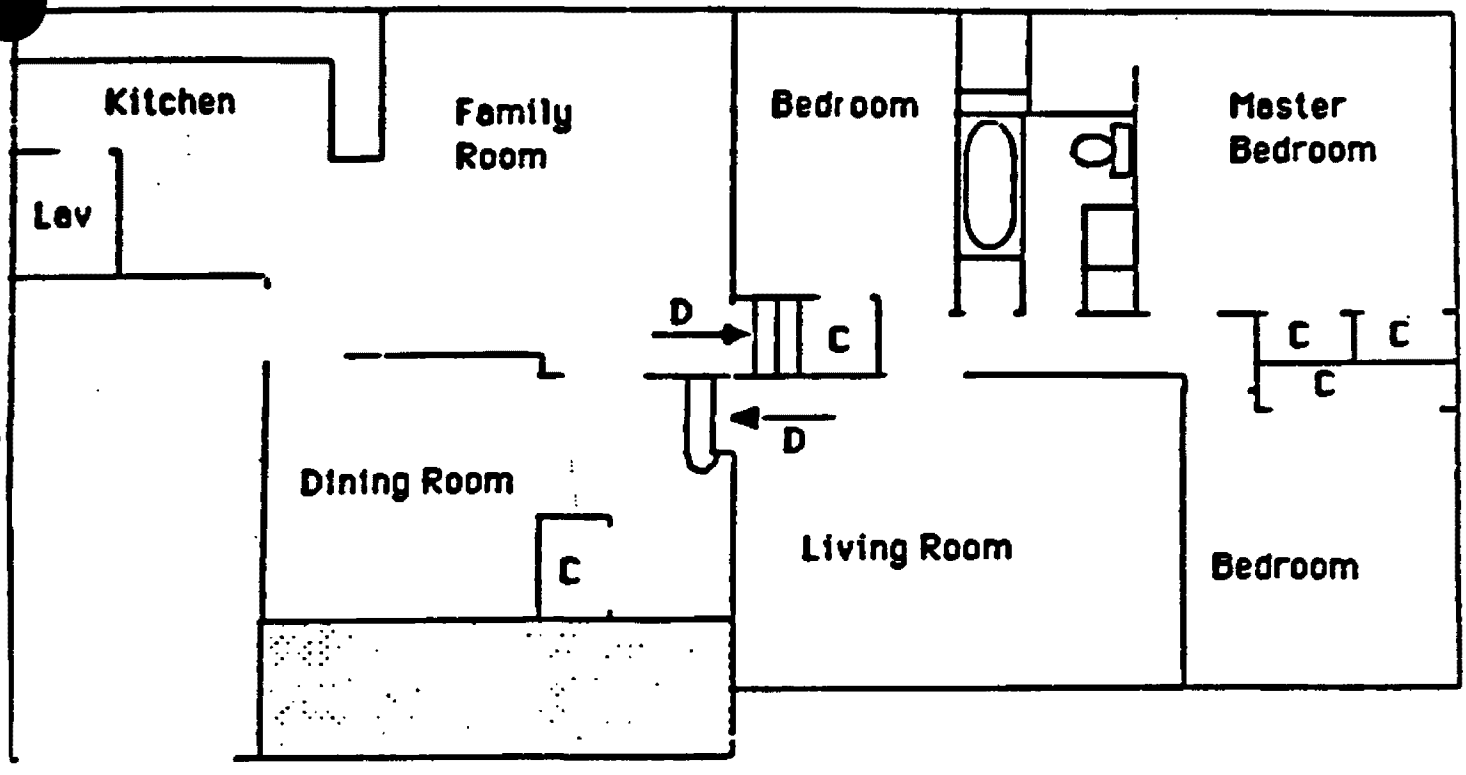


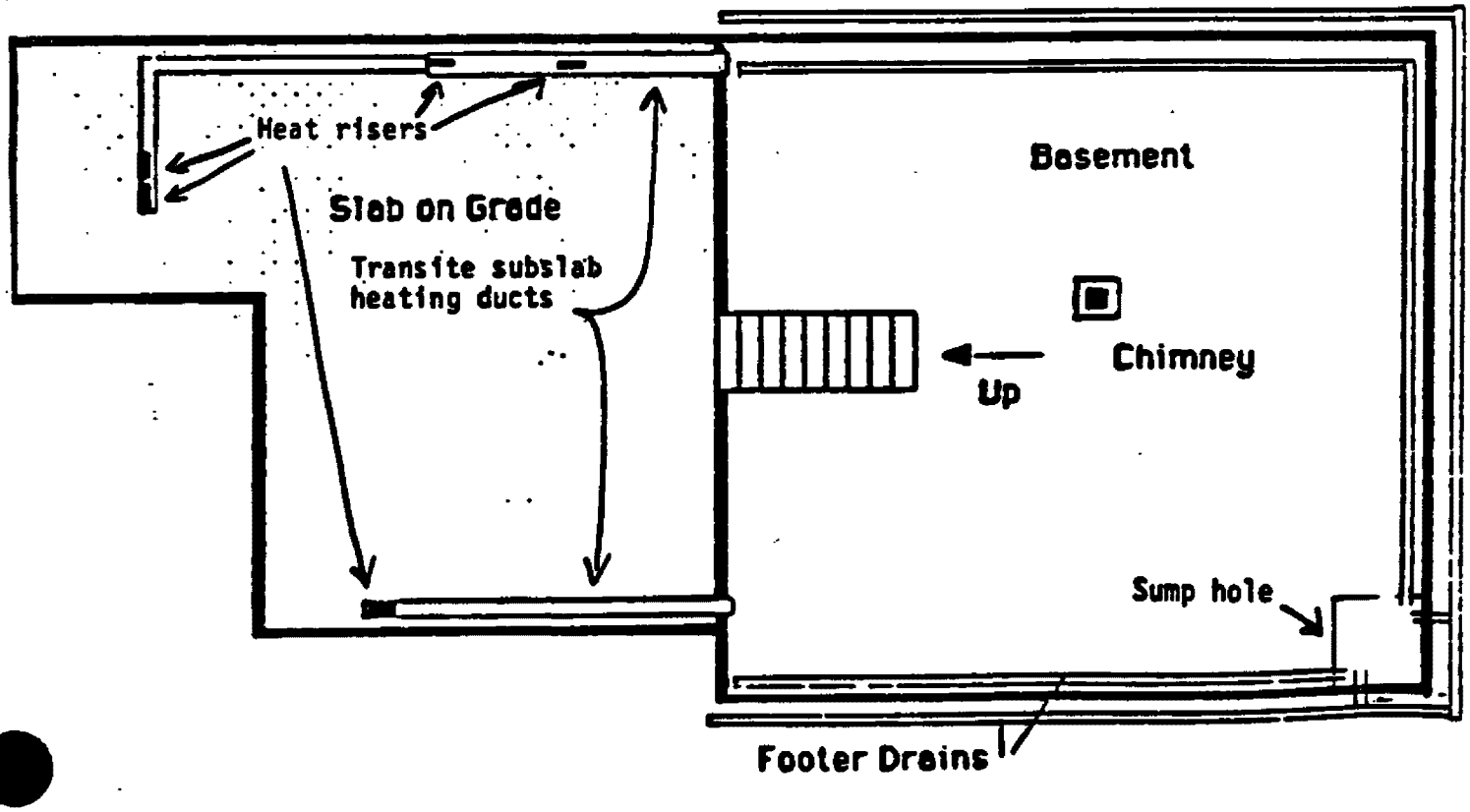
Drain tile ventilation (with soakaway)

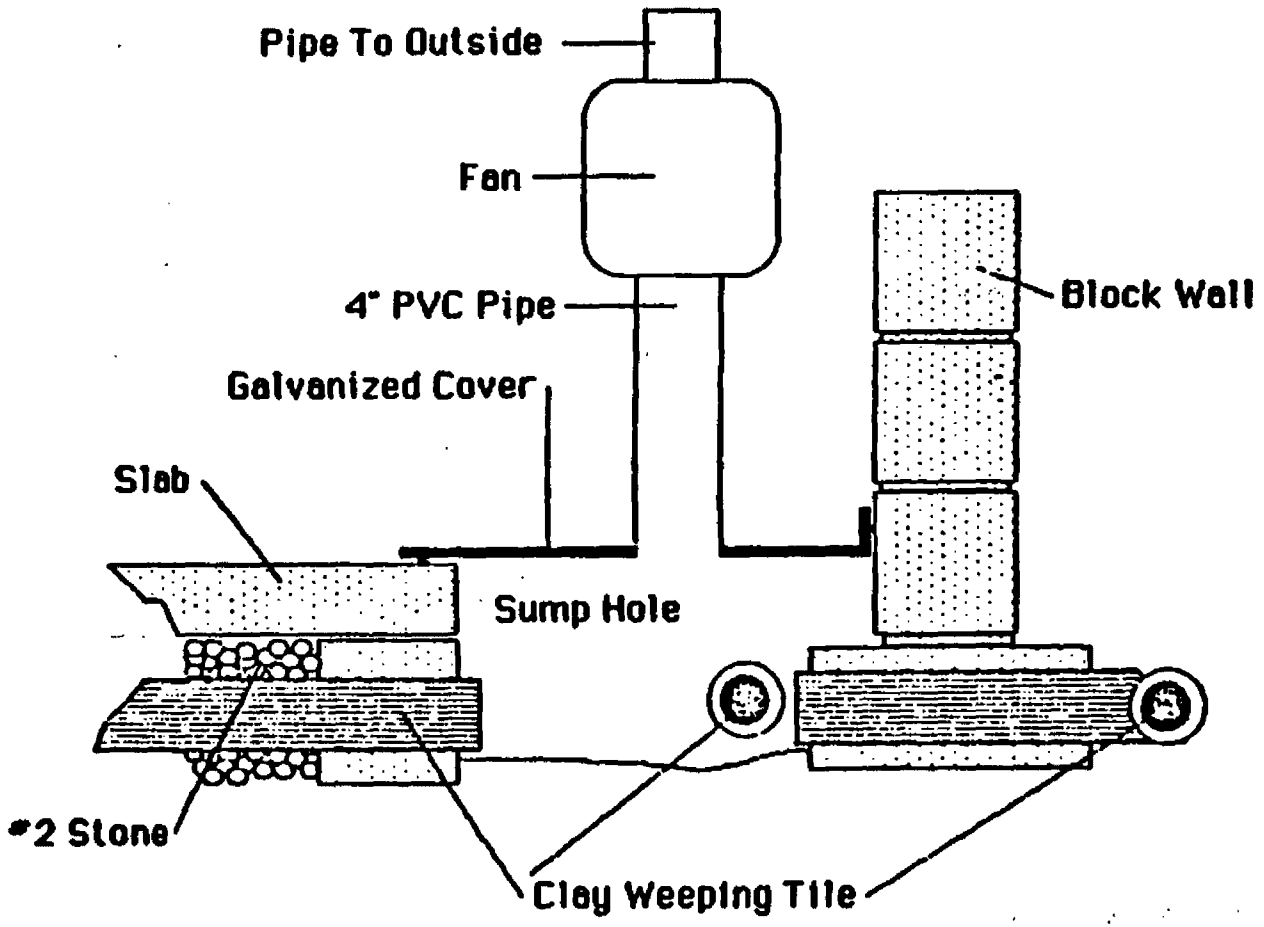


Drain tile ventilation (with sump)

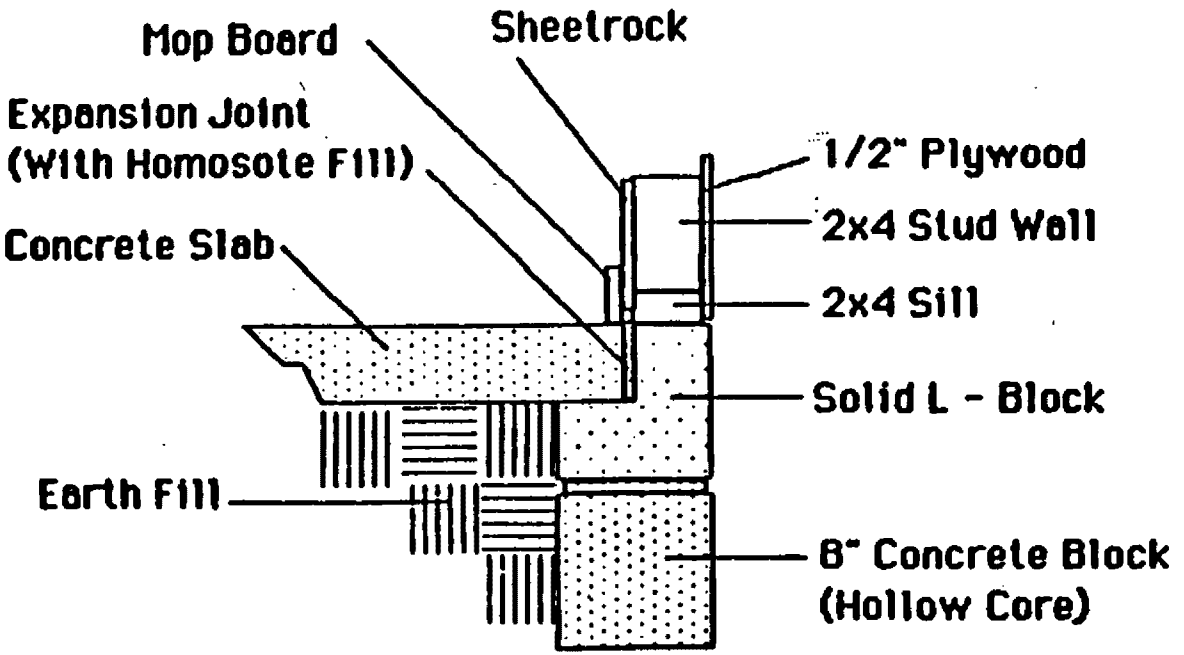
Floorplan for the "Ranch" Style
(Split Level)
1/8" = 1'



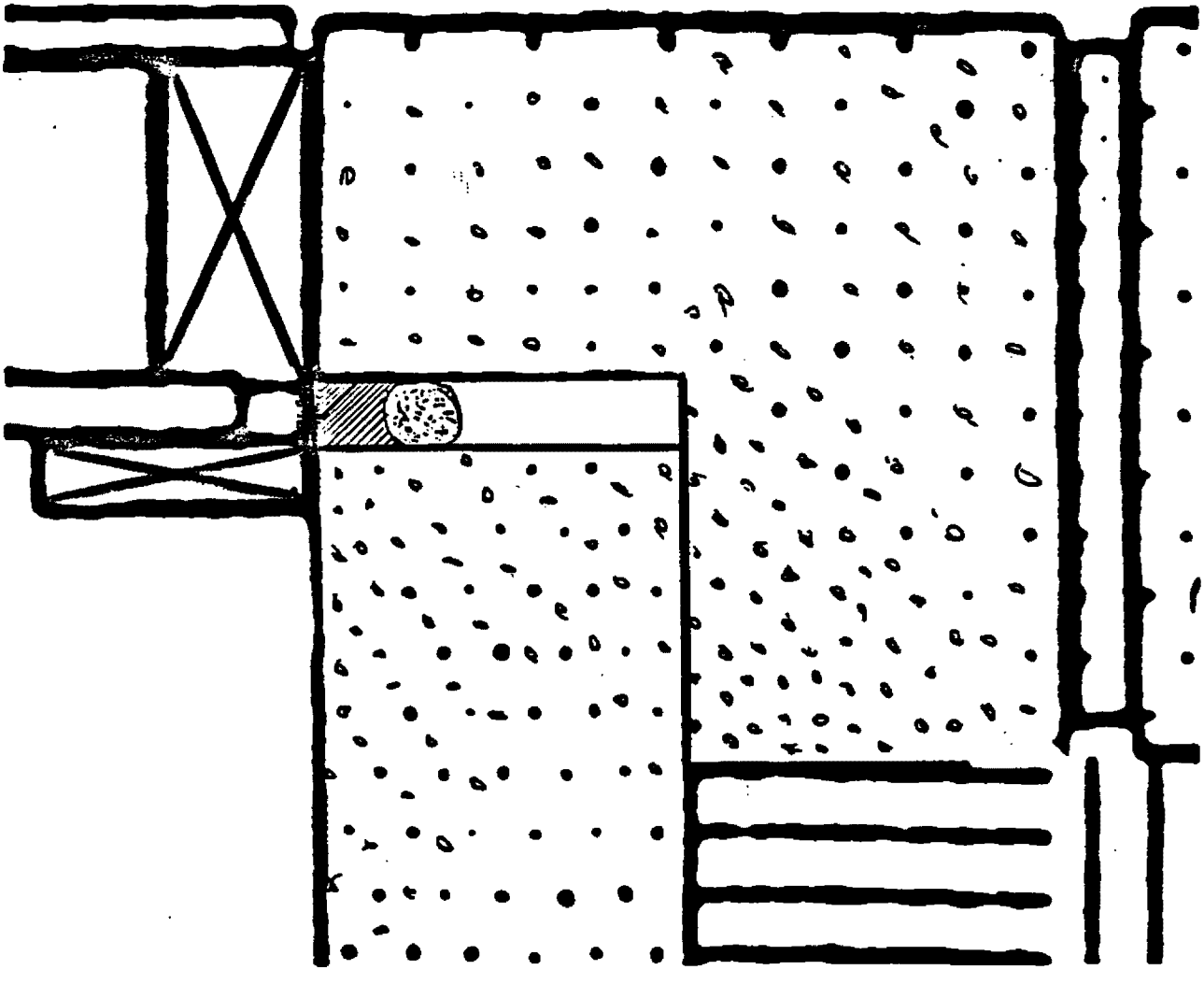




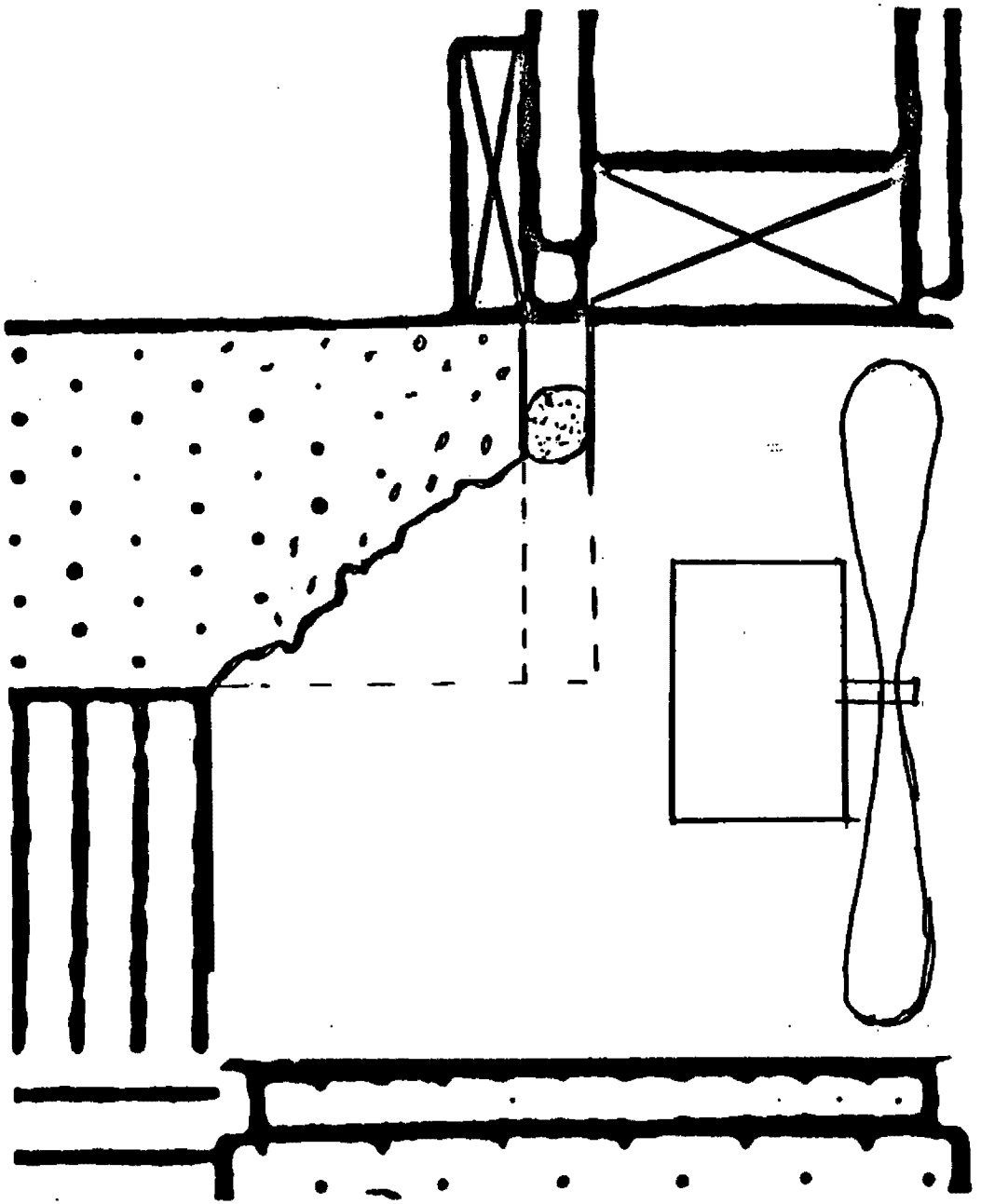
Cross-section of sump hole with footer drain tiles



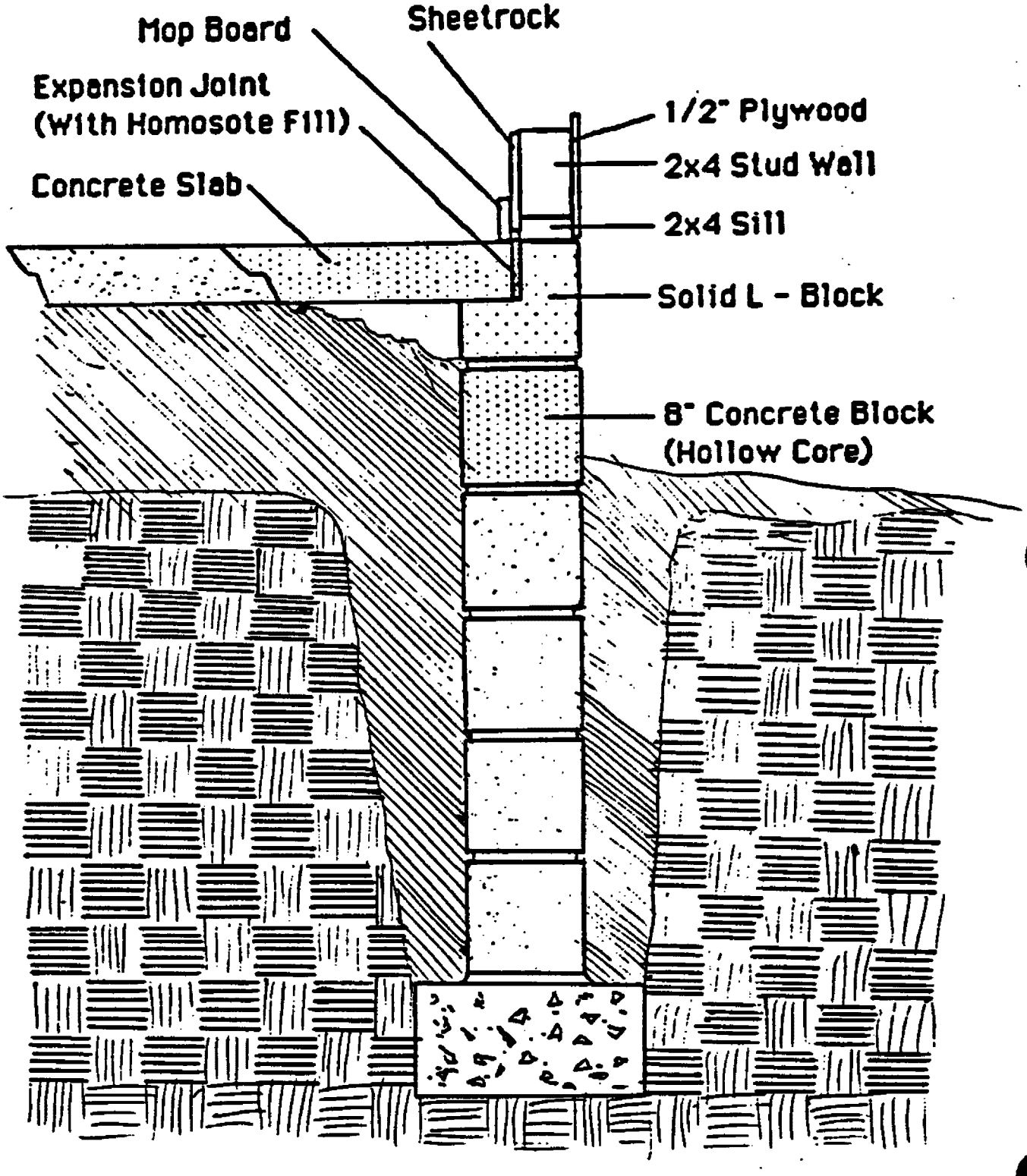
Section of slab-on-grade construction



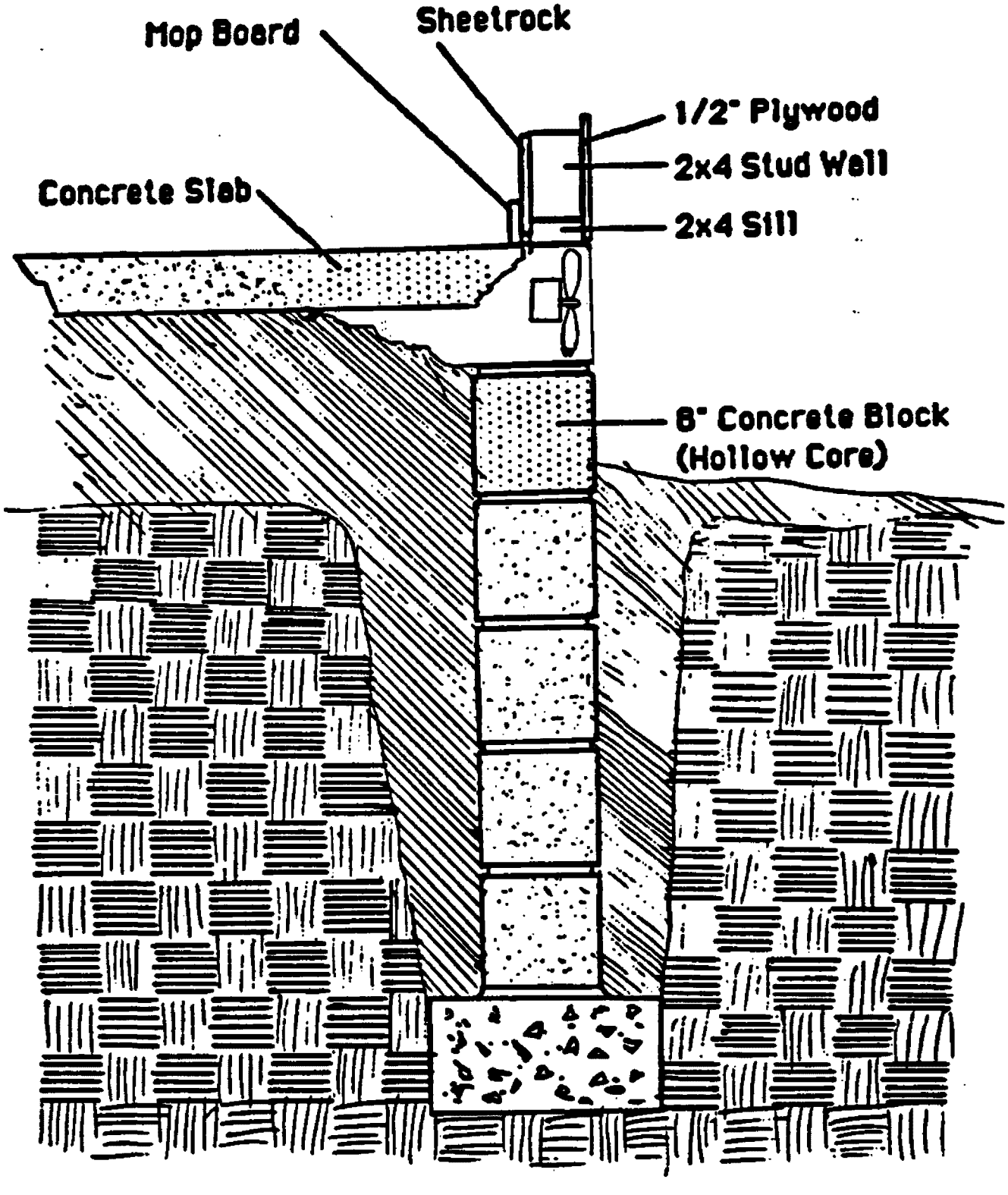
Section of slab-on-grade with expansion joint suction

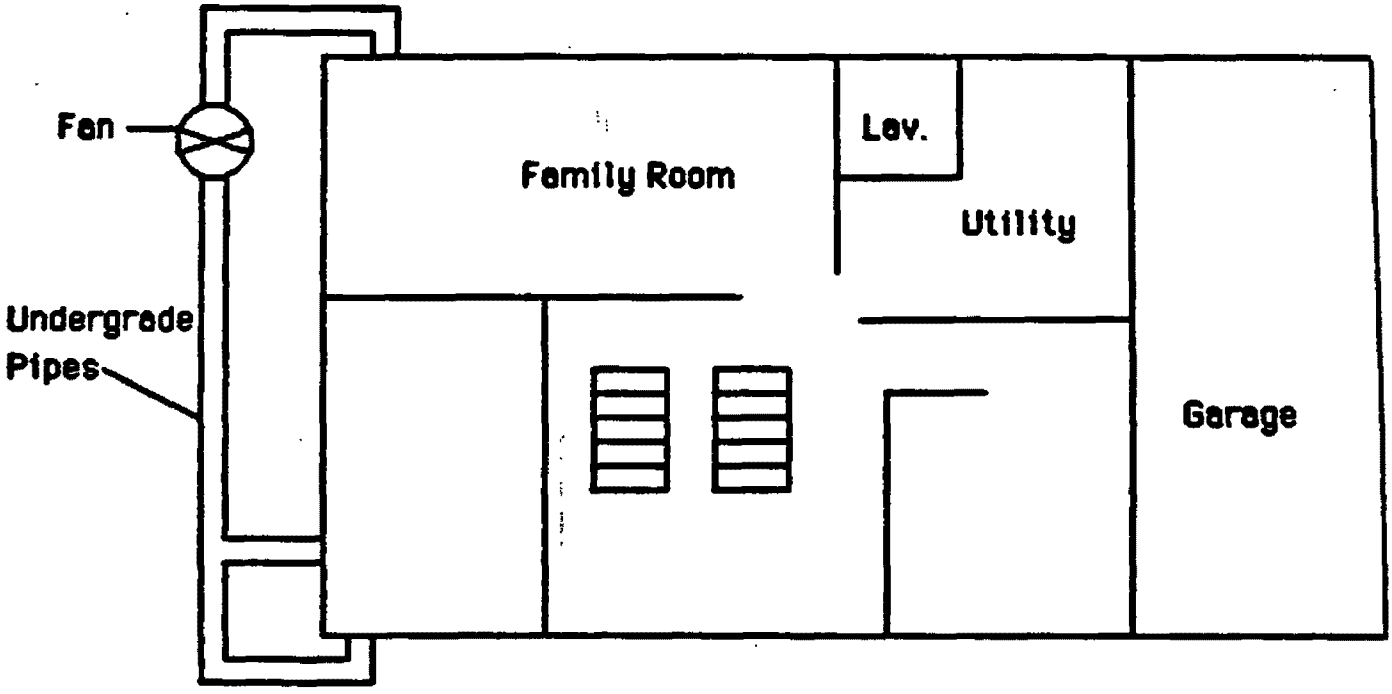


Sub-slab suction through foundation



Full section of slab-on-grade


Mop Board
Sheetrock
1/2" Plywood
2x4 Stud Wall
Concrete Slab
2x4 Sill
8" Concrete Block
(Hollow Core)


Fan
Undergrade
Pipes
Family Room
Lav.
Utility
Garage

RADON MITIGATION ALTERNATIVES

D. PASSIVE SOIL VENTILATION

- o PRINCIPLE: DRAW SOIL GAS AWAY FROM THE VICINITY OF THE HOUSE BEFORE IT CAN ENTER, WITHOUT USING A FAN. SUCTION IS DRAWN ON A SUB-SLAB PIPING NETWORK BY THE THERMAL STACK EFFECT IN A RISER WHICH PENETRATES THROUGH THE ROOF, AND BY REDUCED PRESSURES AT THE ROOFLINE.

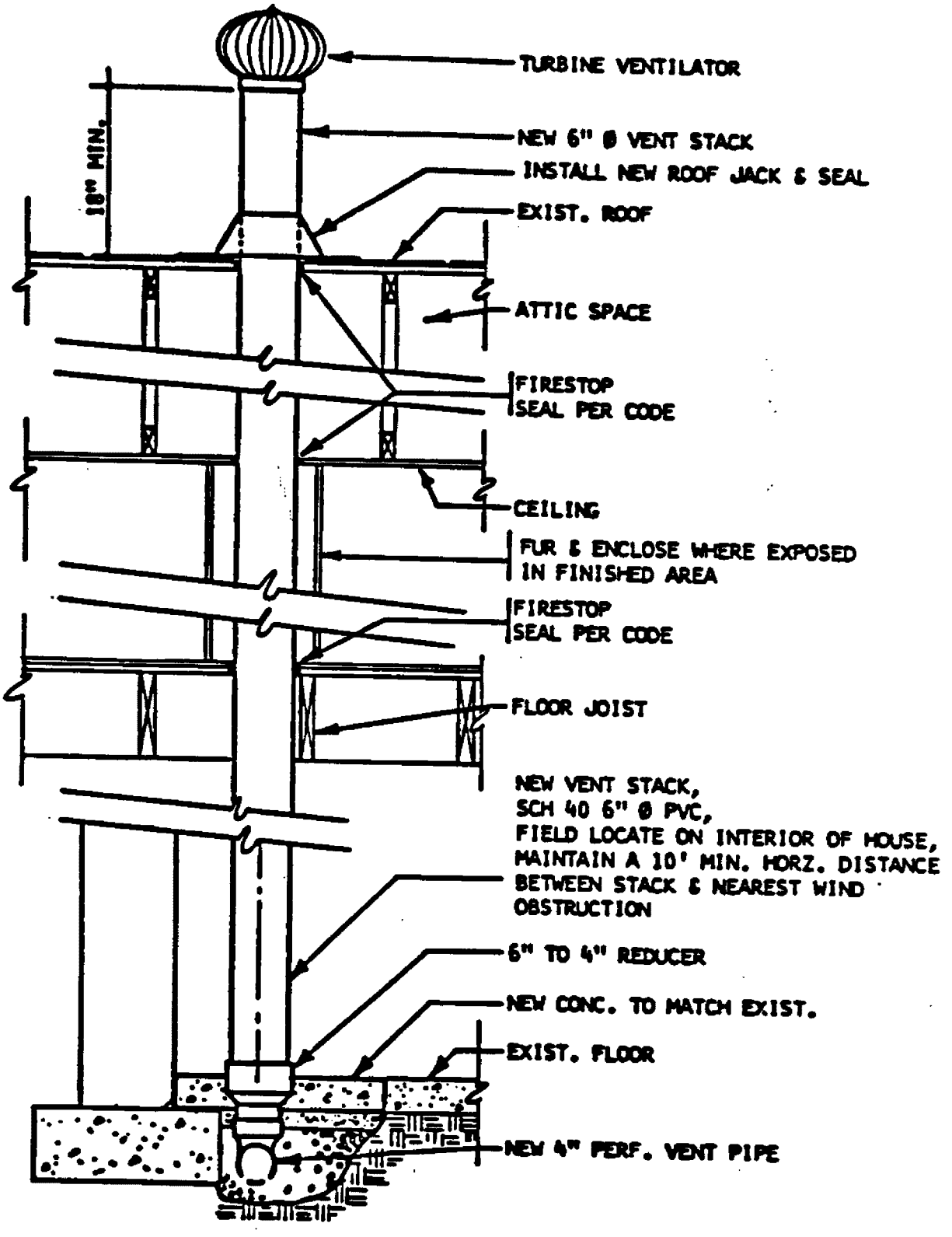
- o SPECIFIC TECHNIQUE:
  - SUB-SLAB VENTILATION

- o EFFECTIVENESS WILL BE HIGHLY DEPENDENT UPON THE EXTENT OF THE SUB-SLAB PIPING NETWORK, WEATHER CONDITIONS, AND OTHER FACTORS.

- o ADVANTAGES:
  - TOTALLY PASSIVE, NO OPERATING COST

- o DISADVANTAGE:
  - SUCTION DRAWN BY THIS SYSTEM IS SMALL; THUS, AN EXTENSIVE PERFORATED PIPING NETWORK MUST BE LAID UNDER THE SLAB TO ACHIEVE ADEQUATE TREATMENT. CAN BE EXPENSIVE TO RETROFIT SUCH A PIPING NETWORK INTO AN EXISTING HOUSE.

- o PRACTICAL CONSIDERATIONS:
  - WOULD BE MOST APPLICABLE IN NEW CONSTRUCTION, OR WHERE A SUB-SLAB PIPING NETWORK ALREADY EXISTS, OR WHERE THE EXISTING SLAB MUST BE TORN OUT FOR OTHER REASONS.



PASSIVE SUB-SLAB VENTILATION SYSTEM

From "General Remedial Action Details for Radon Gas Mitigation"
Pennsylvania Department of Environmental Resources (May 1985)

RADON MITIGATION ALTERNATIVES

E. HOUSE PRESSURIZATION

- PRINCIPLE: KEEP THE HOUSE AT A PRESSURE HIGHER THAN THE SURROUNDING SOIL, SO THAT GAS MOVEMENT IS FROM THE HOUSE OUTWARD INTO THE SOIL.

- SPECIFIC TECHNIQUE:
  - BLOW AIR INTO THE HOUSE (OR INTO THE BASEMENT) TO INCREASE THE PRESSURE

- EFFECTIVENESS DEPENDS UPON A NUMBER OF FACTORS (AMOUNT OF AIR SUPPLIED, EXTENT OF SEALING OF PRESSURIZED REGION FROM THE OUTDOORS AND FROM THE REMAINDER OF THE HOUSE).

- ADVANTAGE:
  - POTENTIAL FOR HIGH LEVEL OF RADON REDUCTION

- DISADVANTAGES:
  - DIFFICULT TO MAINTAIN ELEVATED PRESSURE UNDER NORMAL CIRCUMSTANCES DUE TO NUMEROUS ROUTES BY WHICH AIR CAN LEAK OUT (E.G., BAROMETRIC DAMPER IN FURNACE FLUE)
  - ENERGY PENALTY IF AIR BLOWN IN FROM OUTDOORS
  - MIGHT MAKE HOUSE FEEL DRAFTY; MIGHT REQUIRE INCONVENIENCES (E.G., CLOSING OFF FIREPLACE)

- PRACTICAL CONSIDERATIONS:
  - TECHNIQUE IS DEVELOPMENTAL; MIGHT OFFER POTENTIAL ULTIMATELY, BUT PRACTICAL PROBLEMS MUST BE OVERCOME FIRST

RADON MITIGATION ALTERNATIVES

F. AVOIDANCE OF HOUSE DEPRESSURIZATION

- o PRINCIPLE: TAKE STEPS TO REDUCE HOUSE DEPRESSURIZATION (AND HENCE SOIL GAS INFLUX) CAUSED BY HOUSEHOLD ACTIVITIES AND BY WEATHER.

- o SPECIFIC TECHNIQUES (EXAMPLES):
  - CRACK WINDOW WHEN FIREPLACE IN USE
  - OPEN WINDOWS ON BOTH SIDES OF THE HOUSE
  - PROVIDE OUTDOOR SOURCE OF COMBUSTION AIR FOR FURNACES, OTHER APPLIANCES
  - CLOSE MAJOR OPENINGS BETWEEN FLOORS (REDUCE THERMAL BYPASSING)

- o EFFECTIVENESS HIGHLY SITE SPECIFIC; CAN BE VERY HIGH FOR SHORT PERIODS IN SOME CASES.

- o ADVANTAGES:
  - SOME OF THESE STEPS CAN BE IMPLEMENTED EASILY
  - CAN HAVE MAJOR SHORT-TERM BENEFITS IN SOME CASES

- o DISADVANTAGES:
  - SOME OF THESE STEPS LESS EASY TO IMPLEMENT
  - YEAR-AROUND BENEFITS NOT WELL DOCUMENTED

- o PRACTICAL CONSIDERATIONS
  - WHERE STEPS CAN BE IMPLEMENTED EASILY, THOSE STEPS SHOULD BE TAKEN; SHORT-TERM BENEFITS CAN BE SIGNIFICANT.

RADON MITIGATION ALTERNATIVES

6. HOUSE AIR CLEANERS

- PRINCIPLE: REMOVE RADON PROGENY (OR RADON) FROM THE HOUSE AIR

- SPECIFIC TECHNIQUES:
  - FILTERS, ELECTROSTATIC PRECIPITATORS TO REMOVE PARTICLES (RADON PROGENY) FROM CIRCULATING HOUSE AIR
  - SORPTION UNITS TO REMOVE RADON GAS

- EFFECTIVENESS AT REDUCING GROSS WORKING LEVEL CAN BE MODERATE TO HIGH; EFFECT ON WORKING LEVEL OF UNATTACHED PROGENY IS AN ISSUE WITH PARTICLE REMOVAL DEVICES

- ADVANTAGES:
  - CAN GIVE MODERATE AND HIGHER WORKING LEVEL REDUCTIONS
  - GENERALLY "CONVENTIONAL" TECHNOLOGY; DO NOT REQUIRE SIGNIFICANT MODIFICATIONS TO THE HOUSE

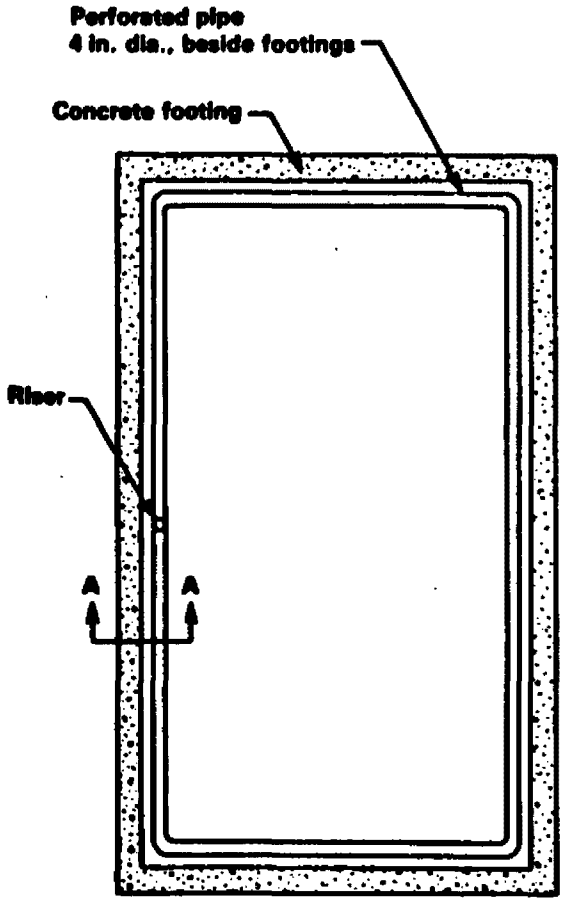
- DISADVANTAGE:
  - PARTICLE REMOVAL DEVICES MIGHT INCREASE THE AMOUNT OF UNATTACHED PROGENY; HEALTH RISKS UNCLEAR

- PRACTICAL CONSIDERATIONS:
  - EFFECTS OF PARTICLE REMOVAL DEVICES ON UNATTACHED PROGENY, AND THE RESULTING HEALTH EFFECTS, MUST BE CLARIFIED BEFORE THESE DEVICES CAN BE RECOMMENDED.

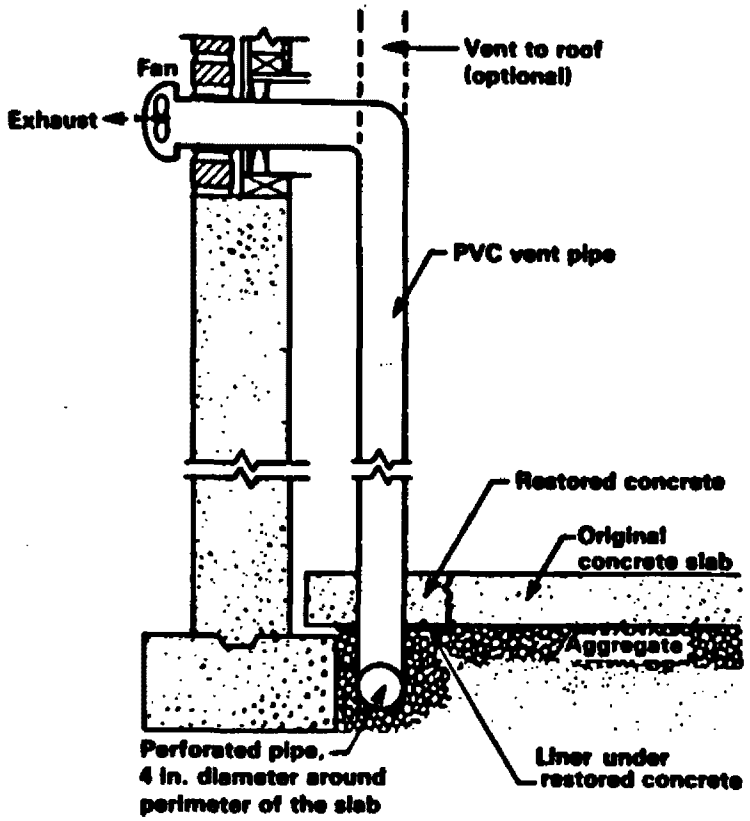
APPROXIMATE COSTS OF RADON MITIGATION (EXISTING HOUSES)

Technique	Approximate % Reduction	Installed Cost ($) By Homeowner	Installed Cost ($) By Contractor	Annual Operating Cost
House ventilation				
1. Natural	Up to 90	0		4 times heating costs.
2. Forced	Up to 90	Low	to 150	Up to $100 + 4 times heating costs.
3. HRV	Up to 90+	---	400-1,500	Up to $100 + 1.6 times heating costs.
Sealing				
4. Comprehensive sealing	Low to 90	Low to moderate	Low to >10,000	"None"
Active soil ventilation				
5. Wall ventilation				
- single point	Up to 99+	100-400	2,500+	$150
- baseboard duct	Up to 99+	200-600	5,000+	$150
6. Sub-slab ventilation	Up to 90-99	200-500	2,000+	$150
7. Drain tile suction	Up to 98+	100-300	1,200	$150
Passive soil ventilation				
8. Sub-slab ventilation	•		•	None
Home pressurization				
9. House pressurization	•		•	•
Avoid depressurization				
10. Avoid depressurization	•		•	•
Air Cleaners				
11. Particle removal devices	•		•	•
12. Gas sorption devices	•		•	•
Well water treatment				
13. Water treatment devices	•		•	•

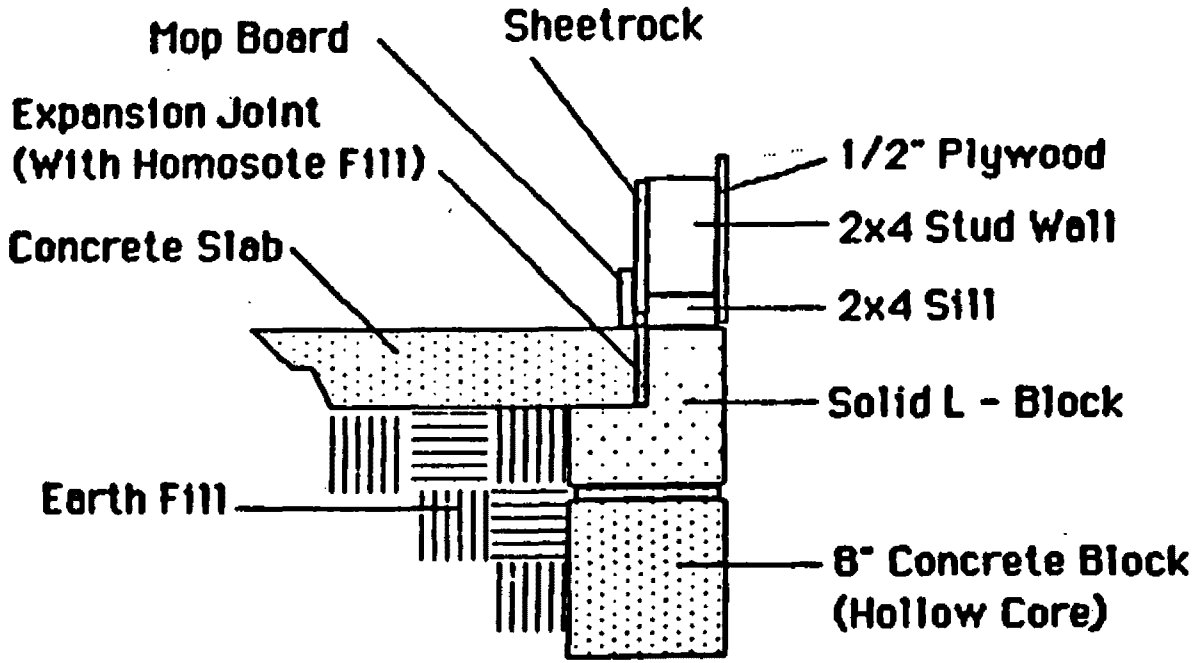
*Performance/costs highly variable, site-specific (or otherwise unable to estimate at this time).

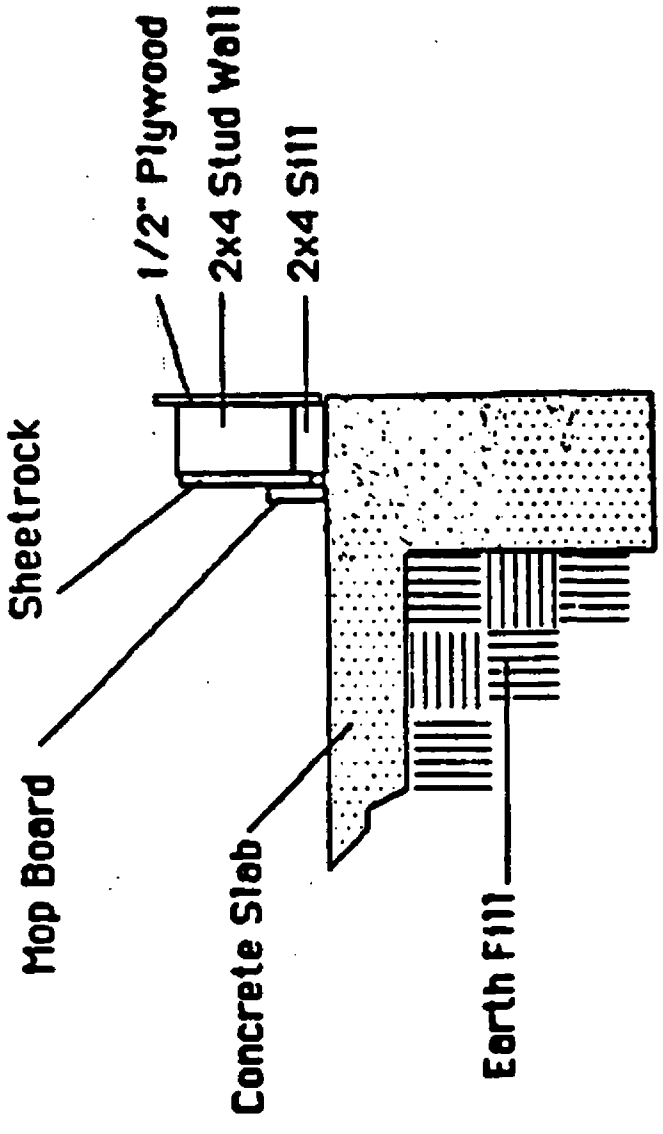


Top view — network around perimeter of slab



Section A-A


Mop Board
Sheetrock
Expansion Joint
(With Homosote Fill)
1/2" Plywood
2x4 Stud Wall
Concrete Slab
2x4 Sill
Solid L - Block
Earth Fill
8" Concrete Block
(Hollow Core)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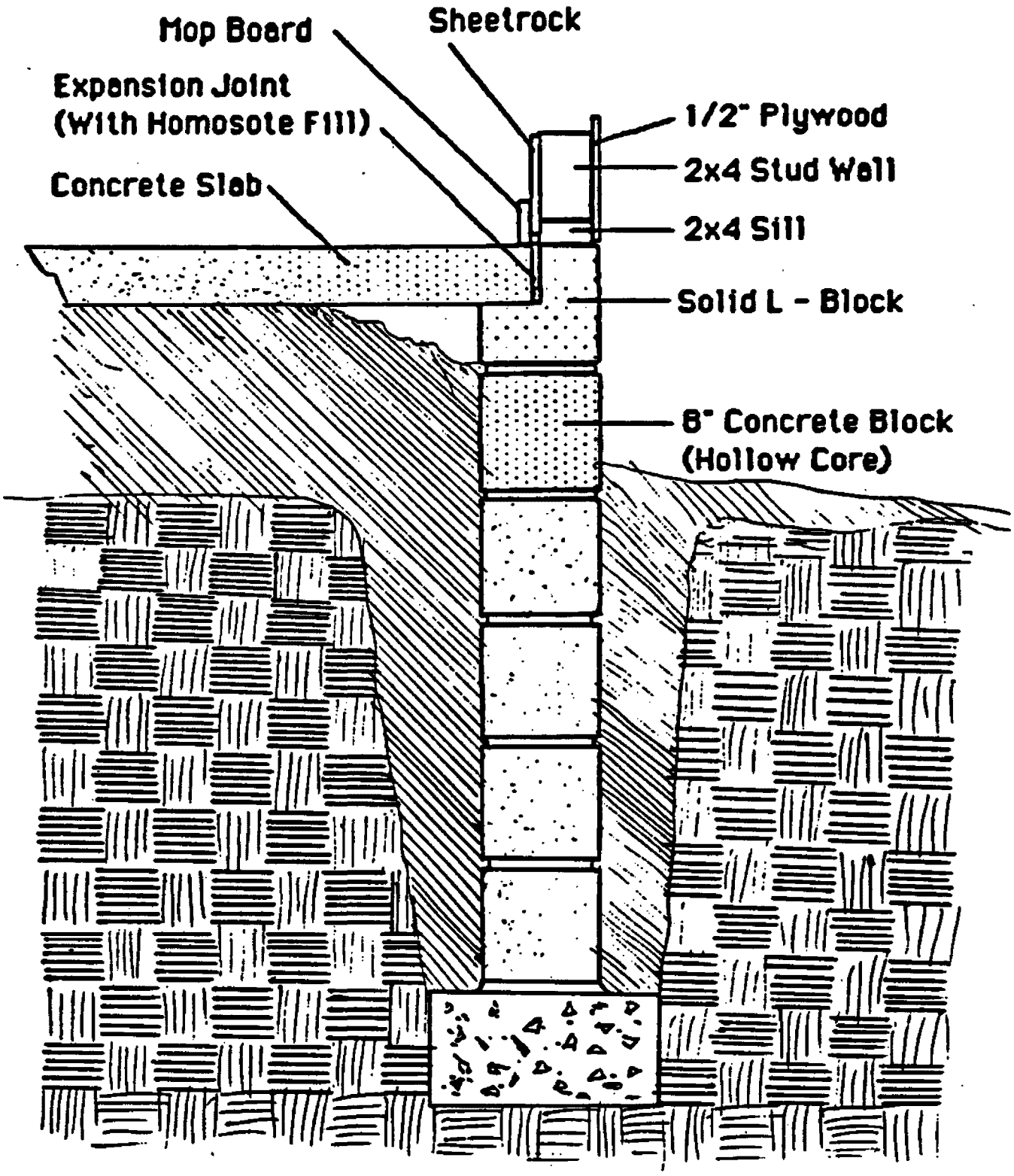
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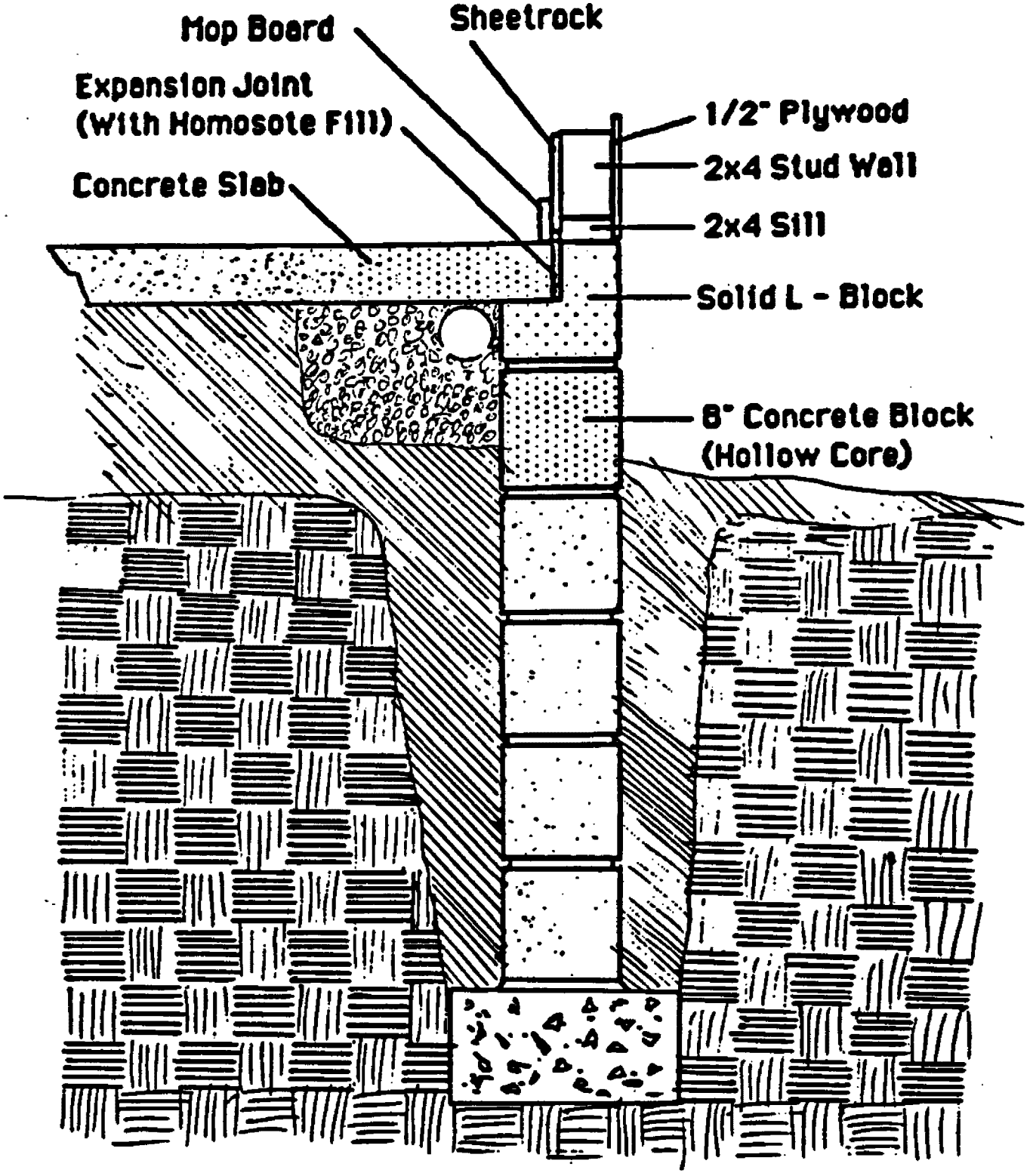
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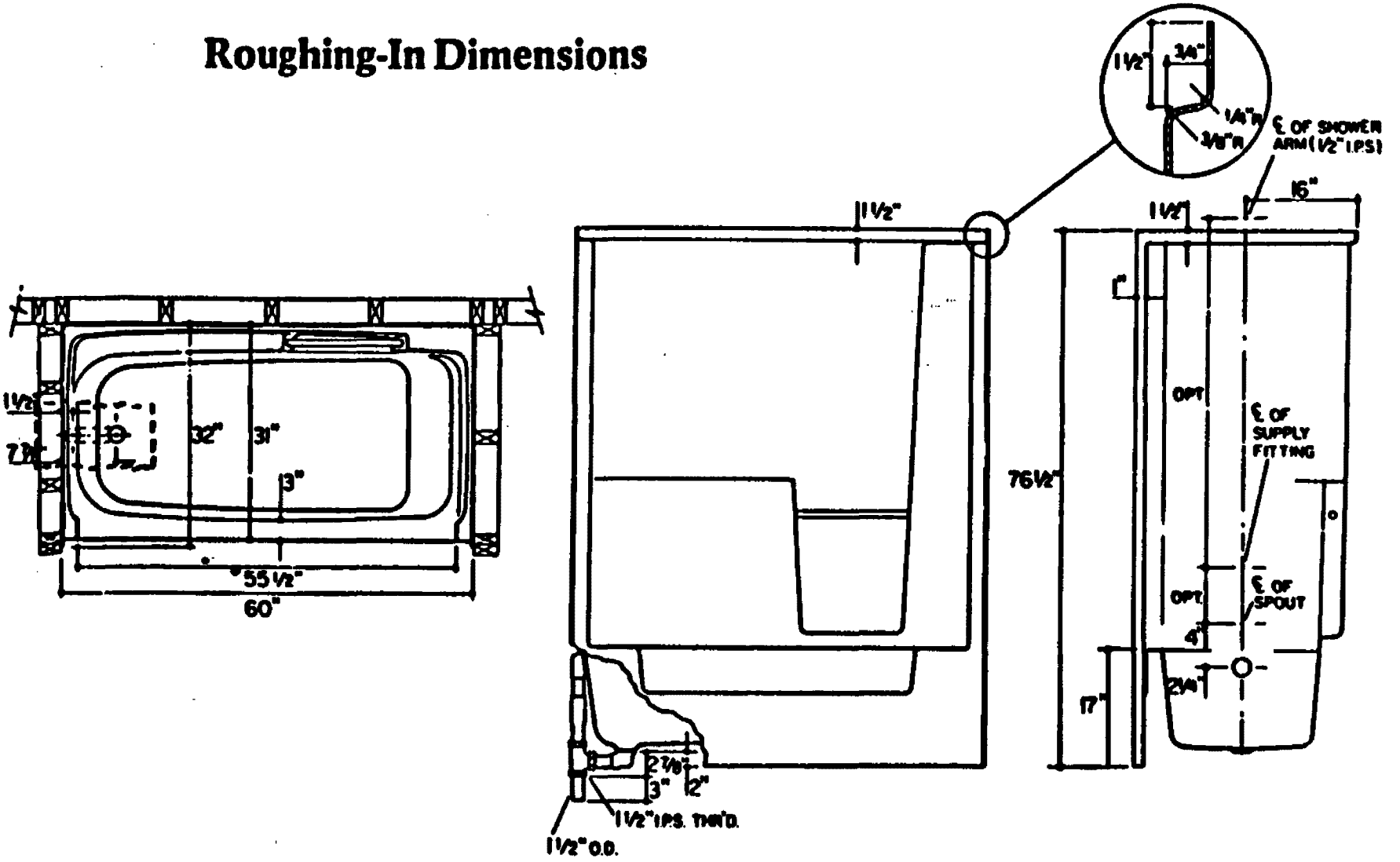
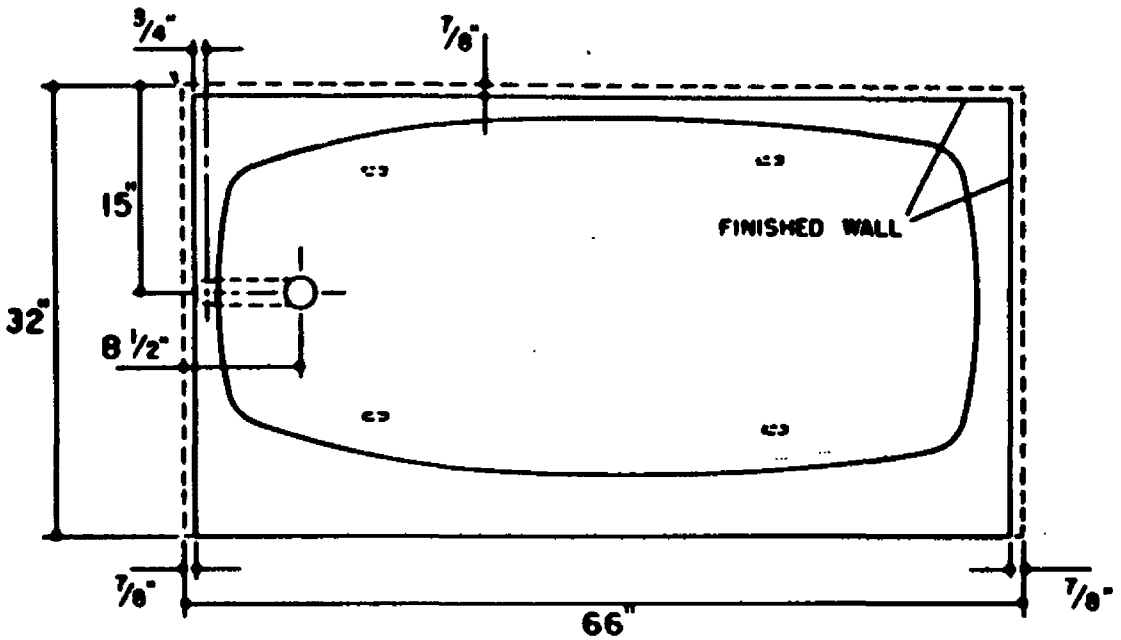
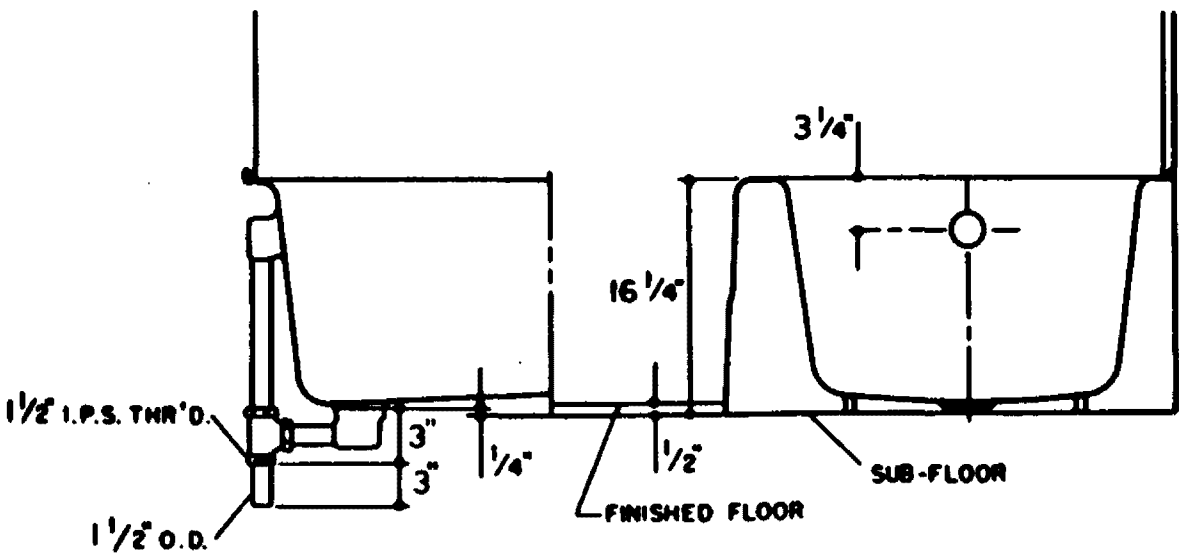
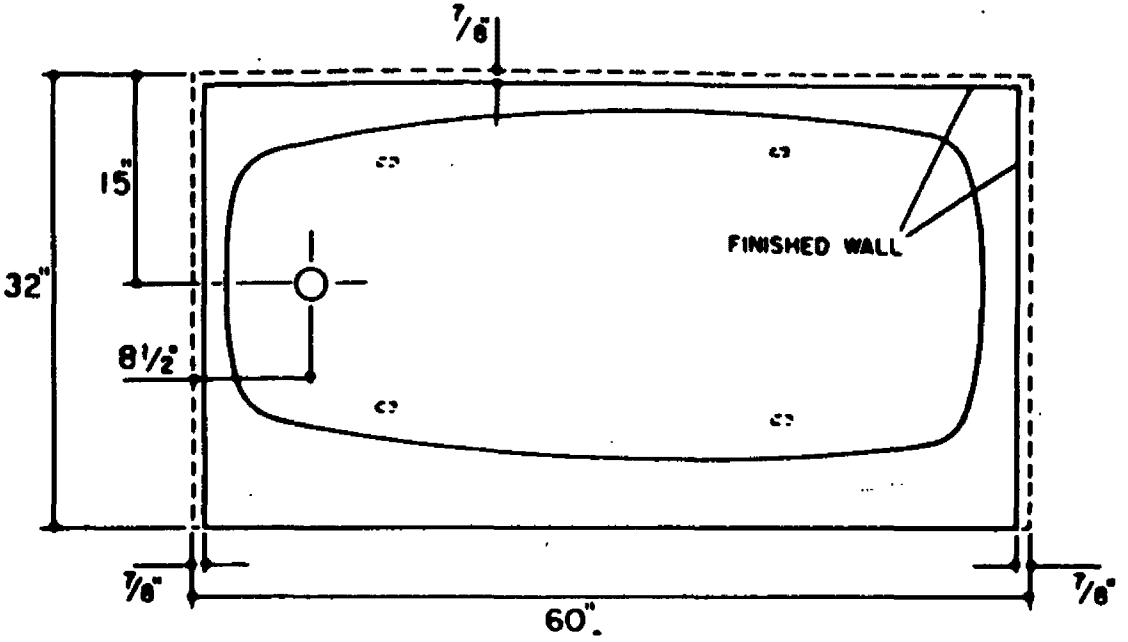
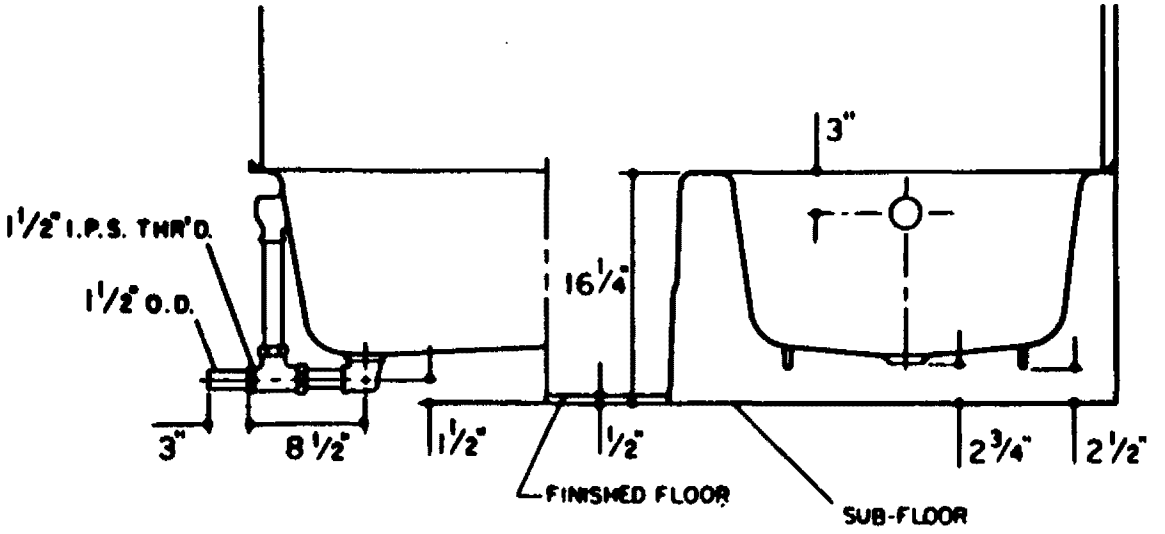
Roughing-In Dimensions

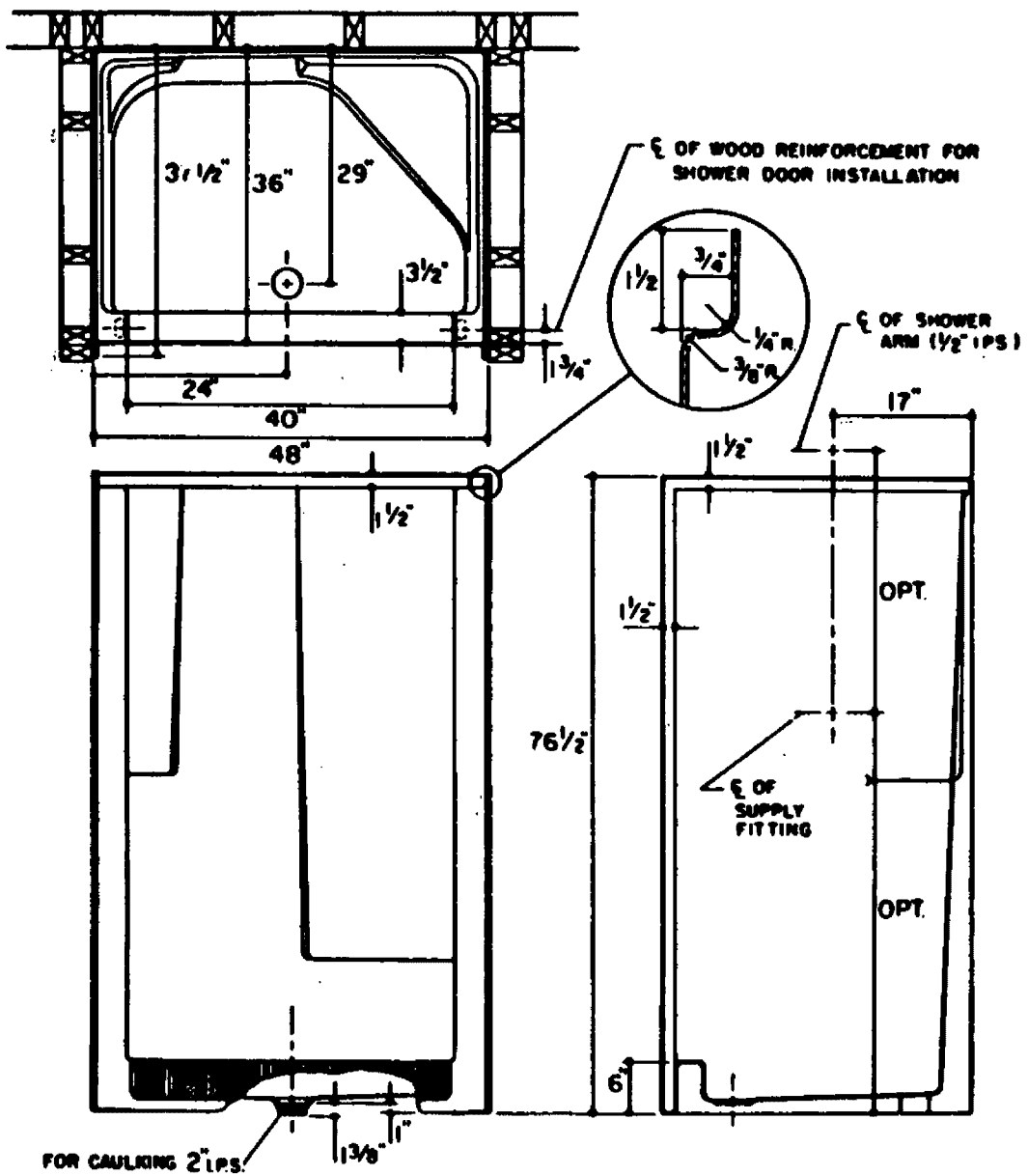


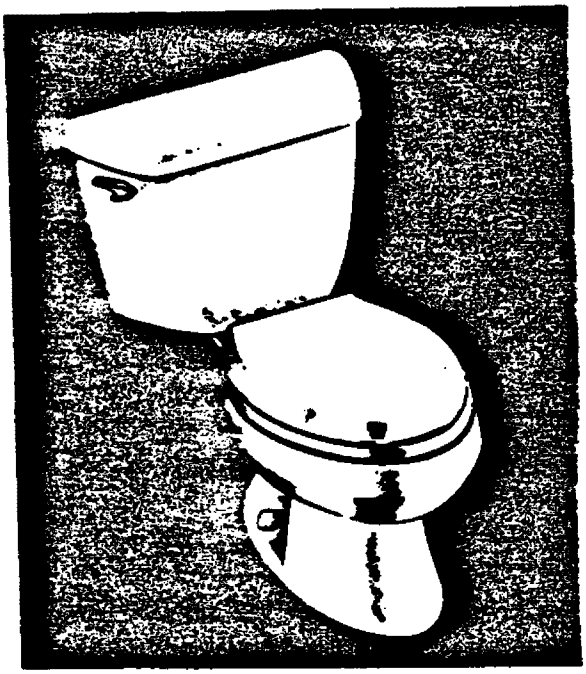

3/4"
7/8"
15"
32"
8 1/2"
FINISHED WALL
7/8"
7/8"
66"

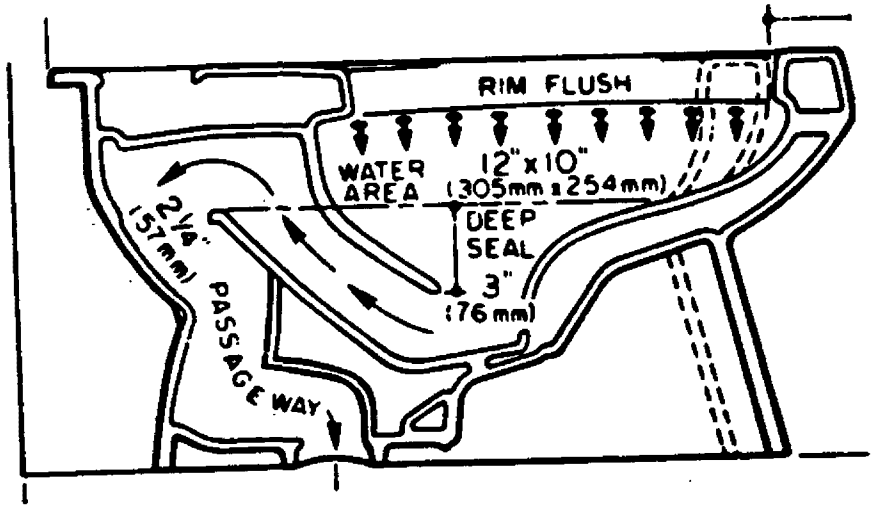

3 1/4"
16 1/4"
1 1/2" I.P.S. THR'D.
3"
3"
1/4"
1/2"
SUB-FLOOR
FINISHED FLOOR
1 1/2" O.D.

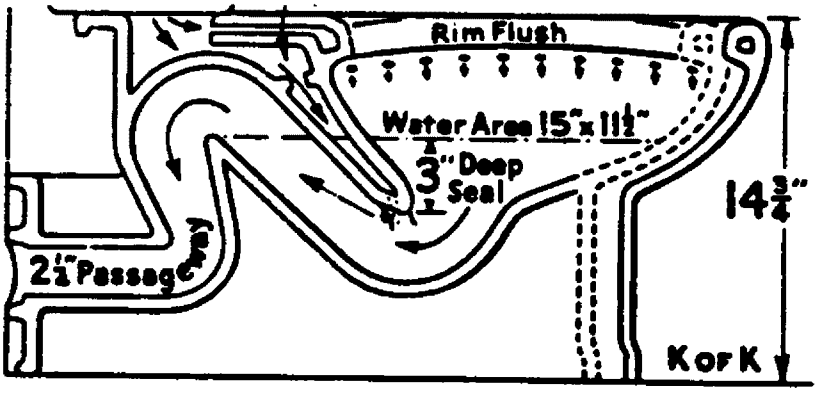

7/8"
15"
32"
8 1/2"
FINISHED WALL
7/8"
7/8"
60"


1 1/2" I.P.S. THR'D.
1 1/2" O.D.
3"
8 1/2"
16 1/4"
3"
1 1/2"
1/2"
2 3/4"
2 1/2"
FINISHED FLOOR
SUB-FLOOR


31½"
36"
29"
3½"
1¾"
24"
40"
48"
1½"
℄ OF WOOD REINFORCEMENT FOR SHOWER DOOR INSTALLATION
3/4"
1½
¼"R.
⅜"R.
℄ OF SHOWER ARM (½" IPS)
17"
1½"
OPT.
1½"
76½"
℄ OF SUPPLY FITTING
OPT.
6"
FOR CAULKING 2" I.P.S.
1⅜"
1"




RIM FLUSH
WATER AREA
12"x10"
(305mm x 254mm)
DEEP SEAL
3"
(76mm)
2 1/8"
(57mm)
PASSAGE WAY


Rim Flush
Water Area 15" x 11½"
3" Deep Seal
2½" Passage
14¾"
K or K

Radon Risk Evaluation Chart

pCi/l	WL	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels	Comparable risk
200	1	440—770	1000 times average outdoor level	More than 60 times non-smoker risk
				4 pack-a-day smoker
100	0.5	270—630	100 times average indoor level	
				20,000 chest x-rays per year
40	0.2	120—380		
				2 pack-a-day smoker
20	0.1	60—210	100 times average outdoor level	
				1 pack-a-day smoker
10	0.05	30—120	10 times average indoor level	
				5 times non-smoker risk
4	0.02	13—50		
				200 chest x-rays per year
2	0.01	7—30	10 times average outdoor level	
				Non-smoker risk of dying from lung cancer
1	0.005	3—13	Average indoor level	
0.2	0.001	1—3	Average outdoor level	20 chest x-rays per year