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ABSTRACT

The protection against radon gas afforded by several types of activated carbon gas mask canisters was determined, since uranium mine personnel are occasionally exposed to radon concentrations in the thousands of pCi/ℓ range, and calculations showed that 3300 pCi/ℓ of radon was equivalent to the permissible level of 0.3 WL of radon daughters on the basis of potential alpha energy release in the respiratory tract. The canisters were tested at radon concentrations from about 1500 to 40,000 pCi/ℓ and flow rates from 8 to 64 ℓ/min. Other variables studied were test air humidity, water content of the carbon, and temperature. Results indicated that a canister containing about 900 ml of dry, high-grade activated carbon, used at a breathing rate of 16 ℓ/min, would provide almost 100% protection against radon for a period of one hour at a temperature of 25°C and an air humidity of about 9 mg/ℓ. Protection would be provided for a longer period at the lower temperatures existing in uranium mines.

INTRODUCTION

Concentration limits for the exposure of uranium miners are expressed in terms of radon daughters, which constitute the predominant inhalation hazard compared to radon gas. Mine atmospheres normally are ventilated to maintain radon daughters below prescribed limits. However, in certain restricted locations such as abandoned workings and exploratory drifts, ventilation may be deficient or absent. This can give rise to extremely high concentrations of both radon and its daughters, often comparable to values of 50,000 pCi/ℓ reported by Holaday et al.[1] in their early investigations. During the occasional brief entries to these areas that are required for exploration or maintenance, personnel should be equipped with respiratory protection against both radon and radon daughters, since exposure to radon itself can be hazardous. To define more accurately when protection is needed, an MPC is required for radon-222 gas in the absence of its daughters. This has not been set in the standard radiation protection handbooks. However, an estimate may be obtained by considering the MPC for radon-222 to be that concentration which will result in the same energy release in the respiratory tract that would be given by a radon daughter concentration corresponding to the current limit of 0.3 working levels (WL).

One WL is defined as that quantity of radon daughters per liter of air which will result in the eventual release of 1.3×10^5 MeV of alpha energy. Hence, 0.3 WL would result in the eventual release of 0.4×10^5 MeV of alpha energy per liter of air. To calculate the alpha energy release in the respiratory tract due to inhalation of air at 0.3 WL, it is necessary to assume values for fractional respiratory deposition and for breathing rate (minute volume).

George and Breslin[2] reported deposition values from 23 to 45% in uranium mines varying with mine location, individual tested, and tidal volume. Most of their results were obtained for sedentary subjects having low tidal volumes. They also found that increased tidal volume resulted in increased deposition. For mine workers doing moderate work, tidal volume would be higher than for the sedentary position. Hence, it seems reasonable to assume a round value of 50% for the purposes of this calculation. The breathing rate adopted by the ICRP[3] for the quantity of air inhaled during an eight hour day, 10^7 cm^3, is used. This value corresponds approximately to 20 ℓ/min.

With these assumptions of fractional respiratory deposition and breathing rate, the deposition of potential alpha energy in the respiratory tract per minute for 0.3 WL is (0.4×10^5) (0.50) (20) = 4×10^5 MeV/min. Accordingly, to calculate the MPC for radon-222, it is necessary to find the radon concentration which would result in the deposition of 4×10^5 MeV/min of potential alpha energy in the respiratory tract. This type of calculation has been done by Holaday et al.[1], who assumed a lung volume of 2.75 liters and complete retention of the radon daughters formed by decay of radon while in the respiratory tract. The assumption of complete retention was presumably made because the freshly formed RaA would be unattached and hence would diffuse rapidly to body surfaces. Their calculation showed that a radon concentration of 1 pCi/ℓ would release 116.7 MeV in the respiratory tract. Hence, the MPC for radon would be $(0.3)\ (1.3 \times 10^5)/(1.17 \times 10^2)$ = 3300 pCi/ℓ. Respiratory protection against radon in absence of its daughters is therefore indicated when the radon gas concentration exceeds about 3000 pCi/ℓ.

At present, the only feasible method of providing this respiratory protection is with supplied air respirators. A typical device of this kind might weigh 20 pounds and last for about 20 minutes. Reduction of this weight and/or increase of servicable time obviously would be highly desirable. Since it is known that activated carbon has a limited capacity to absorb radon even at room temperature[4,5], it appeared that a gas mask canister containing carbon might provide worthwhile protection. The purpose of this work was to investigate the degree of radon protection afforded by the small M11 Army gas mask canister, and a larger commercial canister, the Scott-Acme type 184.

THE M11 AND SCOTT-ACME CANISTERS

The M11 Army gas mask canister, a component of the M9 gas mask, was developed by the Army Chemical Corps during World War II and has been described by West[6]. It was manufactured in large quantities for issuance to Army personnel. The canister contains a pleated, high efficiency filter which should remove radon daughters with very nearly 100% efficiency regardless of their degree of attachment. The canister weighs about 260 grams and is mounted on one side of the gas mask facepiece, a convenient and comfortable arrangement.

The Scott-Acme canisters (Acme Products, South Haven, Mich.) were the manufacturer's types 184-OV and 184-OVWC. The canisters are mounted on the wearer's body and are connected to the facepiece by a corrugated hose. Their size is roughly 2½" × 4½" × 7", and weight about 1½ pounds. The canisters do not contain a high efficiency filter, and hence would not provide protection against particulate radon daughters. Canisters containing both activated carbon and a high efficiency filter, however, are available from Scott-Acme and other companies.

Some of the properties of the carbon beds of the M11 and the Scott-Acme canisters are listed below.

Property	Scott-Acme	M11
Carbon volume, cm^3	900	270
Area of carbon layer, cm^2	60	87
Thickness of carbon layer, cm	15	3.1
Void fraction	0.72	0.70
Mesh size	6-16	12-30

The quantities in the listing above were determined in this laboratory by simple methods or obtained from the manufacturer and must be considered as approximate. An emission spectrographic analysis was also done on carbon from the M11 and the two types of Scott-Acme canisters. The M11 carbon, known to be the impregnated "ASC" type[7], showed about 0.1% silver, 1.0% chromium, and 0.5% copper by weight. The values for the Scott-Acme 184-OVWC carbon were about 0.1% silver, and 0.8% chromium, and 0.7% copper. It appears, within the limits of the analysis, that the Scott-Acme 184-OVWC canisters and the M11 canisters both contain "ASC" impregnated carbon. Carbon from the Scott-Acme 184-OV canisters contained no detectable silver, chronium or copper, and was assumed to be unimpregnated.

APPARATUS AND PROCEDURE

The canisters were tested by passing a radon-air mixture into them at a known flow rate, radon concentration and humidity, and determining the radon transmission vs. time. The dimensionless fractional transmission T is defined as the concentration of radon in the carbon bed effluent divided by the influent concentration at any time. Details of the test apparatus are shown in Figure 1. Radon was generated by bubbling air saturated with water at 1 ℓ/min through a radium chloride solution. Several different solutions were used, with radium contents in the range of 0.2 to 5 mCi. High efficiency filter paper was used downstream of the bubbler to remove any entrained aerosol from the radium bubbler. The main air supply for the apparatus entered through flowmeter F-1 at various flow rates from about 20 to 70 ℓ/min and was humidified, when desired, by one or more of the humidifying tubes shown in the figure. When very dry air was needed, the humidifying tubes were replaced by a silica gel dryer. The total flow into the canister test chamber was set at a higher value than any of the flows to be withdrawn through the test canisters, to provide an excess. The radon concentrations obtained varied from about 1500 to 40,000 pCi/ℓ. Canisters were tested at 8, 16, 32 or 64 ℓ/min, the canister flow being maintained by two flowmeters; F-4 at 8 ℓ/min, and F-3 at the rate needed to make up the total flow. The 8 ℓ/min flow line was arranged to measure radon concentrations in the effluent from the test canister. This line was provided with a bypass so that the flow could be maintained constant whether or not a concentration sample was being obtained.

To prepare for an adsorption test, the air flow was maintained for about 2 or 3 hours to establish equilibrium conditions. The waiting period allows accumulated radon in the radium bubbler to be swept out into the hood, and allows the water in the humidifier to reach an equilibrium temperature. It was found that after the waiting period the apparatus would produce a constant (± 5%) radon concentration for days or weeks. Immediately prior to the test, the input radon concentration was measured at 8 ℓ/min using the two-filter method[8], sampling from line 1 of the figure. Samples were taken for three minutes using 934AH paper (Reeve-Angel Co., Clifton, N. J.) with a 530 ml two-filter tube and were counted from ½ to 6½ minutes after the end of the sampling with an alpha scintillation counter. Usually four determinations were taken prior to a test, and four after completion of the test. After establishing the input radon concentration, the canister was attached to line 2 of the figure and the radon concentration in the canister output determined repeatedly at three minute intervals. The average transmission obtained over the three-minute sampling period was considered to be the instantaneous transmission at the midpoint of the sampling period.

The humidity of the air stream, in milligrams of water vapor per liter of air, was determined when needed by drawing a sample from line 1 at 3 ℓ/min through silica gel (Tell-Tale, Fisher Scientific Co., No. S-160) contained in a sampling tube about 2 cm in diameter and 12 cm long. Such a tube will completely adsorb about 2 grams or more of water vapor at 3 ℓ/min.

In two of the canister tests, CO_2 was introduced at a concentration of 2% by volume. This was done by means of a CO_2 tank and auxiliary flowmeter set at 400 ml/min, not shown in Figure 1. Since it was not known whether CO_2 would have an effect on the two-filter method for radon, a few tests were done at a constant radon concentration with and without the CO_2. Concentration values obtained with CO_2 were a few percent higher than those obtained without CO_2, but since the effect was small it was ignored.

RESULTS AND DISCUSSION

The primary data were obtained in the form of transmission vs. time curves, Figures 2 to 9. From these curves, the canister life to any fractional transmission could be obtained and, by integration, the fraction of input radon adsorbed to a given test time calculated. The principal variables studied were radon concentration, air flow rate, test air humidity and canister water content. Some information was also obtained on the effect of carbon dioxide, the relative efficiency of different carbons, and the effect of temperature.

Effect of Radon Concentration

Theoretically, the transmission of a noble gas through a carbon bed is independent of the gas concentration when the gas is present in low concentration. This has been verified for krypton and xenon[9], and should also apply to radon. To confirm this, dry M11 canisters were tested at radon concentrations of about 1600 and 38,000 pCi/ℓ, with all other conditions being held as nearly constant as possible. The transmission curves are shown in Figures 3 and 4, and the results summarized in Table 1 for intercomparison. The table shows that radon concentration has no detectable effect on the rate of radon adsorption, and in subsequent work the radon concentration was set as high as feasible, to improve the precision of the tests.

Effect of Flow Rate

From theory[9,10] flow rate has a pronounced effect on noble gas transmission through carbon beds. Results are shown in Figures 2 to 9. From these figures a comparison may be obtained of the life of the canisters to, e.g., 10% transmission at flow rates differing by a factor of two, as indicated in Table 2. The table shows that within the range studied, the life of the canister increases by about a factor of 2.5 with halving of the flow rate.

Effect of Water

The effect of water on radon adsorption was studied in two different ways. In the first method initially dry canisters were used and the test humidity varied from nearly zero to about 18 mg/ℓ. In this case, one has co-adsorption of water and radon, and the water content of the canisters varies with time.

In the second method the canisters were first equilibrated with air at different humidities, and then a radon test was done with air at the same humidity. In this method there is very little or no co-adsorption of water during the radon test, and the canisters had essentially the same water content before and after the radon test. The water content of the canisters was arbitrarily defined, for experimental convenience, as the weight of the canisters after equilibration minus their weight when equilibrated with air at about 1.4 mg/ℓ humidity.

Tests done on M11 canisters according to the first method are shown in Figures 2, 3, and 4. The figures show the deleterious effect of air humidity on dry M11 canisters. Tests were also done using the second method, with canisters equilibrated at various test humidities. Figure 10 shows a comparison of results obtained by the two different methods. It is apparent from the figure that water adsorbed during the test is more harmful to canister radon adsorption efficiency than water added before the test. To find the reason for the difference, air at about 15 mg/ℓ humidity was passed into a dry carbon bed containing a thermometer. A temperature rise of about 7°C was immediately noted. This qualitative test showed that the poorer performance with co-adsorption of water is caused by the effect of higher temperature on radon adsorption.

The Scott-Acme canisters were tested using the pre-equilibration method only, and some of the transmission curves obtained for different water contents are shown in Figures 5, 6, and 7. The effect of water content is shown directly in Figure 11, where the canister life to 2% transmission is compared at the three flow rates for different canister water contents.

Integration of the transmission curves permitted calculations of the fraction of total input radon that is adsorbed by the canister during a 60 minute test as a function of canister water content, Figure 12. In this figure there are several data at "zero" water content and also at a water content of about 2 to 3 grams. The data at zero water content were for canisters equilibrated and tested at about 1.4 mg/ℓ humidity; the data at 2 to 3 grams water content were for canisters equilibrated and tested at 9 mg/ℓ humidity. Comparison of the results shows differences in the fraction of radon adsorbed to be of the order of 5% or less. This shows that humidities of about 9 mg/ℓ do not seriously decrease the fraction of radon adsorbed compared to dry conditions, at least at room temperatures (25°C = 77°F).

Effect of Carbon Dioxide

Results of tests at a volumetric concentration of 2% CO_2 are given in Figure 9. It is apparent that CO_2 has a somewhat deleterious effect. However, considering that the CO_2 concentration used in the test was greater by at least one order of magnitude than the concentrations which would be expected in mines, it appears that there need be no concern over the effect of normal CO_2 levels on radon adsorption.

Effect of Temperature

The effect of temperature was studied by varying the room temperature from 25 ± 1°C to 20° + 1°C. In these tests, the radon concentration was about 11,000 pCi/ℓ, the flow rates were 16, 32 and 64 ℓ/min, and the test humidity was about 11 mg/ℓ. The same Scott-Acme canister was used for all tests with desorption of the canister between each test. A series of tests at the three flow rates was done at 20°C, next at 25°C, and then repeated at 20°C, to confirm that the desorption was adequate, and the tests reproducible. The tests were not considered very accurate because of relatively poor temperature control. However, a definite temperature effect was found as shown in Figure 8. The results of these tests in terms of the fraction of radon adsorbed, and the total radon adsorbed in a 60 minute test are given in Table 3. The results are corrected for small variations in water content of the carbon, which averaged about 28 grams. The ratios of radon adsorbed at 20°C compared to 25°C, averaging the two tests at about 20°C, were 1.13 at 16 ℓ/min, 1.14 at 32 ℓ/min, and 1.21 at 64 ℓ/min.

The temperature effect found can be compared, to a limited extent, with that predicted by the Fusamura et al.[11] equation. According to this equation, the "saturated radon adsorption" value, As, over the temperature range 275°K to 305°K, and for one type of activated carbon, may be expressed as

$$As = 6000 \left(\frac{288}{T}\right)^{12.7} Cs$$

where Cs is the radon concentration in μCi/cm³ and T is the absolute temperature. Writing this equation for 20°C (293°K) and 25°C (298°K) and dividing one by the other gives

$$\frac{As\ (20\ C)}{As\ (25\ C)} = \left(\frac{298}{293}\right)^{12.7} = (1.017)^{12.7} = 1.24$$

Hence, the equation predicts 24% more radon adsorbed at 20°C than at 25°C. The experimental results show a somewhat smaller effect, averaging 16%. However, the present results are for unsaturated carbon, as the tests were stopped while the carbon was still adsorbing radon. Also, the type of carbon and water content of the carbon were different than used by Fusamura et al.[11].

Effect of Carbon Type

The Scott-Acme type 184 canisters tested had three different lot numbers, 1381, 1711, and 1478, and were filled with three different types of carbon. According to Scott-Acme, the canisters in lot 1381 contained type 337 carbon, manufactured by Witco Chemical Company. This carbon had a surface area of about 1300 square meters per gram. The carbon of lot 1711 was stated to be type-WV-H, manufactured by Westvaco Corp., and had a surface area of about 1000 square meters per gram. No information was available on the carbon of lot 1478 (OVWC canisters).

Results of a comparison of the different carbons are given in Table 4. The table shows that the 184-OV (lot 1711) canisters had very nearly the same adsorptive capacity as the impregnated OVWC type. The 184-OV (lot 1381) canisters, however, were definitely superior both to the 184-OV (lot 1711) and the OVWC canisters. It appears that high carbon surface area is very desirable, and that ASC impregnation probably has a deleterious effect on radon adsorption.

Canister Regeneration

It was found early in the work that canisters used for radon adsorption could easily be regenerated by passing air through them. Consequently it was possible to make repeated tests using the same canister, with regeneration between tests. All of the transmission curves obtained in Figure 5, for example, were obtained using the same Scott-Acme type 184-OV canister, which was regenerated between tests by passing air at about 1.4 mg/ℓ humidity through it for two to three hours at 70 ℓ/min. The tests were run within the span of a few days in the following sequence: 32 ℓ/min, 64 ℓ/min, 16 ℓ/min, 32 ℓ/min, 64 ℓ/min, and finally 16 ℓ/min. Inspection of the results showed that there was little or no difference between the first and second tests at the same flow rate, which proved that the regeneration was adequate. The results shown in Figures 6 and 7, obtained with higher canister water content and test humidity, confirmed that two to three hours regeneration at 70 ℓ/min was adequate. In the latter two cases the humidity of the air used for regeneration was about 11 and 14 mg/ℓ, respectively; hence it appears that the humidity used for regeneration is not critical. It was also found that much less regeneration air was needed if the canister was heated, e.g., to 100°C.

Regeneration tests were also done using a M11 canister. The data are shown in Figure 13 and the desorbing conditions are given in Table 5. In contrast to the results obtained with the unimpregnated carbon in the Scott-Acme type 184-OV canisters, there was a slight drop off in radon adsorption efficiency with repeated tests. The reason for this is not known, but may be related to the presence of ASC impregnated carbon in the M11 canister. On one of the tests listed in Table 5, the canister was merely stored for 18 days, 4.7 radon half-lives, without passage of air through the canister. Decay of radon was sufficient to regenerate the canister.

PROTECTION AFFORDED BY CANISTERS IN MINES

This work has shown that activated carbon canisters will remove radon efficiently even at room temperatures. However, the radon removed is concentrated in the canister carried near the wearer's body, which could cause an external radiation hazard. For example, if a canister were used for one hour at a breathing rate of 16 ℓ/min and a radon concentration of 50,000 pCi/ℓ, and essentially all radon was removed, about 50 μCi of radon would accumulate in the canister, plus the daughter products removed by the particulate filter.

If we assume that the average loading over the one hour period is 25 μCi of radon in equilibrium with its daughters, and that the radiation from the counter is equivalent to that from a point source at the canister half thickness, 3 cm, it may be calculated(12) that the radiation intensity at the canister surface would average about 25 mr/hr over the one hour period. Hence it may be desirable to position the canister away from the body, or replace it when its radiation level is judged excessive. It appears that the external radiation problem, if significant, may be handled by simple precautions.

All of the radon adsorption test results herein were obtained at about 20 to 25°C, under various humidity conditions. It is difficult to estimate accurately the useful life of a canister at mine conditions, where the temperature would be considerably lower than 20° or 25°C, but where air relative humidities might approach 100%. Also, the life of the canister would depend on the initial water content of the canister, the type of carbon used in the canister and the breathing rate of the wearer. Nevertheless, let us assume that the mine temperature is 10°C and make the pessimistic assumption that the relative humidity is 100%, corresponding to about 9 mg/ℓ humidity at 10°C. Figure 12 shows that a Scott-Acme 184-OV canister, with a water content 2 to 3 grams, which corresponds to equilibration at 9 mg/ℓ, would adsorb about 95% of the input radon if used for an hour at 25°C and a breathing minute volume of 16 ℓ/min. At 10°C, the canister would adsorb more water than at 25°C. If a dry canister were used for an hour at 16 ℓ/min, 9 mg/ℓ humidity, the maximum water adsorption possible would be (16) (60) (9)/1000 = 8.6 grams. Referring to Figure 12, it seems that this water content would not greatly affect the fraction of radon adsorbed, and, in view of the temperature effect found, Figure 8, it seems virtually certain that the protection afforded by canisters at mine conditions would be higher than that provided at 25°C.

CONCLUSIONS

Results of this work show that it is feasible to provide protection against radon by use of gas mask canisters containing activated carbon. The protection provided is independent of radon concentration, increases with decreasing temperature, and decreases with increasing flow rate and humidity or canister water content.

Initially dry M11 canisters which contain about 270 ml of ASC impregnated carbon and a high efficiency particulate filter, provide almost complete protection against radon at room temperature for about 5 to 15 minutes at a flow rate of 16 ℓ/min, depending on test humidity. The larger Scott-Acme canisters, which contain 900 ml of carbon but no high efficiency filter, provide considerably higher protection against radon. Scott-Acme type 184-OV canisters, when filled with unimpregnated dry carbon having a surface area of 1300 m^2/g, were found to remove about 99% of influent radon for a one-hour period at a flow rate of 16 ℓ/min, a humidity of 9 mg/ℓ and a temperature of 25°C. Protection would be expected to be higher at the lower temperature existing in uranium mines.

The use of activated carbon to provide radon protection appears to offer an advantage of at least a factor of 10 over self-contained supplied air respirators, with respect to the weight of the equipment. Another advantage is that the canisters may be regenerated by simply passing air through them overnight. Gas mask canisters containing both activated carbon and a high efficiency filter are recommended for protection against radon and daughters in uranium mines.

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TABLE 1

EFFECT OF RADON CONCENTRATION ON LIFE OF M11 CANISTERS*

Radon Concentration (pCi/ℓ)	Temperature (°C)	Humidity (mg/ℓ)	Canister Life (min) Transmission			
			2%	10%	30%	50%
1,640	24	0.2	13	17	22	27
37,250	23	0.2	13	18	23	27
1,650	23	5.0	9	13	17	22
39,100	23	5.3	10	13	17	21
1,590	23	18.0	4	7	10	12
37,050	23	17.0	5	8	11	13

*Flow rate was 16 ℓ/min.

TABLE 2

EFFECT OF FLOW RATE

Canister Type	Moisture Conditions	Relative life to 10% transmission		
		8 ℓ/min / 16 ℓ/min	16 ℓ/min / 32 ℓ/min	32 ℓ/min / 64 ℓ/min
Scott-Acme	"Zero" water content (Fig. 5)	-	2.3	2.5
Scott-Acme	Medium water content (Fig. 6)	-	2.9	2.5
Scott-Acme	High water content (Fig. 7)	-	2.7	2.5
M11	Fresh dry canister, tested at 0.2 mg/ℓ humidity (Figs. 2 and 3)	2.3	-	-
M11	Fresh dry canister, tested at 9.4 mg/ℓ humidity (Figs. 2 and 3)	2.2	-	-

TABLE 3

EFFECT OF TEMPERATURE ON EFFICIENCY OF SCOTT-ACME CANISTERS

Test No.	Temp. (°C)	Flow Rate (ℓ/min)	Water Content (grams)	Fraction Radon Adsorbed Observed	Fraction Radon Adsorbed Corrected*	Radon Adsorption (pCi)
74	20	16	25.6	0.928	0.911	9.62×10^6
79	21	16	25.9	0.897	0.882	8.47×10^6
77	25	16	27.7	0.835	0.833	8.00×10^6
73	19	32	23.0	0.653	0.618	13.05×10^6
80	21	32	29.5	0.555	0.566	11.95×10^6
76	25	32	29.8	0.508	0.521	11.00×10^6
75	20	64	28.8	0.412	0.414	17.49×10^6
81	20	64	33.8	0.354	0.365	15.42×10^6
78	26	64	27.2	0.323	0.321	13.56×10^6

Time of test, 60 minutes.

Radon concentration, about 11,000 pCi/ℓ.

Test humidity, about 10 mg/ℓ.

*All results corrected to a water content of 28 grams per canister.

TABLE 4

COMPARISON OF SCOTT-ACME TYPE 184 CANISTERS

Canister Type	Lot	Water Content (grams)	Test Humidity (mg/ℓ)	Life to 2% Transmission (min)	Fraction Radon Adsorbed 1 hour	Fraction Radon Adsorbed 2 hours
184-OV	1381	0	9	50	0.99	0.86
184-OV	1381	4	9	53	0.99	0.86
184-OV	1711	0	1	38	0.97	-
184-OV	1711	0	1	37	0.97	-
184-OV	1711	3	9	35	0.96	-
184-OV	1711	3	9	32	0.95	-
184-OVWC	1478	0	9	36	0.96	0.73
184-OVWC	1478	9	9	37	0.96	0.70

Flow rate 16 ℓ/min, temperature 25 ± 1°C in all tests.

Radon concentration 38,000 pCi/ℓ for tests of 184-OV (Lot 1381) and 184-OVWC canisters and 11,000 pCi/ℓ for tests of 184-OV (Lot 1711) canisters.

TABLE 5

DESORBING CONDITIONS FOR REPEATED RADON TESTS
ON A M11 CANISTER

Before Test No.	Canister Treatment
1	None (fresh canister)
2,5	5 hrs at 1.5 mg/ℓ humidity, 20 ℓ/min
3,4,6,8,9,11	16 hrs at 1.5 mg/ℓ humidity, 20 ℓ/min
7,10	16 hrs at <0.1 mg/ℓ humidity, 20 ℓ/min
12	No regeneration, stored 18 days
13,14	16 hrs at 4.5 mg/ℓ humidity, 20 ℓ/min

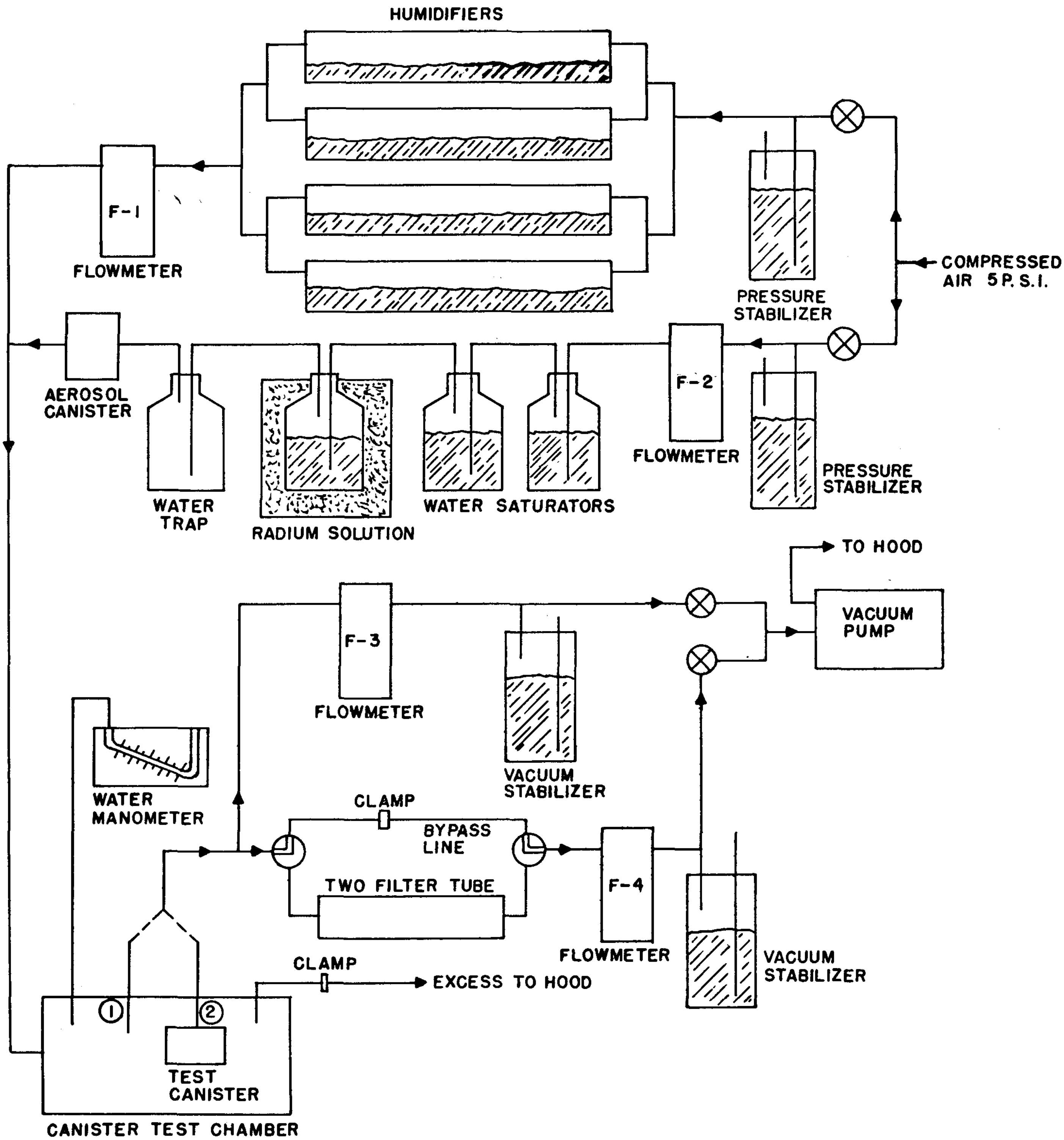

Figure 1. Radon canister test apparatus.

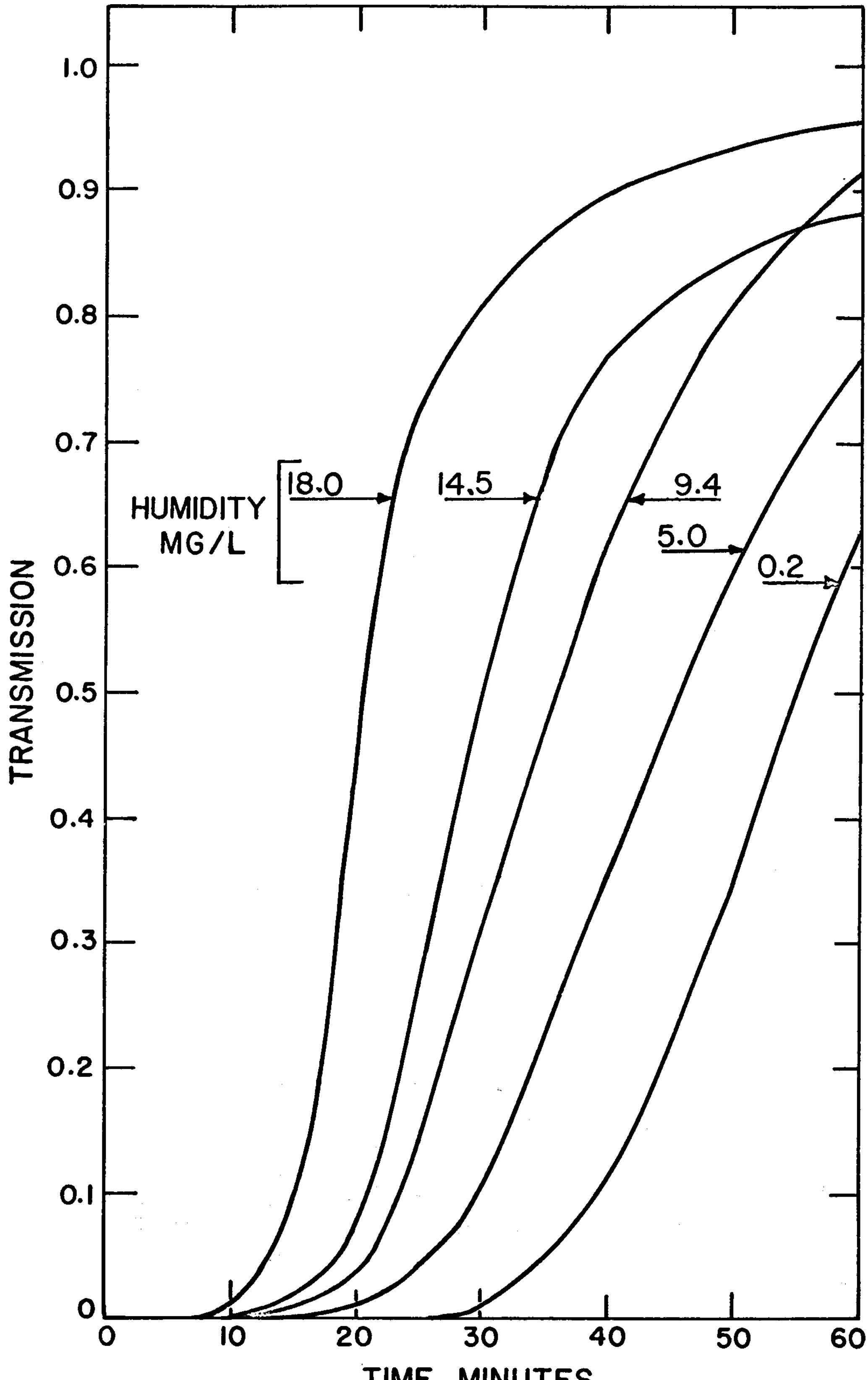

Figure 2. Test of initially dry M11 canisters at 1600 pCi/ℓ radon. Flow rate 8 ℓ/min, temperature 22°C, various test humidities.

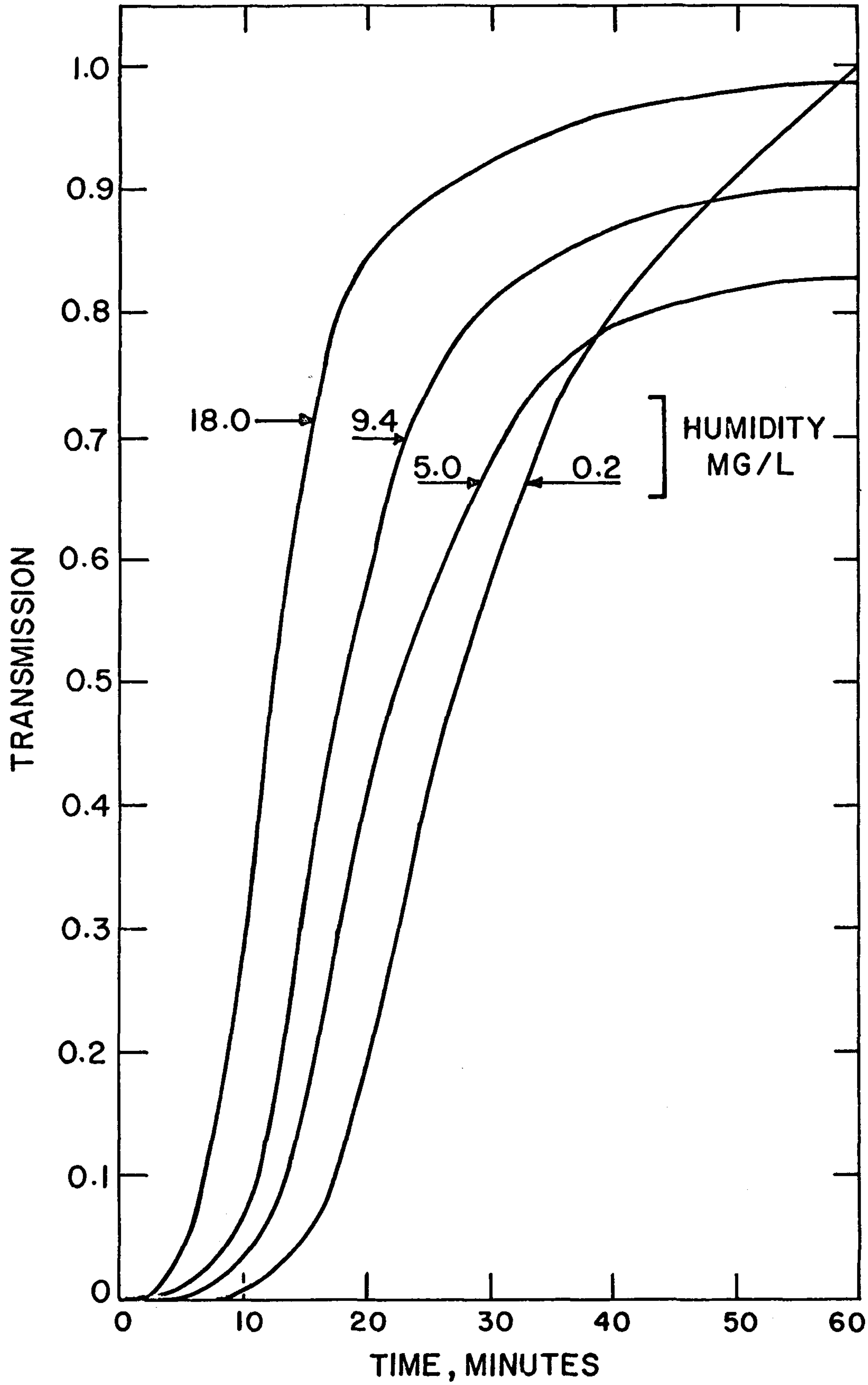

Figure 3. Tests of initially dry M11 canisters at 1600 pCi/ℓ radon. Flow rate 16 ℓ/min, temperature 22°C, various test humidities.

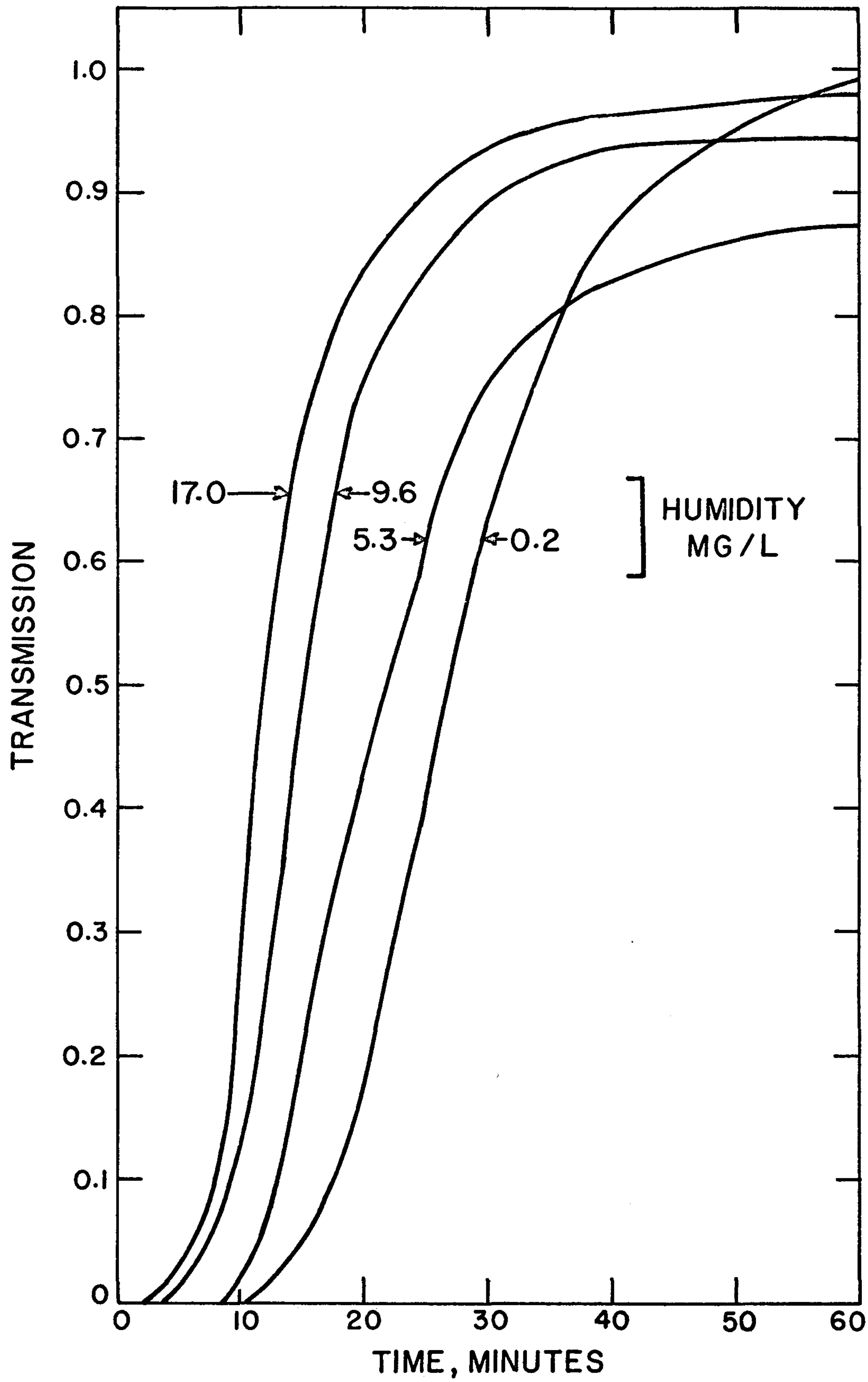

Figure 4. Test of initially dry M11 canisters at 38,000 pCi/ℓ radon. Flow rate 16 ℓ/min, temperature 22°C, various test humidities.

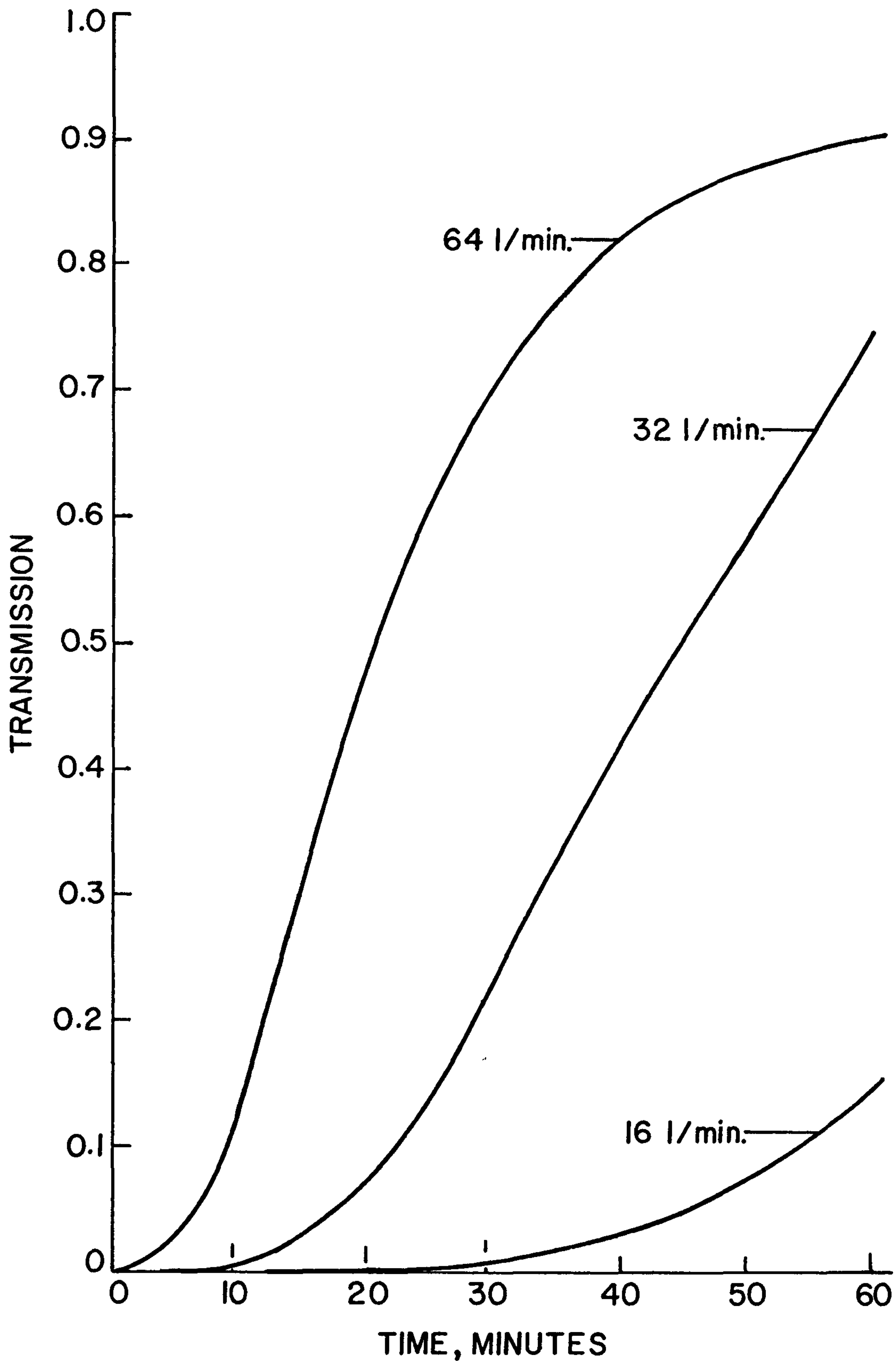

Figure 5. Test of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon. Equilibrated and tested at about 1.4 mg/ℓ humidity, temperature 25°C.

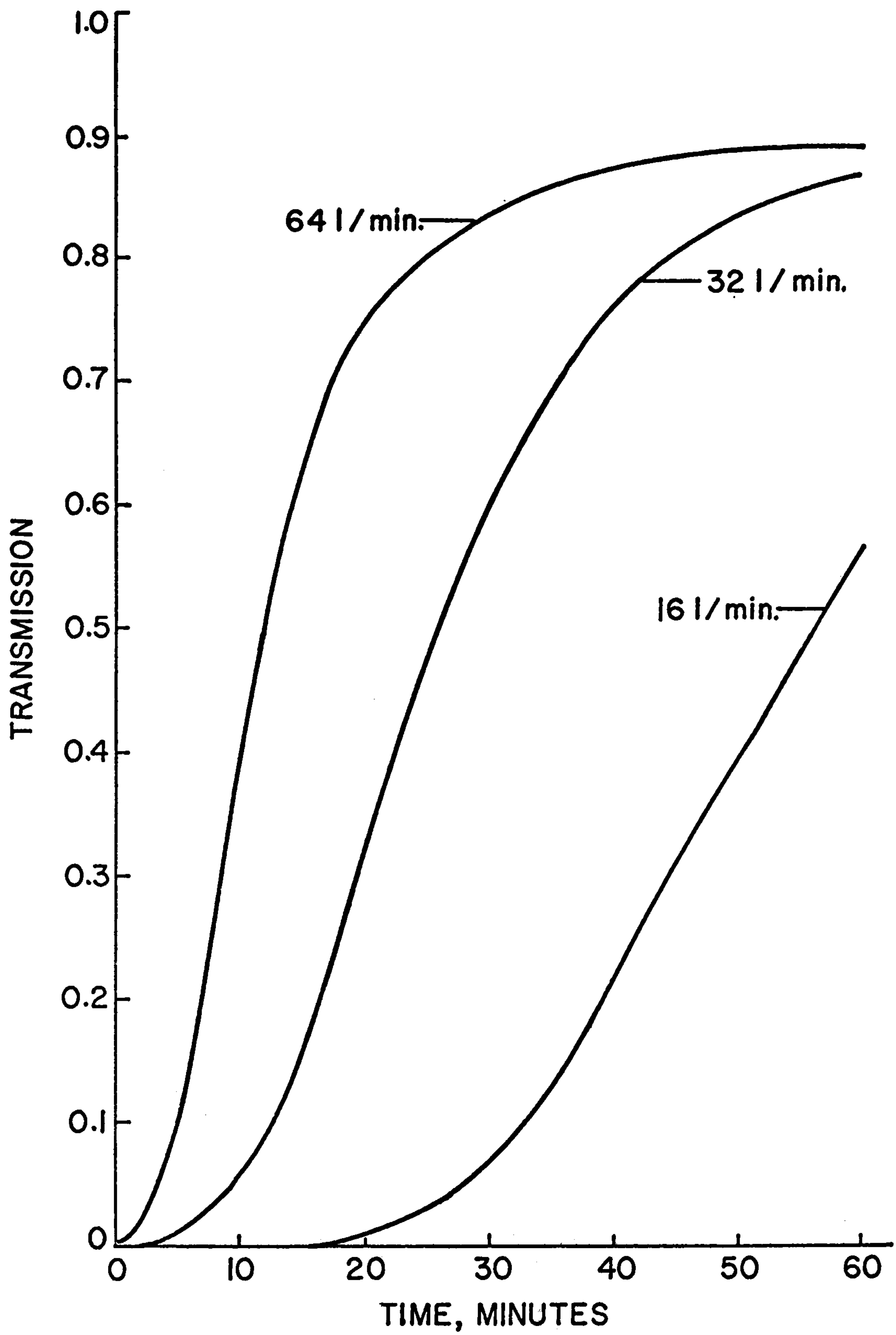

Figure 6. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, intermediate water content (about 28 grams). Equilibrated and tested at about 11 mg/ℓ humidity, temperature 25°C.

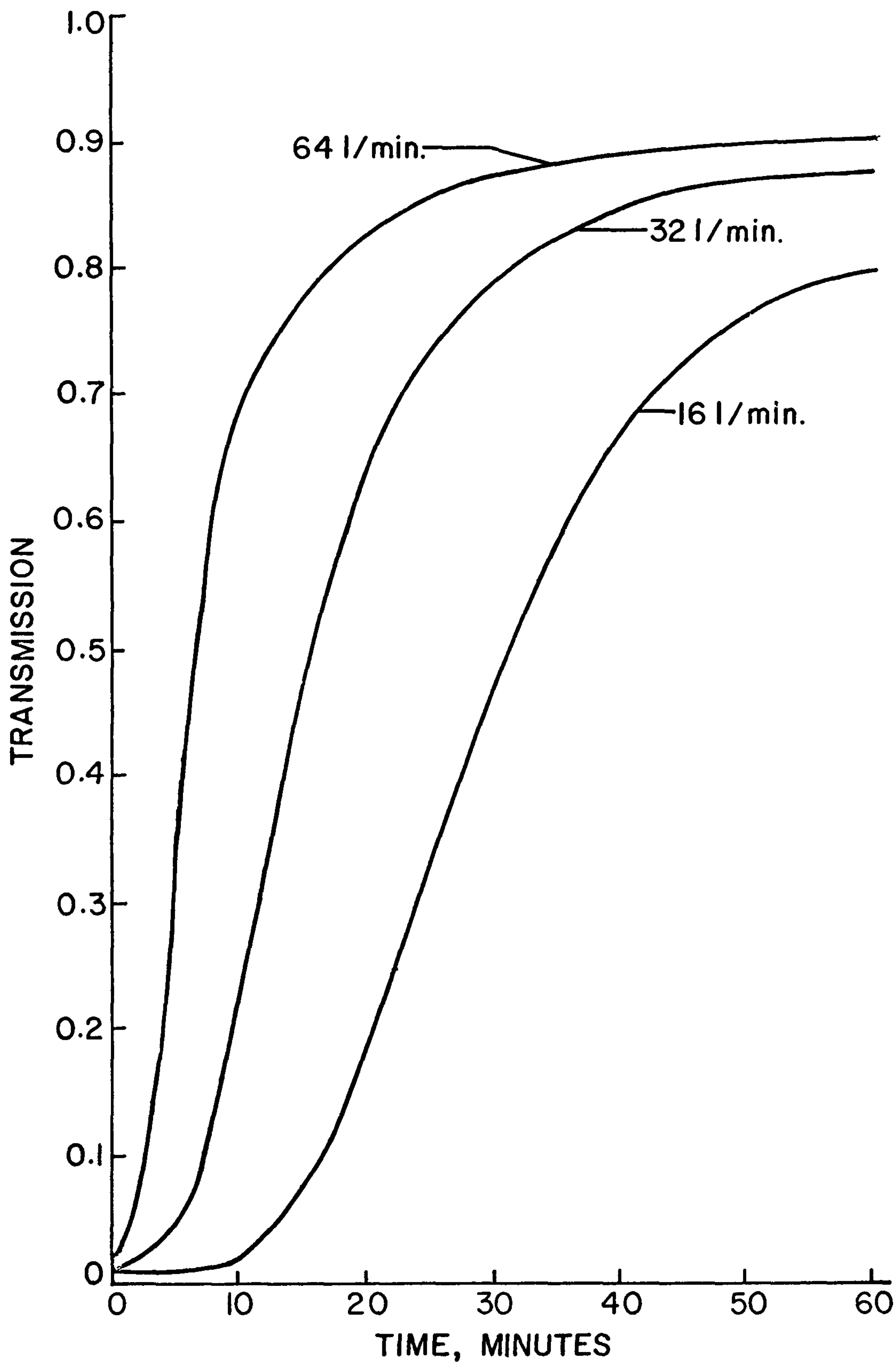

Figure 7. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, high water content (about 57 grams). Equilibrated and tested at about 14 mg/ℓ humidity, temperature 25°C.

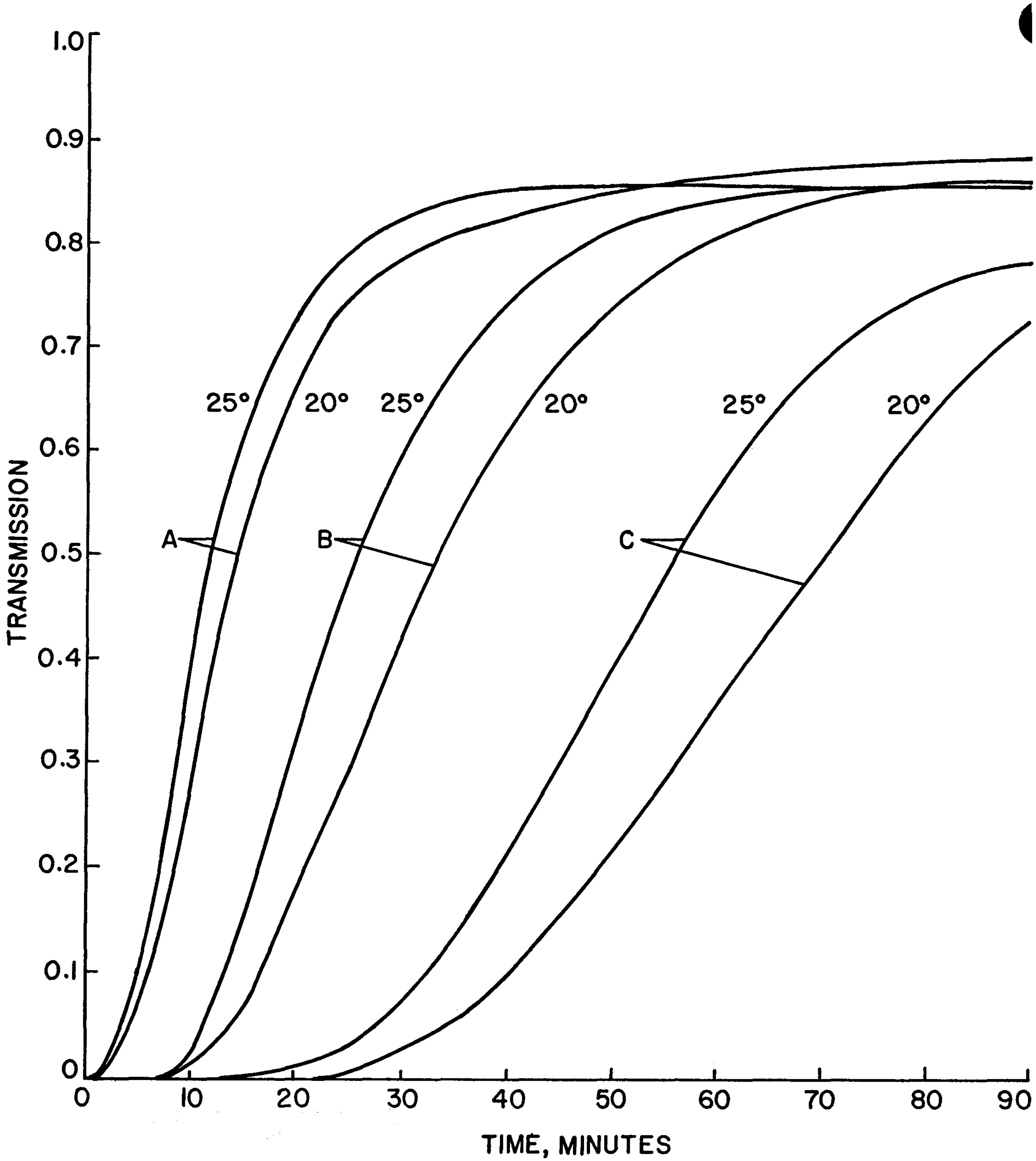

Figure 8. Tests of a Scott-Acme 184-OV (lot 1711) canister at 11,000 pCi/ℓ radon, at temperatures of 20°C and 25°C. Equilibrated and tested at about 11 mg/ℓ humidity, water content about 28 grams. Flow rates 64 ℓ/min (A); 32 ℓ/min (B); and 16 ℓ/min (C).

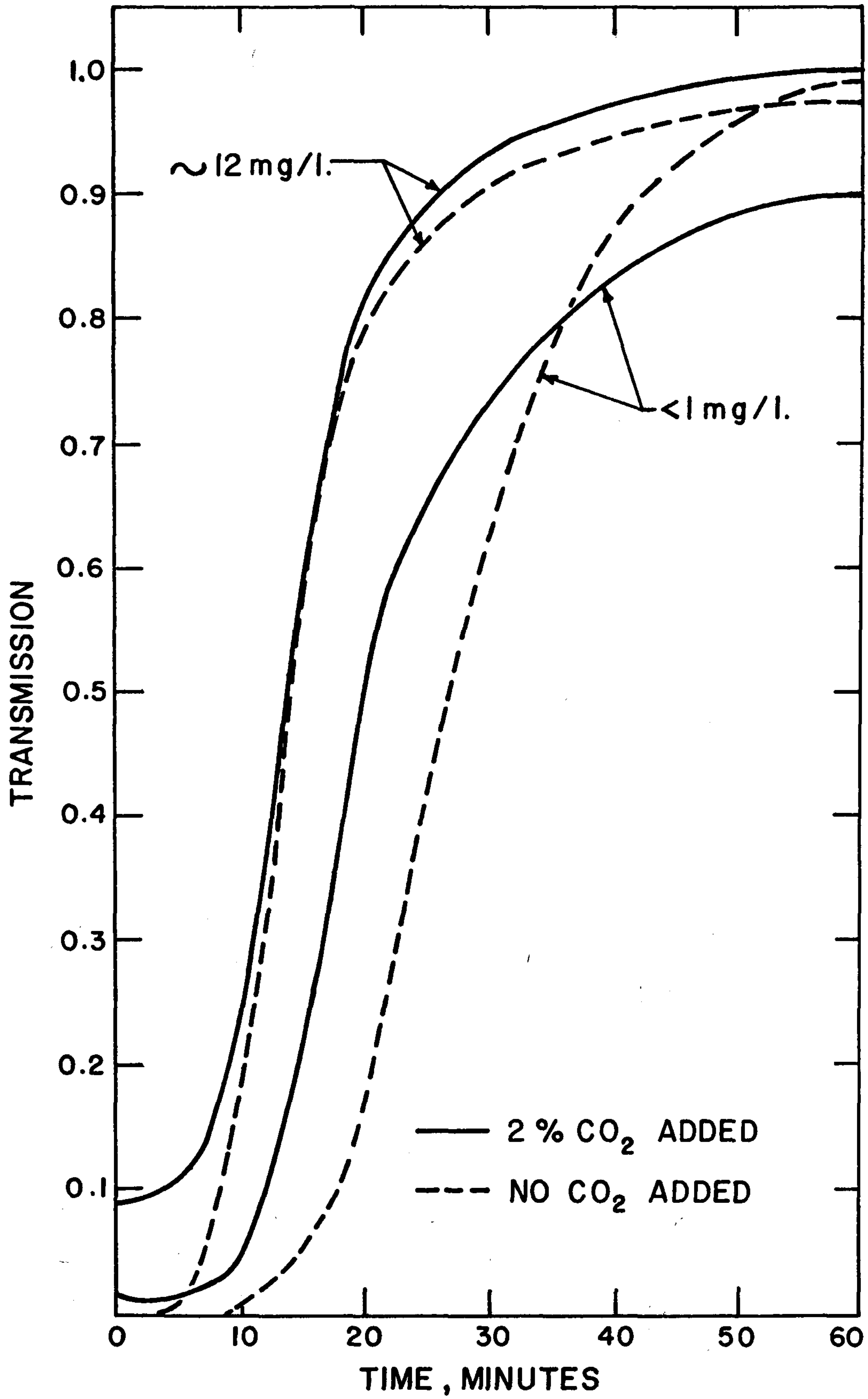

Figure 9. Effect of CO_2 on radon transmission by initially dry M11 canisters, at 38,000 pCi/ℓ radon, two test humidities. Flow rate 16 ℓ/min, temperature 22°C.

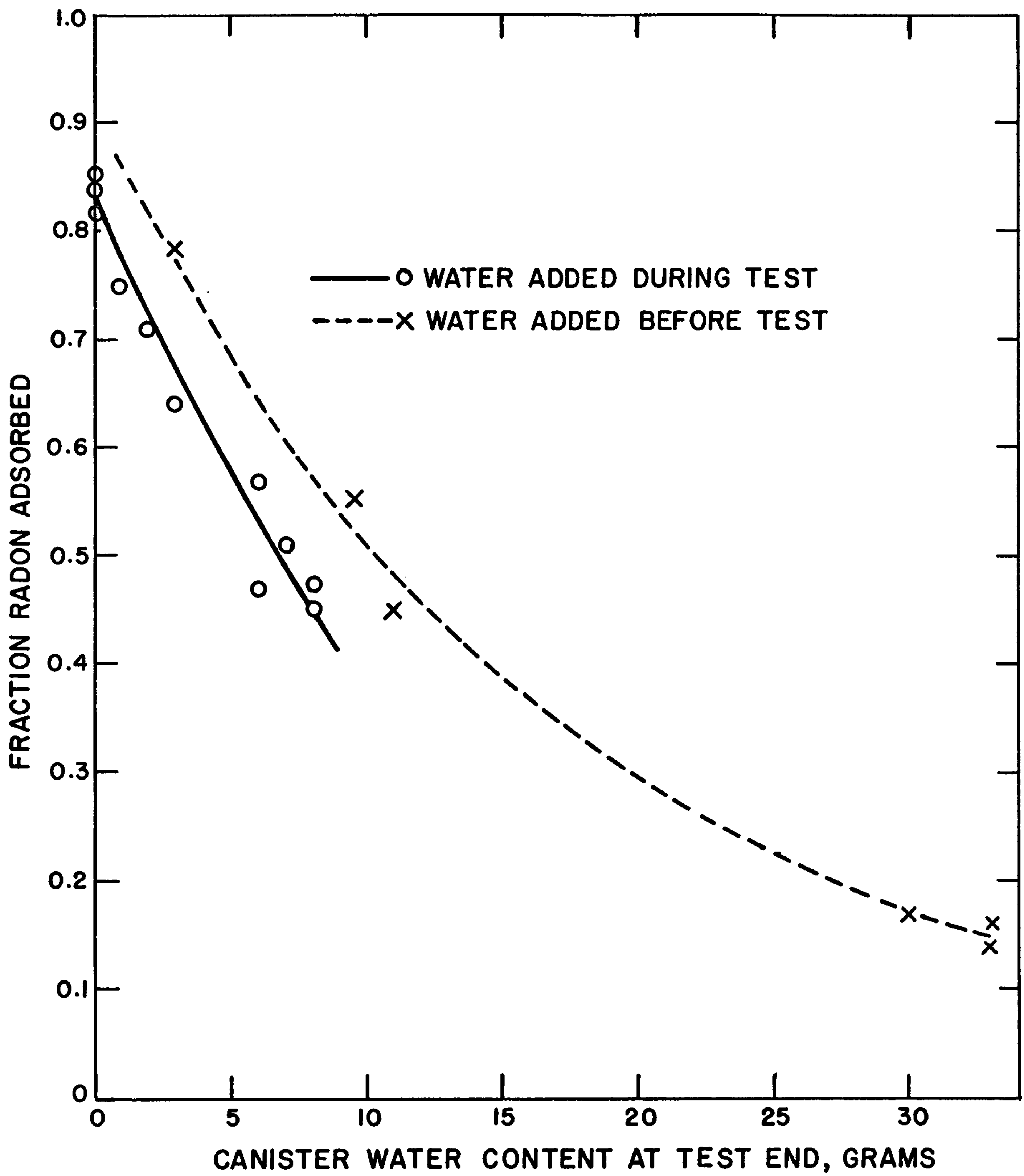

Figure 10. Effect of carbon water content on fraction of input radon absorbed by M11 canisters. 30 minute test time, flow rate 16 ℓ/min, radon concentration 38,000 pCi/ℓ.

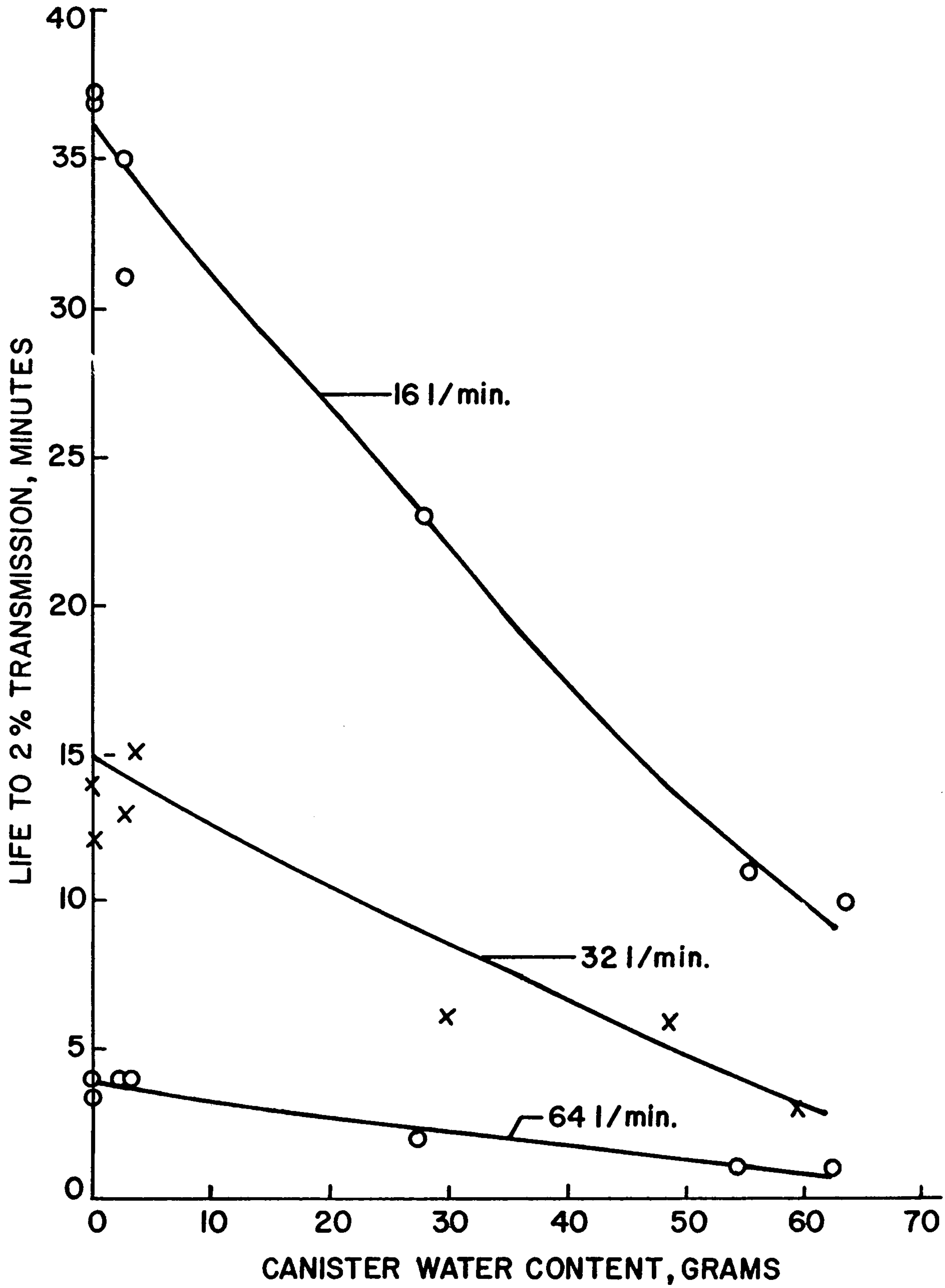

Figure 11. Effect of water content on transmission curves of Scott-Acme 184-OV (lot 1711) canisters. Radon concentration 11,000 pCi/ℓ, temperature 25°C.

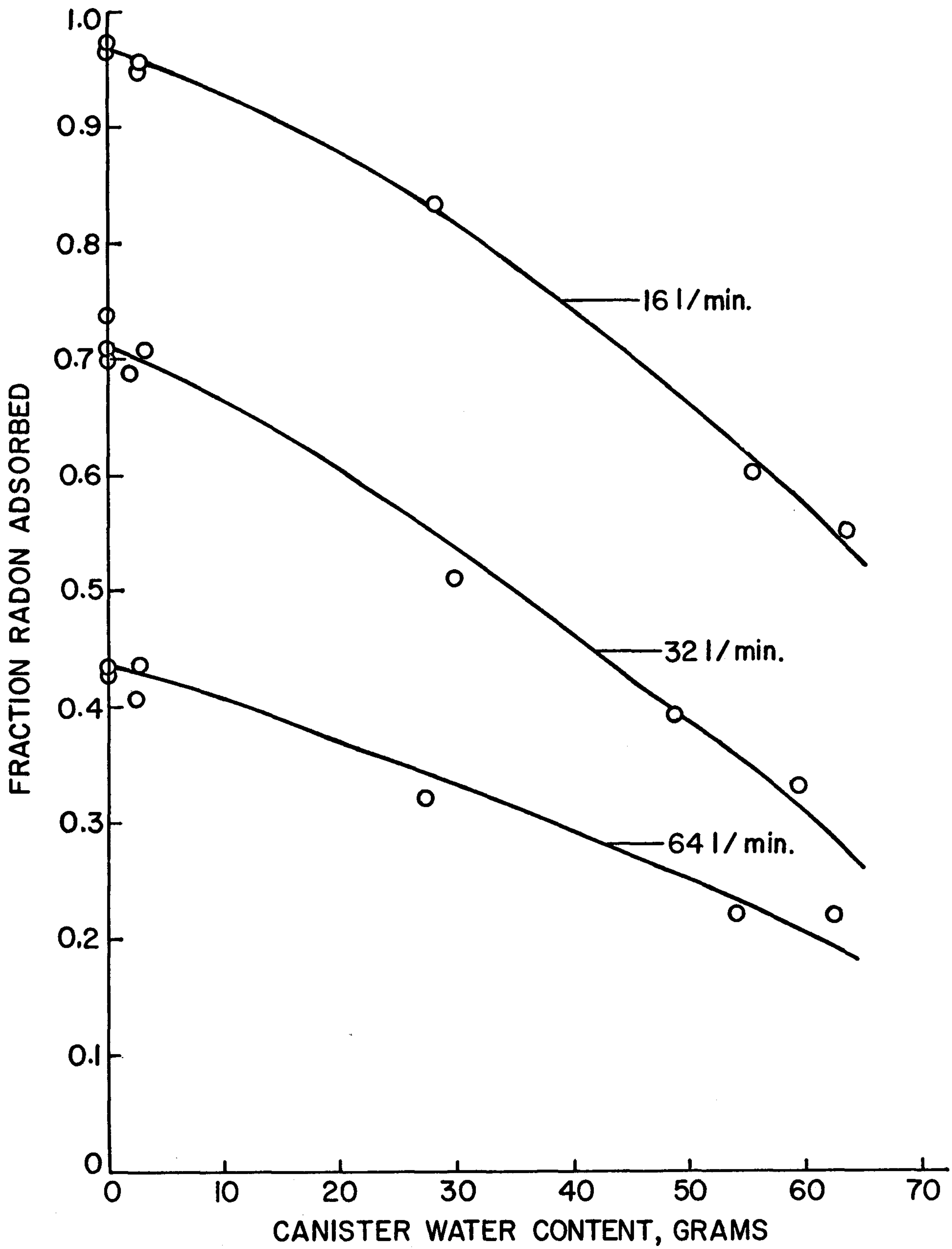

Figure 12. Fraction of input radon adsorbed in a 60 minute test time for Scott-Acme (lot 1711) canisters. Radon concentration 11,000 pCi/ℓ, temperature 25°C.

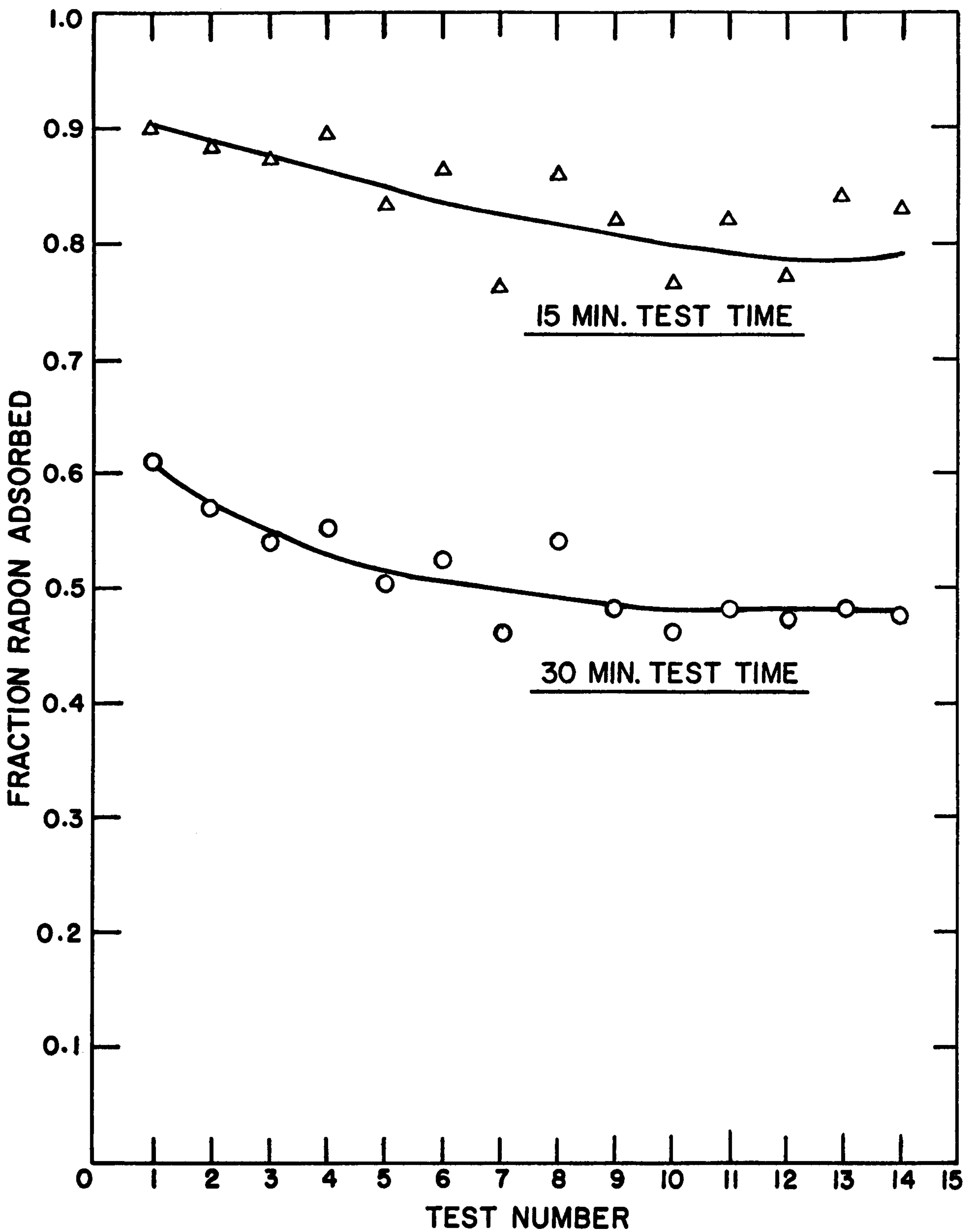

Figure 13. Repeated radon tests on a M11 canister; fraction of radon adsorbed in 15 and 30 minute test times. Flow rate 16 ℓ/min, humidity 9 mg/ℓ, radon concentration 38,000 pCi/ℓ, temperature 23°C.